NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

COMPUTER SIMULATION OF DIGITAL SIGNAL MODULATION TECHNIQUES IN SATELLITE COMMUNICATIONS

by

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This thesis is a tutorial on digital signal modulation techniques used in satellite communications and includes computer simulation of those digital signal modulation techniques introduced. The purpose of the thesis is to introduce digital signal modulation techniques and through the use of computer simulation, generate statistics which represent the characteristics of the FFT for the respective signal type. Further, an analysis of the statistics

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Computer Simulation of Digital Signal Modulation Techniques in Satellite Communications

by

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I. INTRODUCTION

A. BACKGROUND

Since the introduction of the sampling theorem and the matched filter, digital communications techniques have developed into a highly proficient discipline. The marriage of this discipline with the rapidly expanding space program has resulted in communication satellites employing a multitude of digital signal modulation techniques. A modulation technique is a method of transmitting the information contained in a message by varying or modulating the characteristics of a carrier waveform. These methods offer a range of advantages and disadvantages depending on the specific characteristics of the modulation technique employed. The applications of the various signal modulation techniques likewise vary. In order to understand this exciting new field it is necessary to look at some of the aspects of satellite communications systems in general. Then an investigation will be made into the general attributes of digital communications and their relationship to the satellite system.

The ability to understand these digital signal modulation techniques is the first step in being able to intercept, identify and demodulate unknown digital signals. These digital signals, transmitted from unknown sources, are believed to display frequency characteristics peculiar to the modulation technique employed in the encoding process. The digital computer offers unique opportunities in simulating these modulation techniques, in signal processing and in decoding of an intercepted signal.

B. SPECIFIC GOALS

It is the specific goal of this thesis to investigate the open literature on the topic of digital signal modulation techniques in satellite communications. This includes a basic understanding of the communications satellite system as well as the specific techniques employed in signal modulation. Additionally, once a basic understanding of these digital signal modulation techniques is achieved, computer code in the FORTRAN programming language will be developed which simulates these modulated signals. The statistics of the time-varying Fast Fourier Transforms (FFT) of these simulated signals will be investigated. The purpose of this analysis will be to lead to follow-on research in the area of signal analysis of intercepted digital signals whereby they can be classified by their FFT as employing a specific digital signal modulation technique.

C. SCOPE OF THE PROJECT

Although an indepth analysis of all the digital signal modulation techniques which will be introduced involves considerable higher level mathematics, it is not within the scope of this project to delve heavily into the mathematics. It would be advantageous, however, for the reader to have had integral and differential calculus and an introduction to statistics. Also a course in electrical engineering may prove helpful but is not essential since in actuality it is the electrical engineering aspects of satellite communications that this tutorial is attempting to present. The computer programming will be accomplished utilizing the techniques of software engineering and top down modular design. Existing blocks of code will be used as modules whenever appropriate and available. Again it is the ultimate purpose of this project to examine a variety of digital signal modulation techniques and develop computer code that simulates common signals used in satellite communications that have been produced by one of the many digital signal modulation techniques to be investigated.

II. UNDERSTANDING SATELLITE COMMUNICATIONS

A. HISTORY AND APPLICATIONS

Forty years ago, in 1945, Arthur Clarke first envisioned the use of space stations placed in geosynchronous orbit for communicating to different points on the earth [Ref. 1]. Nine years later in 1954, J.R. Pierce of Bell Laboratories performed a system analysis on such a communications system [Ref. 2]. In 1957, the launch of Sputnik demonstrated the feasibility of using a satellite for just such an application. However, by 1961 the only satellite communications technologies which had been demonstrated were the Courier 1B satellite, a short-life active retransmission teletype communications satellite in a 1000 km orbit, and the Echo I balloon in a 1600 km orbit which demonstrated passive reflection of powerful microwave signals from one earth station to another. Active microwave communications demonstrated in Projects Telstar and Relay were years away [Ref. 3]. The first geostationary orbit was achieved by Project Syncom in 1963 [Ref. 4].

In 1964, communication organizations from several countries joined together to form the international organization of INTELSAT (International Telecommunications Satellite Organization). INTELSAT's purpose was to develop a satellite network which would provide truly global communications capabilities. This resulted in the launch in 1965 of the world's first commercial communications satellite, INTELSAT I, also known as "Early Bird". With "Early Bird", telecommunications utilizing satellite relay were established between the United States and Europe. [Ref. 3]

The reliability of these satellite systems has improved dramatically since INTELSAT I in 1965. Reliability of individual links in the system approach 99.99 percent or higher. Total system reliability exceeding 99.9 percent is common [Ref. 5], making satellite communications more reliable than many other modes of communications. In this sense, reliability is a measure of the probability that no failure will occur in a respective channel or in the system during the design life of the satellite.

In order for the operability, capability and reliability of these systems to have developed at this pace, it was necessary for the technologies associated with them to develop as rapidly or even more rapidly than the systems themselves. Engineering sciences and specifically the fields of aerospace and electrical engineering historically have required between 7 and 10 years to take a concept from operational requirement to full scale operation. This was not the case with the concept of communications satellites which has seen four generations of INTELSAT satellites within a decade's time. [Ref. 3]

The "Early Bird" satellite weighed approximately 38 kilograms and possessed limited power and bandwidth capacity enabling it to carry only 240 two-way telephone conversations. Today's communications satellites represent order-of-magnitude improvements in many important operating parameters such as power and bandwidth. Additionally, increased effective radiated power from the techniques of stabilized earth pointing antennas have greatly increased the capacity of later generation communications satellites. INTELSAT V, the current generation of communications satellites, is a three-axis stabilized platform using not only the 6/4 GHz frequency band (6 GHz receive/4 GHz transmit) as in earlier generation satellites but also a 500 MHz bandwidth available in the 14/11 GHz band. The separation in the receive and transmit frequencies is necessary to prevent interference during simultaneous operation of the receiver and transmitter. Another factor increasing the capacity of present generation satellites is the increase in primary power available in the satellite. [Ref. 3]

The technologies which have contributed to the evolution of communications satellites come from two primary sources, namely technology from the space program of the 1960's supported by NASA and DoD and communications technology due largely to commercial and private sector contributions. [Ref. 3]

Electronic devices and components have contributed significantly to the rapid development of satellite systems. These electronic devices range from something which is now considered basic, i.e., the transistor, to devices such as Traveling Wave Tube amplifiers, lightweight antennas and antenna feed systems. There have been major improvements in satellite power sources including more efficient solar cells and high storage capacity/lightweight batteries. Additionally, two significant developments in electrical engineering have made modern day digital signal processing a reality. They are the sampling theorem and the matched filter. [Ref. 3]

Communications satellites of the future are likely to utilize onboard signal processing. Signal processing functions such as signal reshaping, switching and/or multiplexing and compression could soon take place on the satellite due to the reduction in size and weight of the necessary hardware. Operation at over 100 megabits per second are envisioned. Onboard signal processing will greatly reduce the expense and complexity of earth stations thereby making services of a satellite available to a wider range of small and geographically disperse users. [Ref. 3]

Satellite communications hold great promise to provide service to a multitude of users over a wide area. Applications lie not solely in retransmission but also in data collection from that same large geographic area. Military users have definite applications in these areas when warning, intelligence and surveillance systems provide digital inputs to a central source. Although most of the present applications for satellite communications are still provided by the government, commercial applications have seen tremendous increases in the last several years. [Ref. 3]

B. ORBITS AND LIMITATIONS

Satellite orbits are generally categorized as either equatorial (0 degrees inclination), polar (90 degrees inclination) or inclined at some angle other than 0 or 90 degrees relative to the spin axis of the earth as illustrated in Figure 2.1 [Ref. 6]. Each satellite orbit has a characteristic velocity which is dependent on the height of the orbit and the orbit's eccentricity. Eccentricity is a measure of the degree to which the orbit approximates a circle. A circle has eccentricity equal to zero since the focus is located at the center. See equation 2.1 and Figure 2.2.

A communications satellite in elliptical orbit about the earth obeys Kepler's second law of planetary motion. That is, a satellite's constant angular momentum about the earth means that its areal velocity also remains constant. See Figure 2.3. Of particular interest is the satellite velocity at apogee (Va) and perigee (Vp) given by equations 2.2 and 2.3.

Note that for a circle, e = 0 and Ra = Rp. Therefore a satellite in circular orbit about the earth has an orbital velocity as given in equation 2.4.

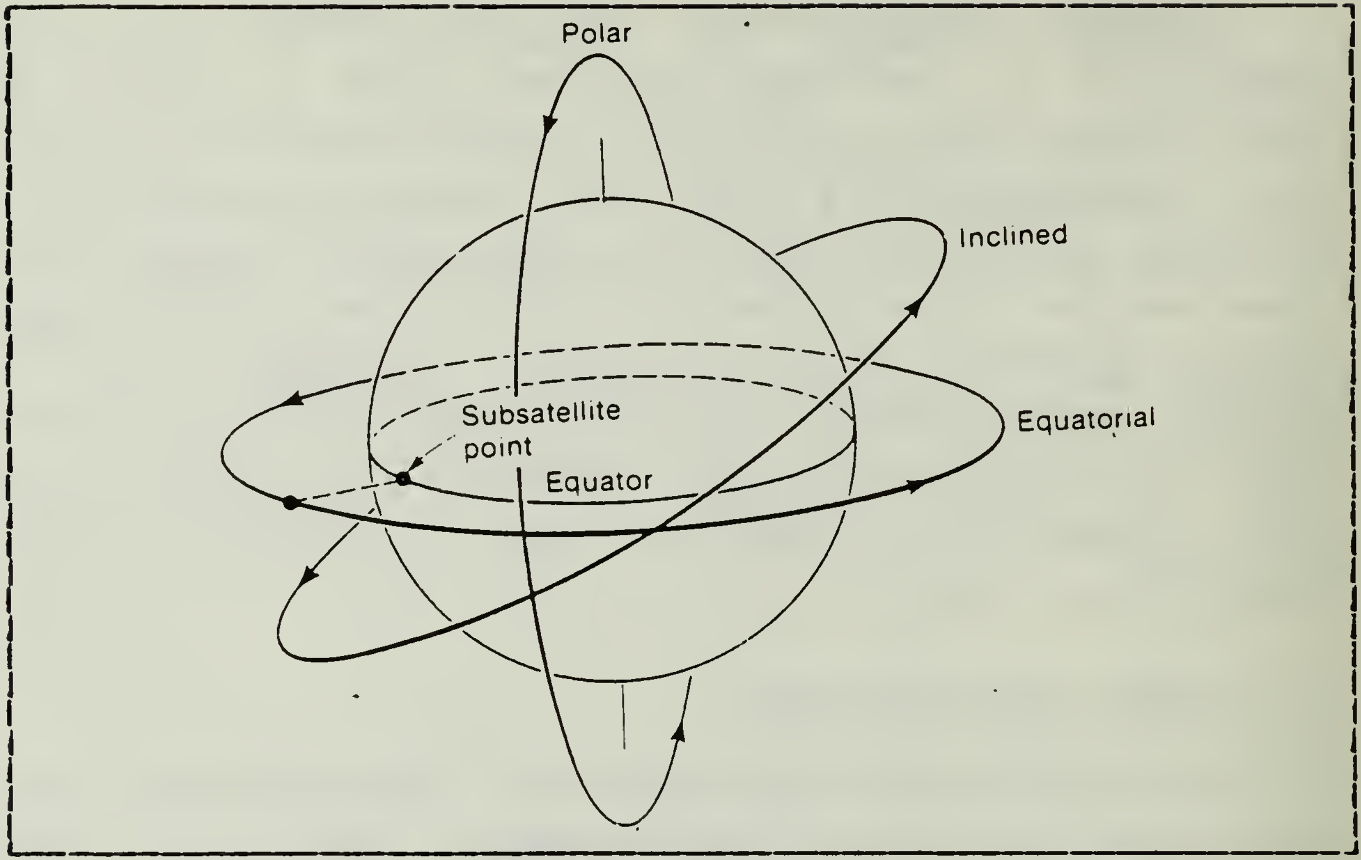
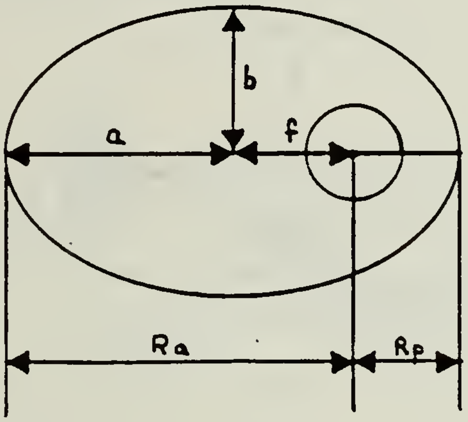


Figure 2.1 Satellite Orbits

Most communications satellites are placed in a circular equatorial orbit where the desire is to stabilize them over a fixed point on the surface of the earth called the subsatellite point. This type of orbit is called geostationary or stationary. Any satellite which has an orbital period equal to the period of rotation of the earth is called synchronous or geosynchronous. These terms are used almost interchangeably in most literature. As mentioned for a geosynchronous communications satellite, the orbital period of the satellite, T, must be equal to the period of rotation of the earth. Kepler's third law of planetary motion can be rewritten to yield equation 2.5.

The period of revolution of the earth for a sidereal day is 23 hr 56 min 4 sec. For that given period there is only one satellite altitude as expressed by Kepler's third law.



0≤ e ≤ 1.0
Circle has
e = 0.

Figure 2.2 Eccentricity

eccentricity (e) = c/a (eqn 2.1)

c = distance from focus
a = semi-major axis

b = semi-minor axis
Ra = radius cf apogee
Rp = radius cf perigee

By rearranging terms that altitude is given in equation 2.6. Since the orbit is circular, a = Ra = Rp and the height of the orbit above the surface of the earth is h = a - Re; or 35,804 km.

One disadvantage of a geosynchronous communications satellite is the lack of global coverage. These satellites provide excellent coverage of the subsatellite point and

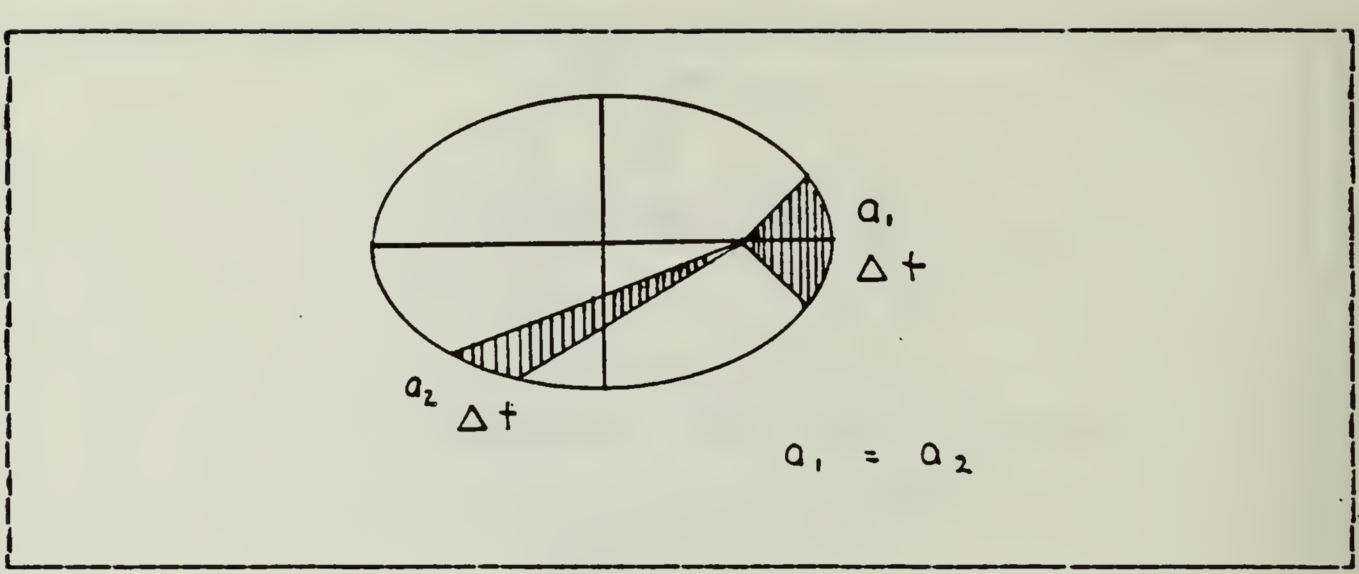


Figure 2.3 Kepler's Second Law of Planetary Motion

Va = (k/Ra(1-e))**.5 (eqn 2.2)

Vp = (k/Rp(1+e))**.5 (eqn 2.3)

k = GMe = 3.98866 x 10**-11 m^3/s^2
G = universal gravitational constant
G = 6.67 x 10**-11 N m^2/kg^2
N = newtons = m kg/s^2
Me = mass of the earth = 5.98 x 10**24 kg

Vc = (k/Rc)**.5 (eqn 2.4)

Rc = Re + h
Re = radius of the earth = 6.37 x 10**6 m
h = satellite orbital altitude

T = 2 pi a**1.5 / k**.5 (eqn 2.5)

T = period of rotation
a = semi-major axis

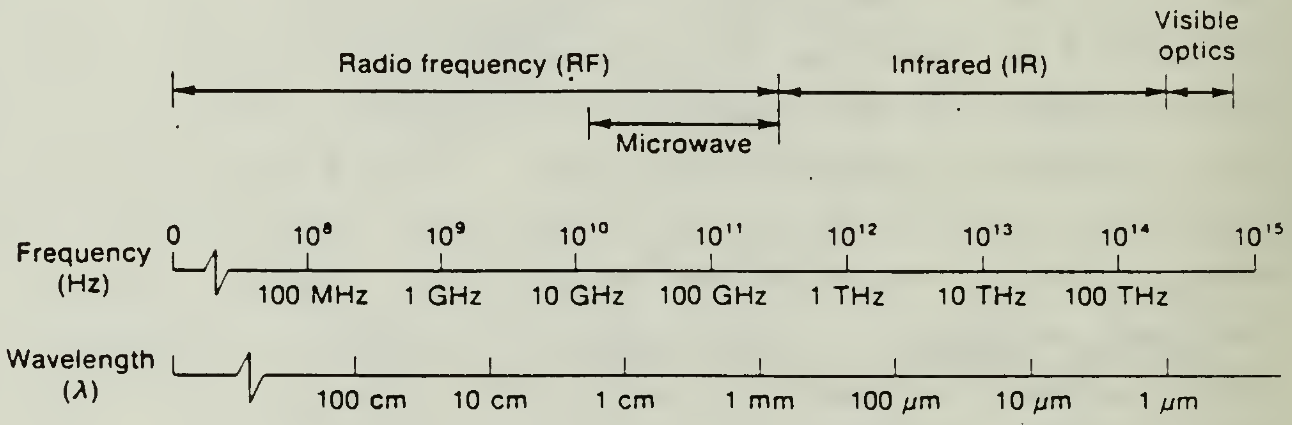
a = (T / 2 pi)**2/3 (k)**1/3 (eqn 2.6)

a = 42,173 km

laterally to a latitude of about ±80° [Ref. 6]. This is generally no problem for commercial applications since the polar regions do not require a significant degree of access. The military, on the other hand, does have an interest in communications in the polar region and therefore has several communications satellites that have orbits inclined at various angles. This type of orbit generally has disadvantages of lack of continuous coverage and a much more complicated system of ground tracking and receiving stations.

C. FREQUENCY BAND CONSIDERATIONS

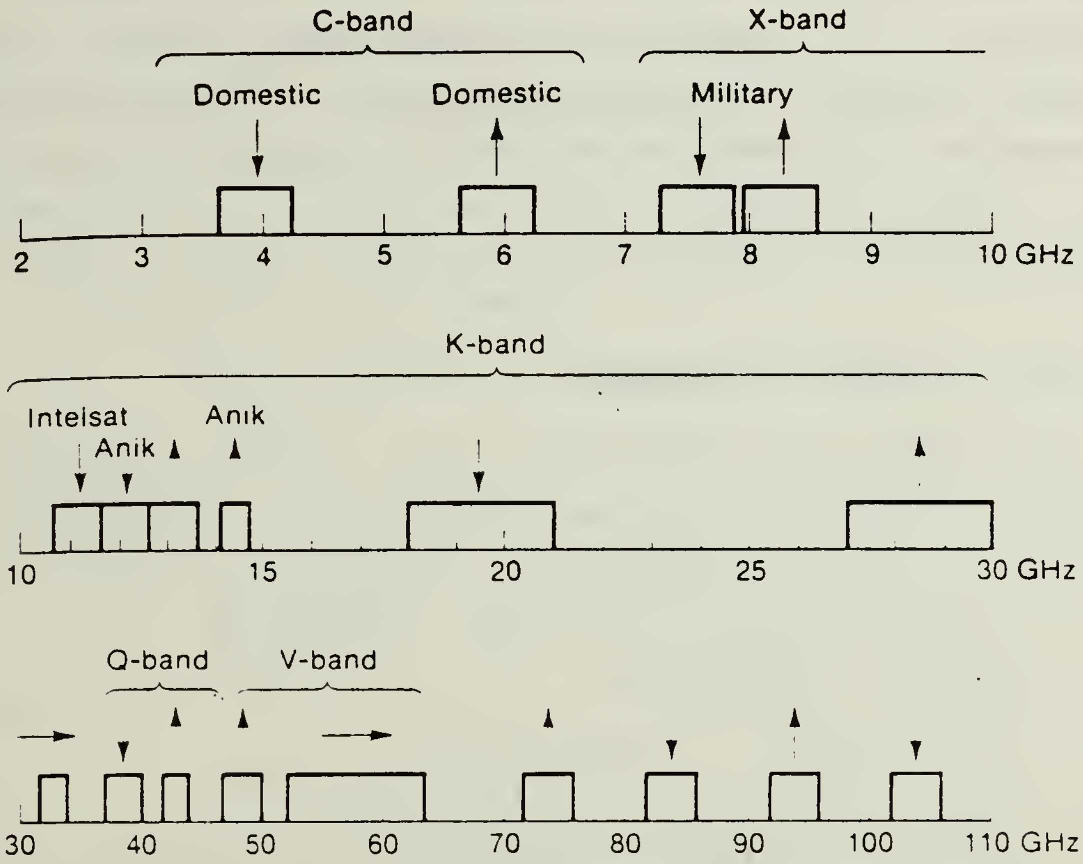
Although there appears to be an infinite number of frequencies available for communications, restrictions do exist as to those which are practicable. Limitations on available frequency bands for satellite communications are due to the need to select segments of the electromagnetic spectrum which reduce noise and interference and are most favorable in terms of power efficiency and propagation distortions. Trade offs must be made to arrive at the optimum frequency for a particular application since single frequencies seldom offer the best performance for all variables. The problems arise when consideration is given to the number of users requiring the same frequency bands including terrestrial communications networks. Since the problem of interference is global, a worldwide organization has been established to assign frequency bands for various applications. This organization is called WARC, World Administrative Radio Conference [Ref. 6]. Illustrations of the portions of the electromagnetic spectrum in question and current allocations of satellite frequency bands are shown in Figures 2.4 and 2.5 [Ref. 6].



Bands	Frequency
VHF	54 – 216 MHz
UHF	470 – 890
L	39 – 1 55 GHz
S	1 55 – 5.2
C	3.9 – 6.2
X	5.2 – 10.9
K	10.9 – 36
Ku	11.7 – 14.5
Ka	17 – 31
Q	36 – 46
V	46 – 56

Figure 2.4 Electromagnetic Spectrum

In general, as long as the hardware and technology will support it, higher frequencies are more desirable and more in demand because they offer higher theoretical capacity. This is due to the fact that only a percentage of the carrier frequency is capable of actually transmitting a signal of a given bandwidth. Higher frequencies would also experience less interference with existing land and satellite systems. A further discussion of the bandwidths available as a function of frequency will be included at a



Allocated satellite frequency bands, WARC 1979 (↑ = uplink, ↓ = downlink, → = crosslink).

Figure 2.5 Satellite Frequencies

later point under the topic of actual digital signal techniques.

As an additional note, in order to assist in the ability to handle more signals in an obviously limited electromagnetic spectrum, several multiple access schemes have been developed. The most common techniques involve frequency-division multiple access (FDMA) where the allocated satellite frequency band is divided among the users into specific uplink and downlink frequencies. Next is time-division multiple access (TDMA) where the satellite frequency band is shared by all users by carefully dividing the time any one user has access. Finally there is code-division multiple access (CDMA) which involves modulating a specific address code which has been superimposed on the signal directly onto the carrier. In this manner all users share the satellite frequency band and only those receiving stations that can demodulate the address code can receive the specific signal. [Ref. 6]

D. WHY DIGITAL MODULATION

In general, digital signal modulation techniques are superior to analog signal modulation techniques used in satellite communications for the following reasons:

1. Compatibility with digital computers
2. Economic advantages
3. High degree of flexibility
4. Less susceptible to interference
5. Quality of signal independent of transmission distance and network makeup

1. Compatibility with Digital Computers

Clearly one of the most distinctive advantages of digital techniques over analog techniques involves computer applications. Properly formatted digital signals can be used to represent any analog signal (more on this under the discussion of the sampling theorem). Once in the digital format these signals can be easily manipulated within the digital computer. Arithmetic operations can be applied as well as logical operations. The signal can be stored without alteration or delayed and therefore can be used to "simulate" real physical situations.

The hardware associated with digital circuits is free from drift or aging and does not require calibration. Additionally digital circuitry is compatible with present day integrated circuit technology allowing a standardized building block construction approach. The operating characteristics of these systems employing a digital computer can be changed by altering the software rather than the hardware as is the case for analog systems. Finally, the use of digital computer technology allows time multiplexing.

2. Flexibility and Economy

The flexibility and economy of digital satellite communications comes from the fact that more and more processing can be done onboard. This allows the uplink and downlink to be completely separated. This regenerative nature makes it possible for low error rates and high reliability through the use of digital techniques not available to analog systems. Because digital signal processing or multiplexing is less costly than for analog signals, simpler and cheaper interfaces between earth stations and terrestrial communications networks are possible. Additionally, there are reduced production costs and increased capacity associated with digital circuits. [Ref. 7]

3. Quality and Interference

The capability of digital systems to regenerate the signal and allow for multiple switching and signal processing without degradation in signal quality makes the digital signal basically independent of transmission distance. Multiple hops from satellite to earth station or satellite to satellite are possible without accumulation of the noise characteristic of analog systems. Additionally, digital systems are capable of operating at a signal to noise ratio of 20 dB to 30 dB as compared to analog systems requiring a much more powerful signal. [Ref. 8]

III. INTRODUCTION TO THE FOURIER TRANSFORM, SAMPLING THEOREM, AUTOCORRELATION FUNCTION AND THE MATCHED FILTER

Essential to the understanding of digital signal modulation techniques are a few basic tools of the electrical engineer and the mathematician. These tools will be developed and elaborated on to the extent necessary to understand their applicability to the subject of digital communications. The description is not meant to be a detailed investigation of the respective topics. Where relevant, the application of the concept being described will be mentioned.

A. FOURIER TRANSFORM

In mathematical terms, voltages can be expressed as functions of time or of frequency. It is more common to see voltages represented as a function of time as in equation 3.1.

$$v(t) = A \cos(wt) \qquad \text{(eqn 3.1)}$$

A = amplitude
w = angular frequency = 2 pi f
f = frequency = 1/T
T = period

It is important to note that both the time and frequency functions are representations of voltage and as such may be used interchangeably. The Fourier representation [v(t)] = V(f) is a voltage descriptor in the frequency domain (a function of frequency) while v(t) is a voltage descriptor in the time domain (a function of time). They are different but equivalent and either voltage descriptor may be used, depending on the concept being explored, to best represent the voltage within context.

The Fourier transform is of principle interest rather than the Fourier series since the latter is applicable only to periodic voltages. The Fourier transform is applicable to voltage pulses, random voltages and other non-periodic voltages.

DEFINITION:

$$\mathcal{F}[\,v(t)\,] = V(w) = \int_{-\infty}^{\infty} v(t)\,e^{**-jwt}\,dt \qquad \text{(eqn 3.2)}$$

$$\underset{\text{time domain}}{v(t)} \longleftarrow\!\!\longrightarrow \underset{\text{frequency domain}}{V(w)}$$

Remembering Euler's formula

$$e^{**-jwt} = \cos(wt) - j\sin(wt) \qquad \text{(eqn 3.3)}$$

the Fourier transform becomes

$$\mathcal{F}[\,v(t)\,] = V(w) = \int_{-\infty}^{\infty} v(t)[\cos(wt) - j\sin(wt)] \qquad \text{(eqn 3.4)}$$

$$V(w) = \int_{-\infty}^{\infty} v(t)\cos(wt) - j\int_{-\infty}^{\infty} v(t)\sin(wt) \qquad \text{(eqn 3.5)}$$

Since it will be seen that digital communications deals primarily with pulses of finite duration (expressed as period, T), it is worthwhile to examine the Fourier transform of a pulse of amplitude A and duration T.

$$\text{let } v(t) = \begin{cases} A; & -T/2 < t < T/2 \\ 0; & \text{elsewhere} \end{cases}$$

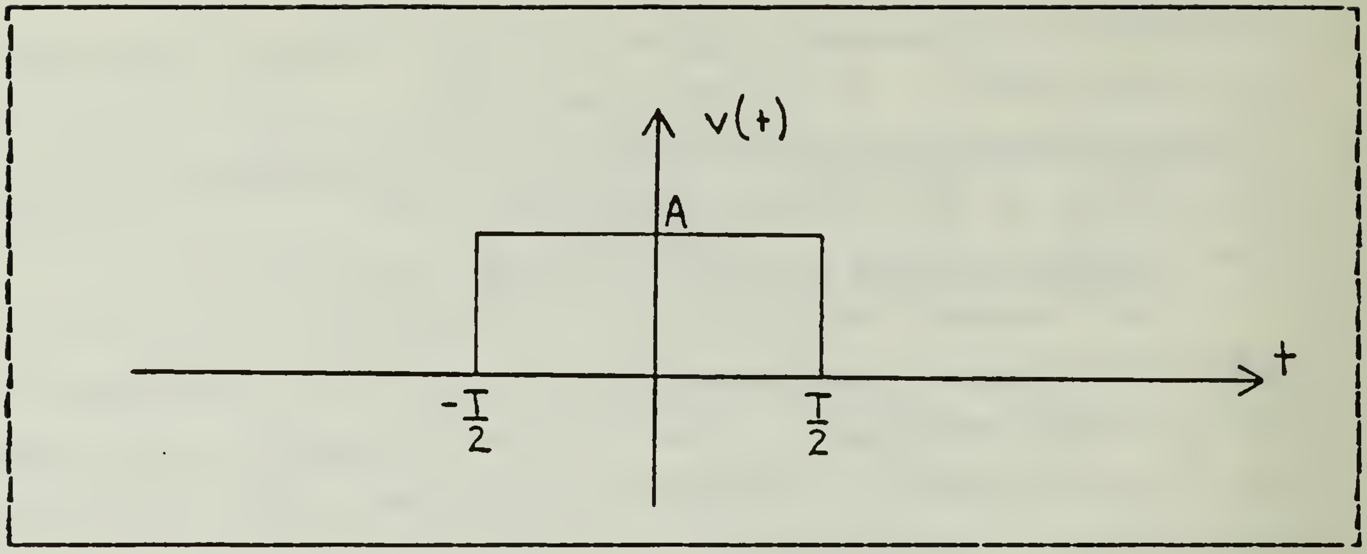


Figure 3.1 Square Pulse

Figure 3.1 is a representation of v(t) or the voltage expressed in the time domain. The position of v(t) on the t-axis was chosen for convenience of integration but could have been situated anywhere on the time line.

$$\mathcal{F}[v(t)] = V(w) = \int_{-\infty}^{\infty} v(t)\,\text{e**-jwt}\;dt \qquad \text{(eqn 3.6)}$$

$$V(w) = \int_{-\infty}^{-T/2} \text{e**-jwt}\;dt + \int_{-T/2}^{T/2} A\;\text{e**-jwt}\;dt + \int_{T/2}^{\infty} 0\cdot\text{e**-jwt}\;dt \qquad \text{(eqn 3.7)}$$

$$V(w) = \int_{-T/2}^{T/2} A\;\text{e**-jwt}\;dt \qquad \text{(eqn 3.8)}$$

The integration above may be attacked either head on or by substituting cos(wt) - j sin(wt) for e**-jwt. The direct approach is illustrated due to the relative simplicity of the integrand.

$$V(w) = \int_{-T/2}^{T/2} A\;\text{e**-jwt}\;dt \qquad \text{(eqn 3.9)}$$

$$V(w) = -A/jw[\text{e**-jwt}]\Big|_{-T/2}^{T/2} \qquad \text{(eqn 3.10)}$$

V(w) = -A/jw[e**-jwT/2 - e**jwT/2] (eqn 3.11)

V(w) = A/jw[e**jwT/2 - e**-jwT/2] (eqn 3.12)

By substituting 2pi f = w, the following result is obtained:

V(f) = A/j2 pi f[e**j2 pi fT/2 - (eqn 3.13)
e**-j2 pi fT/2]

V(f) = A/j2 pi f[e**j pi fT - e**-j pi fT]

Using Euler's formula, i.e., sin θ = (e**jθ-e**-jθ)/2j:

V(f) = 2jA/j2 pi f[(e**j pi fT - (eqn 3.14)
e**-j pi fT)/2j]

V(f) = A/pi f[sin(pi fT)]

Knowing that sin x / x = sinc x

V(f) = AT/pi fT[sin(pi fT)] (eqn 3.15)

V(f) = AT sinc(pi fT)

The sinc function is common in digital electronics and plots as the product of sin(pi fT) and 1/(pi fT) as in Figure 3.2. In Figure 3.2, V(f) in the frequency domain is equivalent to v(t) in the time domain. Note that as the pulse, T, gets longer, 1/T gets smaller or the first zero crossing of the sinc function occurs at a lower and lower frequency.

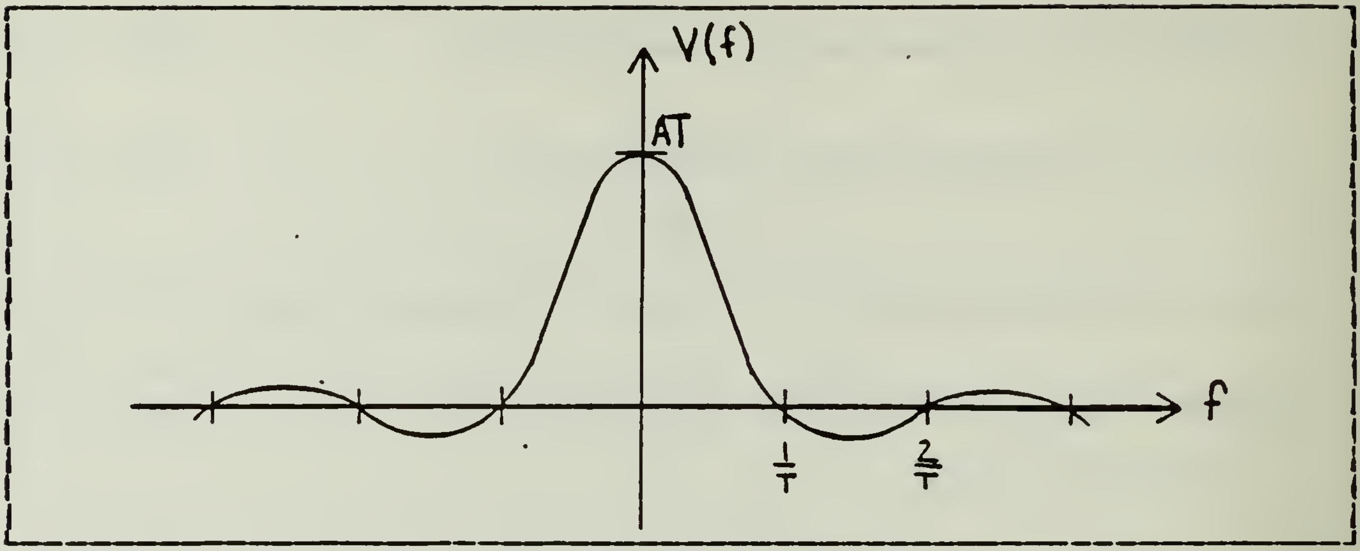


Figure 3.2 Plot of Sinc Function

1. Amplitude and Phase Spectrum

Recall that V(w) can be represented as in equation 3.16. The cosine term is the real part while the sine term is the imaginary part. By referencing Figure 3.3, a brief review of the complex plane is accomplished and its relationship to the amplitude and phase spectrum of a given voltage is represented. See equations 3.17 through 3.20.

$$V(w) = \underbrace{\int_{-\infty}^{\infty} v(t)\cos(wt)}_{\text{real}} - j\underbrace{\int_{-\infty}^{\infty} v(t)\sin(wt)}_{\text{imaginary}} \qquad \text{(eqn 3.16)}$$

|V(f)| is called the amplitude spectrum of the given voltage. The amplitude spectrum can also be calculated by using the complex conjugate of the Fourier transform and is always positive as shown in equation 3.21. The phase spectrum, θ, of the function in question is represented by the arctan[imaginary/real] and is illustrated in Figure 3.5.

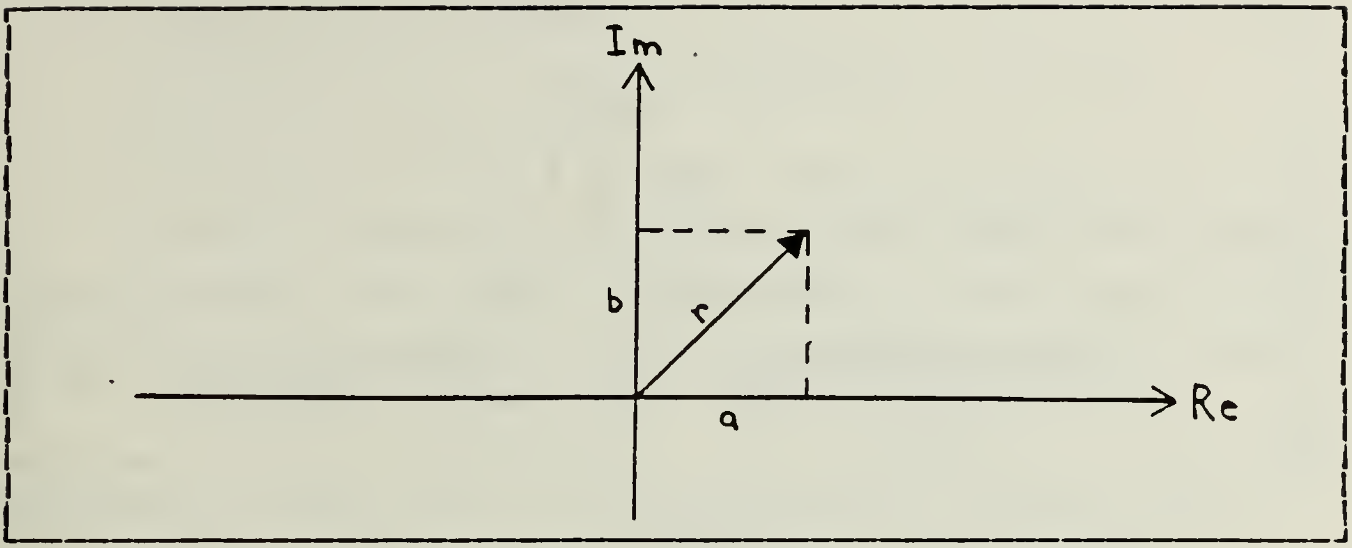


Figure 3.3 Phasor Diagram

$r = [a^2 + b^2]$ (eqn 3.17)

$a + jb = [a^2 + b^2]**.5\ e**j\theta$ (eqn 3.18)

$V(f) = [\mathrm{real}^2 + \mathrm{imaginary}^2]**.5\ e**j\theta$ (eqn 3.19)

$|V(f)| = [\mathrm{real}^2 + \mathrm{imaginary}^2]**.5$ (eqn 3.20)
since $|e**j\theta| = 1$

$|V(f)| = [V(f) \bullet V*(f)]**.5$ (eqn 3.21)

2. Properties of the Fourier Transform

Several properties of the Fourier transform are useful in the study of digital signals. They are represented here without proof and without a great deal of detail.

a. Linearity

if v1(t) <-> V1(f) and
if v2(t) <-> V2(f) then
$\mathcal{F}[av1(t) + bv2(t)] = aV1(f) + bV2(f)$

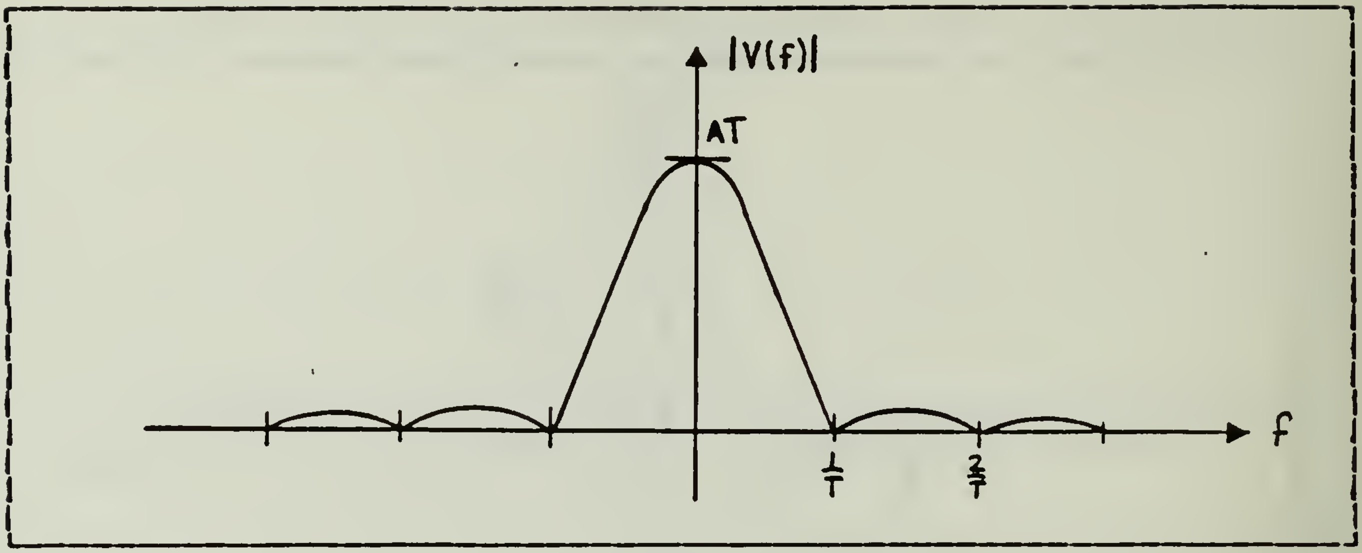


Figure 3.4 Amplitude Spectrum of Square Wave

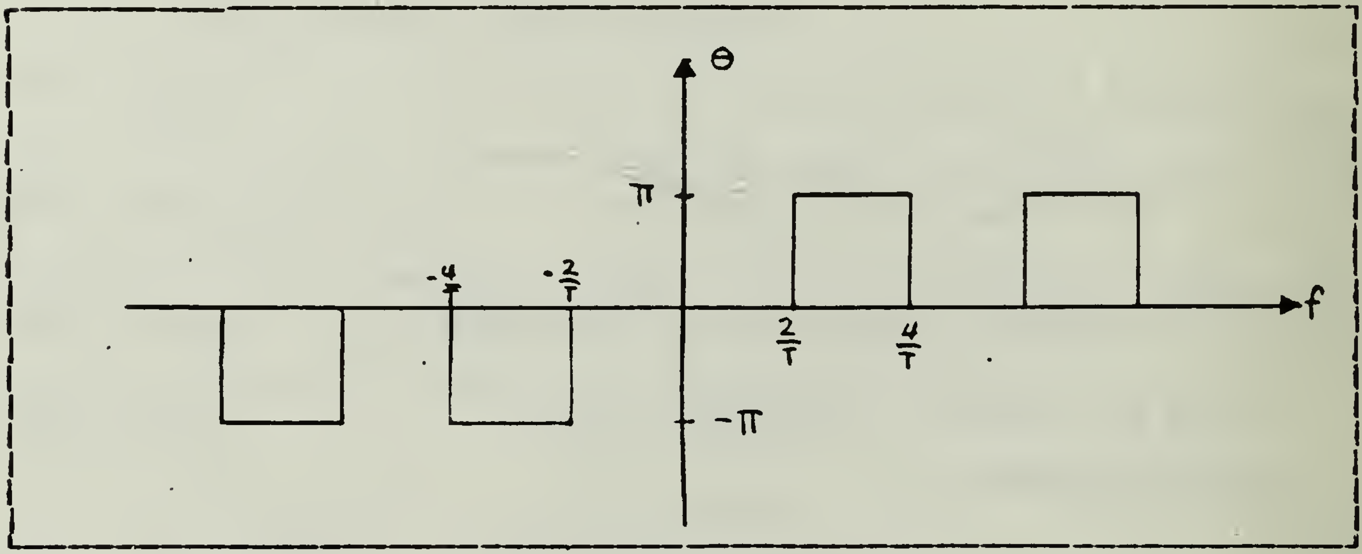


Figure 3.5 Phase Spectrum of Square Wave

b. Time-delay

$\mathcal{F}$[v(t-to)] = V(f) e**-jwto

Note that the amplitude spectrum of the delayed version is the same as the amplitude spectrum of the undelayed version. It is comforting to note that the Fourier transform of a pulse is the same tomorrow as it is today.

c. Scale change

$\mathcal{F}$[v(at)] = 1/|a| V(f/a)

d. Frequency translation

v(t)cos(2 pi fc t) <-> 1/2[V(f+fc) + V(f-fc)]

v(t) is any voltage

cos(2 pi fc t) is a carrier wave of frequency fc

Since understanding of this very important property of the Fourier transform is essential to the understanding of digital signal modulation it is expanded slightly here.

As we have seen, the Fourier representation of a voltage pulse of amplitude A and duration T is the sinc function of amplitude AT as illustrated in Figure 3.6.

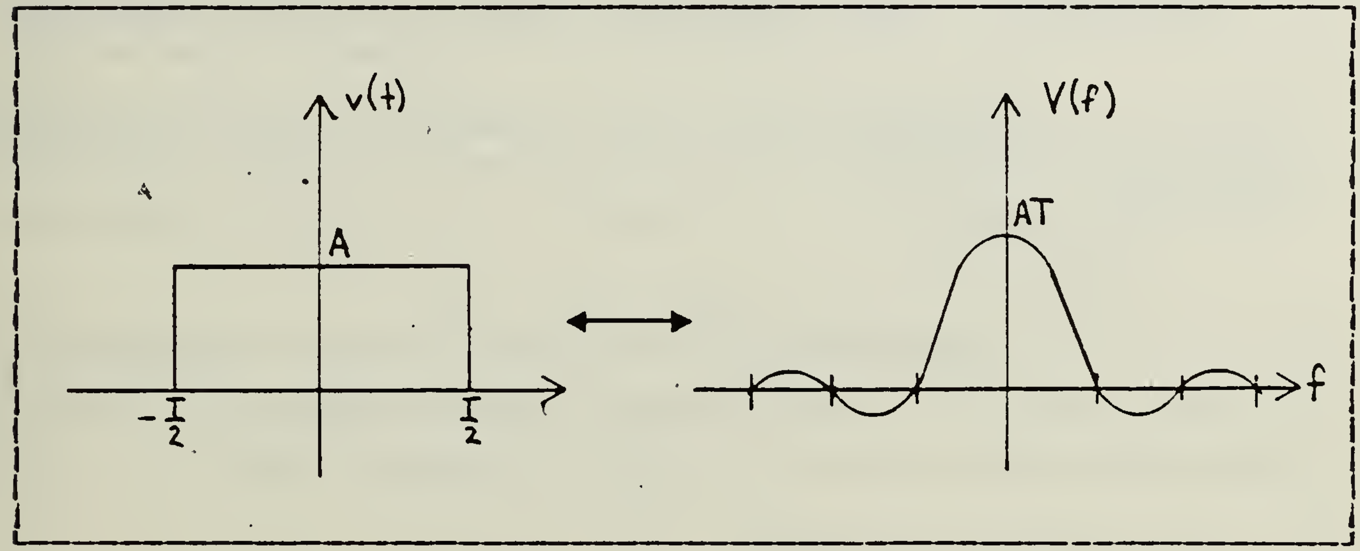


Figure 3.6 Square Wave in Time/Sinc Function in Frequency

The translation is the product of v(t) and in this case cos(2 pi fc t). In the time domain this product only exists in the interval between -T/2 and T/2 as in Figure 3.7. The significance of this translation and its relationship to the bandwidth of the voltage will be discussed further in the section dealing with bandwidth.

e. Differentiation

d v(t)/dt <-> jw V(f)

A differentiator could be used as a clock for timing but would never be used in the presence of noise since the

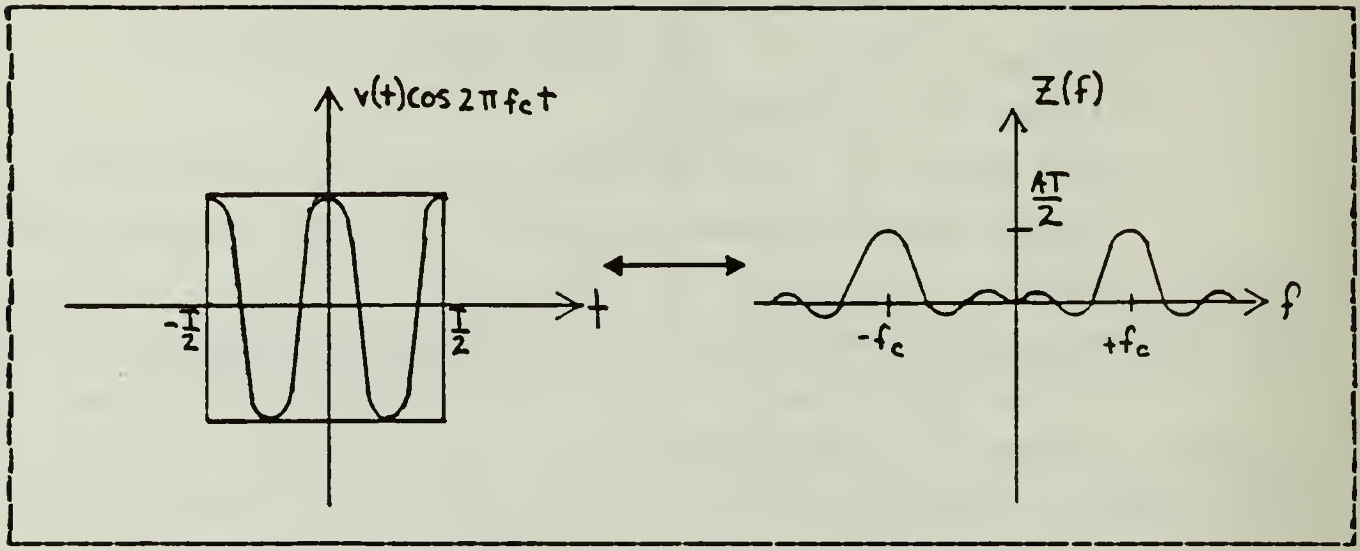


Figure 3.7 Multiplication and Translation Diagrams

result is exaggerated in the presence of high frequencies because w = 2 pi f.

f. Integration

v(t) dt <-> 1/w V(f)

An integrator could be used to reduce the effects of noise since w = 2 pi f is in the denominator tending to deemphasize the presence of high frequency noise.

B. THE SAMPLING THEOREM

Essential to the understanding of digital communications is the sampling theorem which was first introduced by Nyquist in 1928 [Ref. 9], and later by Shannon in 1948 [Ref. 10]. The sampling theorem states that any voltage can be uniquely represented by appropriately spaced sample values of the original voltage. More correctly stated, the sampling theorem places limits on the accuracy with which a signal can be represented.

The implication is that an analog signal can be represented digitally or by a set of numbers, i.e., samples. A description of the sampling theorem follows.

Given any analog voltage, v(t) as in Figure 3.8, the sampling theorem says that the entire analog signal is not required to accurately represent the voltage but only samples of it, call them vs(t). Figure 3.9 shows samples of a representative analog voltage. Samples can be taken of v(t) at every T seconds for a period of seconds. This can be accomplished by the use of a voltage clock, call it vc(t). The sampling can be viewed graphically as a block diagram representing an analog voltage multiplier as shown in Figure 3.10. To be of further use in the understanding of digital communications we are interested in a frequency description of the sample voltage, vs(t). Note that the system which describes the obtaining of vs(t) involves a voltage multiplication. It was demonstrated in the proceeding section that voltage multiplication amounted to frequency translation, a property of the Fourier transform.

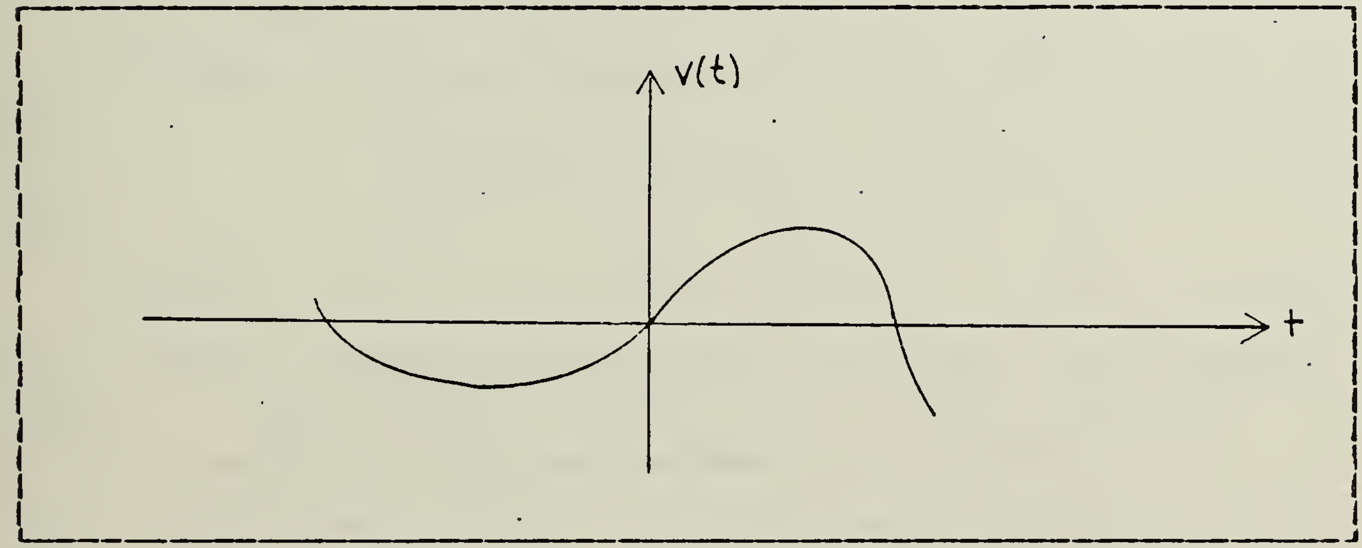


Figure 3.8 Representative Analog Voltage

First it is necessary to find the frequency description of the clock, vc(t), Let vc(t) be a periodic square wave of height 1 and duration d as in Figure 3.11. Since vc(t) is periodic, it can be shown that the Fourier series representing vc(t) is given by equation 3.22.

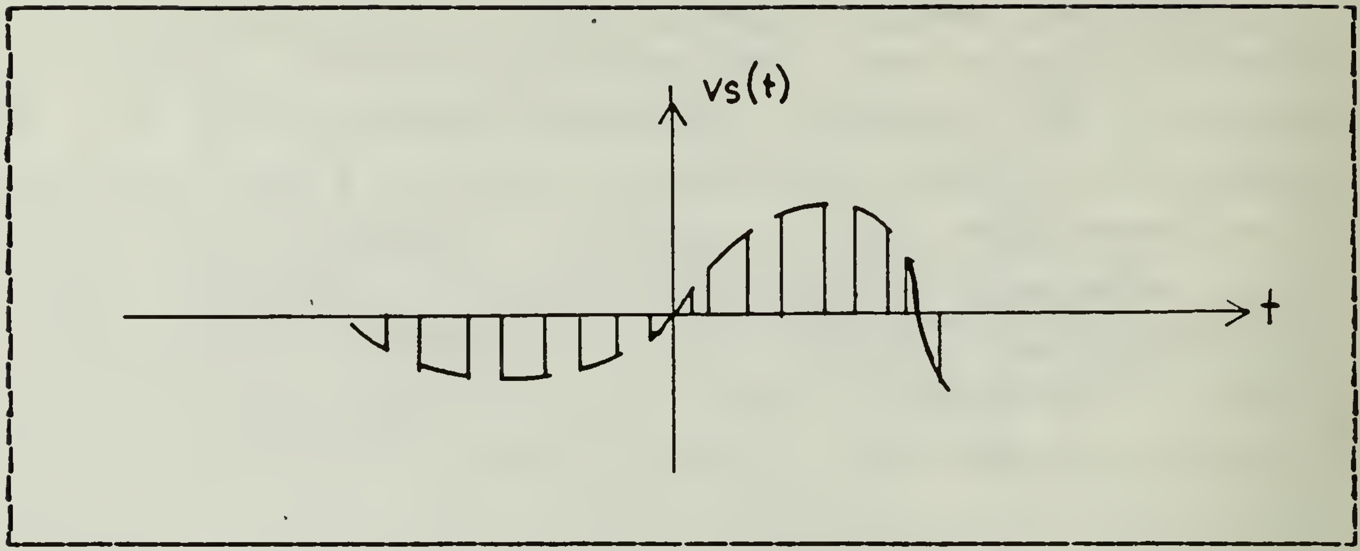


Figure 3.9 Samples of a Representative Voltage

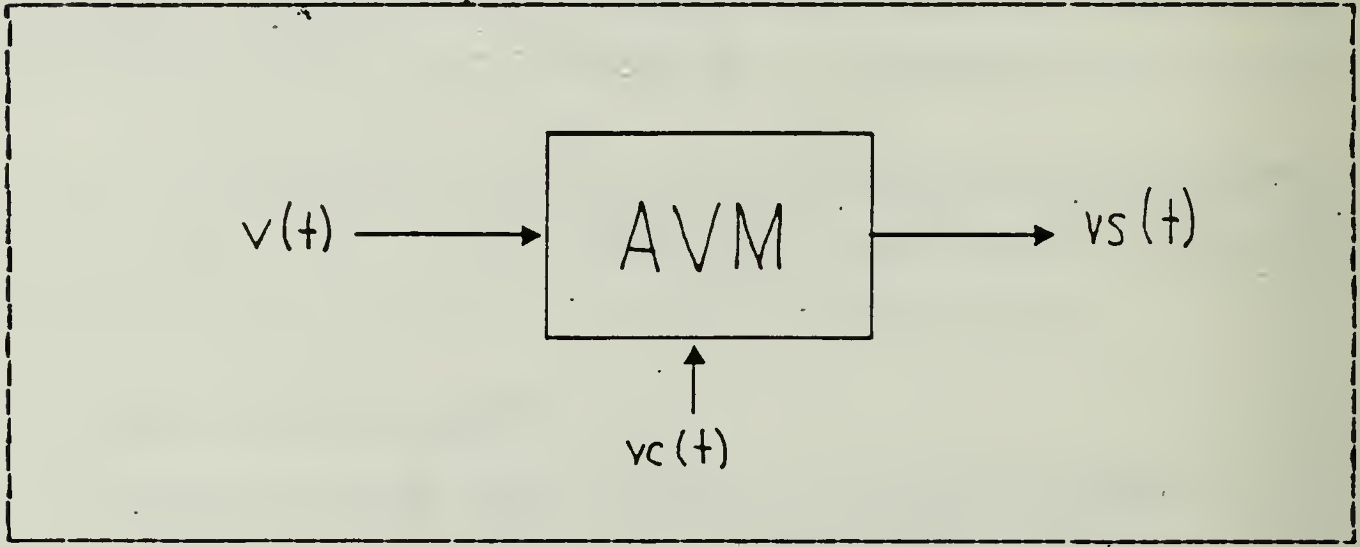


Figure 3.10 Analog Voltage Multiplier

Again it is noted that vs(t), the sample voltage, is the product of v(t), the original analog voltage, times vc(t), the clock voltage. In other words vs(t) = v(t) times a series of cosine terms.

$$vc(t) = ao + \sum_{n=1}^{\infty} an \cos(2\ pi\ n\ fc\ t) \qquad \text{(eqn 3.22)}$$

ao and an are left unevaluated

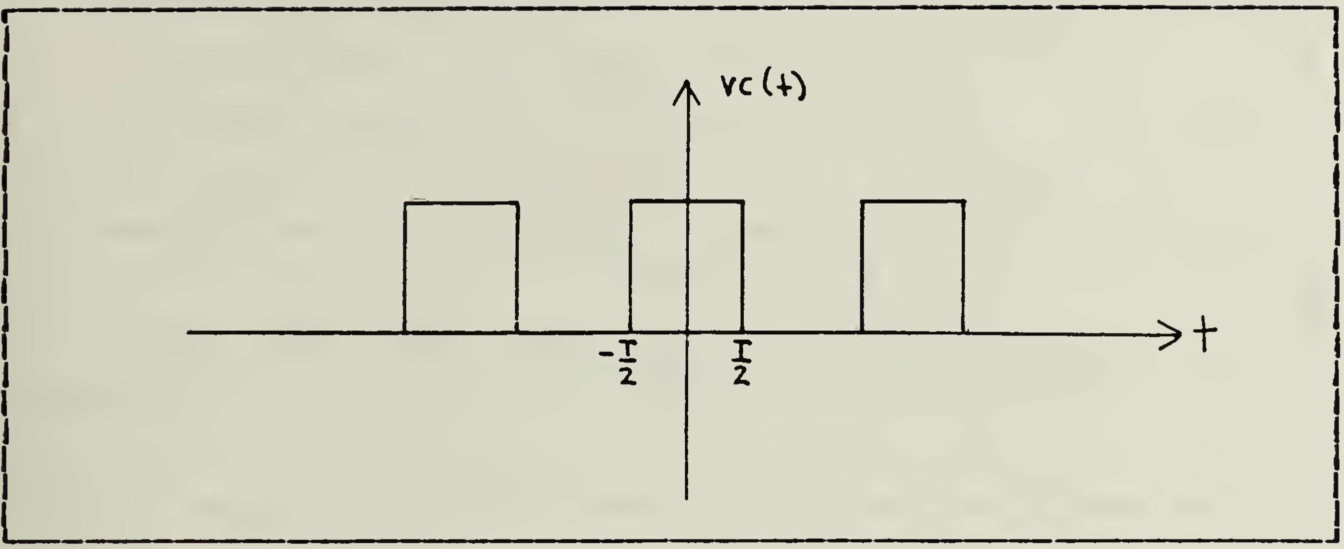


Figure 3.11 A Representative Voltage Clock

$$vs(t) = v(t)[ao + \sum_{n=1}^{\infty} an \cos(2\,\mathrm{pi}\,n\,fc\,t)] \qquad \text{(eqn 3.23)}$$

Now, assuming any form of the Fourier transform of v(t), as in Figure 3.12 and since vs(t) is a product and by utilizing the frequency translation property of the Fourier transform, the following is obtained as a representation of the frequency spectrum of vs(t). See Figure 3.13.

Remember that the curve highlighted in the box in Figure 3.13 is the Fourier represention of v(t), the original signal. This original signal can now be recovered by filtering with an appropriate low pass filter of bandwidth equal to or greater than B. This low pass filter would only permit the reception of that portion of the signal which represents the original voltage.

The only question left to resolve is how often to take a sample. Again referring to the diagram in Figure 3.13, it is noted that in order to prevent any overlap of successive translations (aliasing)

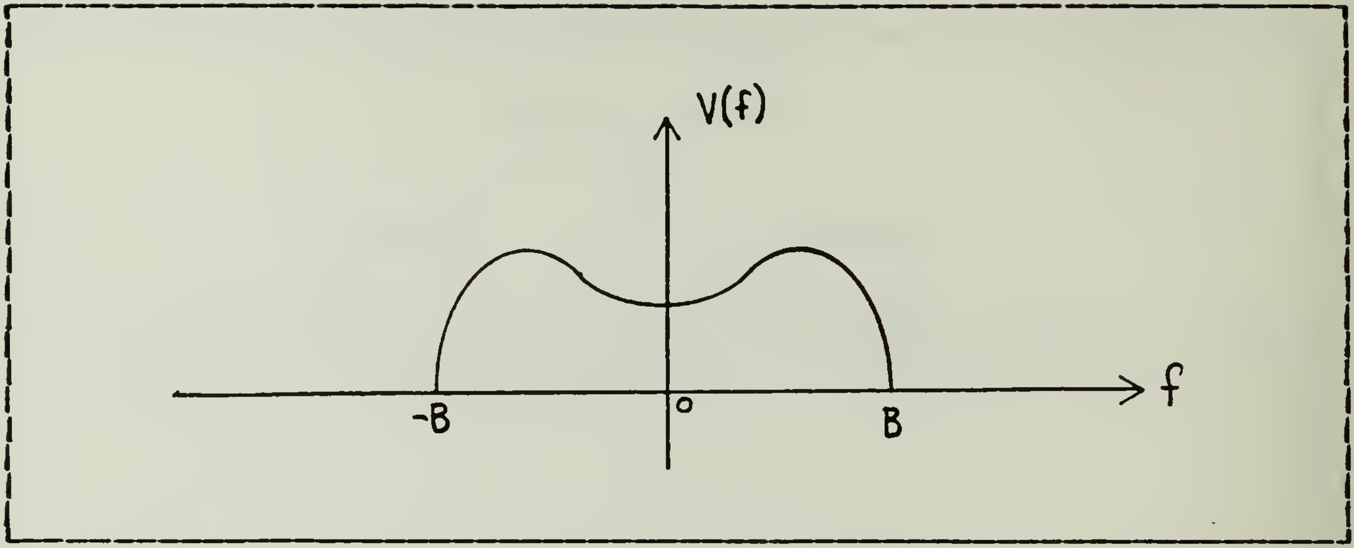


Figure 3.12 Fourier Transform of v(t)

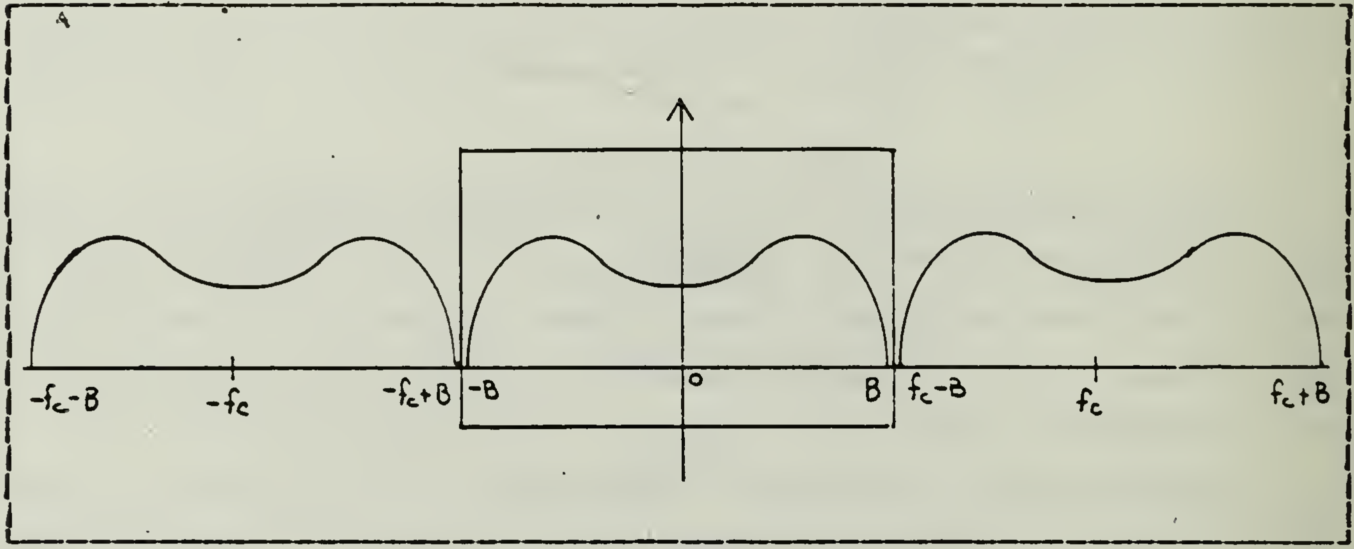


Figure 3.13 Fourier Transform of vs(t)

fo - B >> B

fo >> 2B

or the frequency of the clock, fc (the sampling rate = 1/T) must be strictly greater than 2 times the largest significant Fourier frequency component present. Since B will vary with different v(t), the sampling rate necessary to uniquely recover that v(t) also varies.

In summary on the sampling theorem, it can be said that any analog signal can be represented as certain sample values spaced the appropriate distance apart. The sampling theorem places limits on the accuracy of this representation. These sample values can then be transmitted from one position to another using analog to digital conversion and any one of a variety of modulation techniques. It has been shown that the Fourier frequency representation of the sample is not equivalent to the Fourier frequency representation of the source voltage; however, the source voltage can be recovered at the receiving end by filtering. A block representation of the system is shown in Figure 3.14.

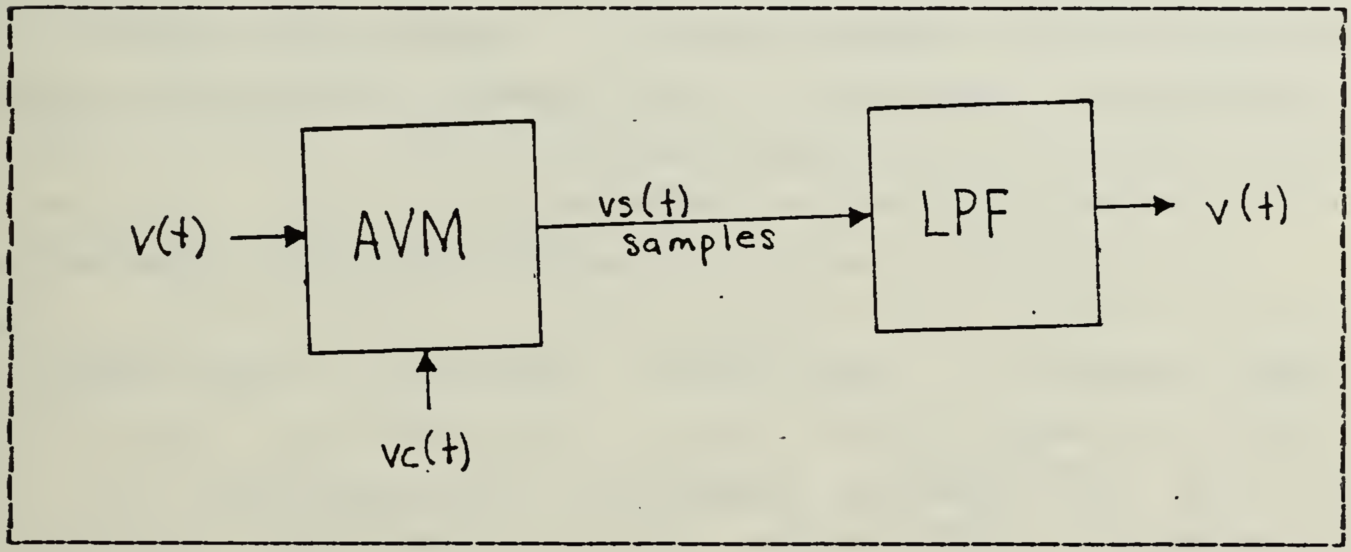


Figure 3.14 Analog Voltage Multiplier and Low Pass Filter

C. THE AUTOCORRELATION FUNCTION

The above concept certainly seems simple enough. If a signal is present and it is desired to transmit it from point A to point B, all that has to be done is to take appropriately spaced samples of the signal, encode them, somehow transmit them to point B, filter the received signal and the uniqueness of the original voltage has been reproduced. Unfortunately it isn't quite that easy. The reason it is not, is due to the presence of noise. The sources of noise will not be discussed here, however, the effects of noise in general terms and how a faint signal can be recovered in the presence of noise will be discussed.

The time varying descriptor of voltage and the frequency varying descriptor of voltage have been introduced. Both are precise mathematical descriptions of something (voltage) that is deterministic. That is, it can be described in mathematical or graphical terms during any period of time. Such is not the case for noise corrupted voltages which are entirely random. Therefore other descriptors of voltages must be employed in the presence of noise. They are partial descriptors of voltage since a random signal cannot be described with precision. These partial descriptors are the

1. Autocorrelation function and the
2. Probability density function (p.d.f.)

It is important here to note the difference between the source voltage at the receiver and the sample voltage. The source voltage at the receiver, vsr(t), is the digitally converted sample voltage, vs(t), modulated onto a carrier by one of the digital modulation techniques yet to be discussed. Understanding the autocorrelation function is the basis for understanding how a decision is made that vsr(t) is present at the receiver in the presence of noise. It should be remembered that the exact form of the carrier is known at both the transmitter and receiver.

First of all, an additive noise model is assumed where the signal at the receiver, vr(t), is equal to the signal which is being transmitted, vsr(t), (i.e., the digital samples of v(t) modulated onto the carrier), plus random noise, vn(t)

$$vr(t) = vsr(t) + vn(t) \qquad \text{(eqn 3.24)}$$

$vr(t)$ = voltage at the receiver
$vsr(t)$ = signal voltage at the receiver
$vn(t)$ = noise voltage at the receiver

If it is realized that most receivers operate on the principal of detection of DC voltage, the problem becomes one of rectification of the received signal and determination if the DC voltage, characteristic of the transmitted signal is present.

A common type of rectification of an analog voltage involves squaring the input waveform. If the given signal at the receiver is vr(t) as in equation 3.24 above, squaring the waveform introduces the square of not only the desired signal but also the square of the noise term. If instead of squaring vr(t) and introducing or at least not eliminating the noise, vr(t) is multiplied by vsr(t), the results in equation 3.25 are obtained.

$$vr(t) \cdot vsr(t) = vsr{*}{*}2(t) + vsr(t)\,vn(t) \qquad \text{(eqn 3.25)}$$

By averaging, all that remains is $\overline{vsr{*}{*}2(t)}$ since the average of vsr(t)vn(t) is zero because $\overline{vn(t)}$ is random and the average of any random voltage is zero. The DC component of vr(t)•vsr(t) is $\overline{vsr{*}{*}2(t)}$. Any remaining AC component can be removed by a low pass filter. Graphically in block diagram form this receiver looks like Figure 3.15 illustrated below. If vsr**2(t) > 0 then vsr(t) is present in the signal vr(t). If vr (t) is pure noise or some other signal is present exclusively, then the output of the receiver will be 0.

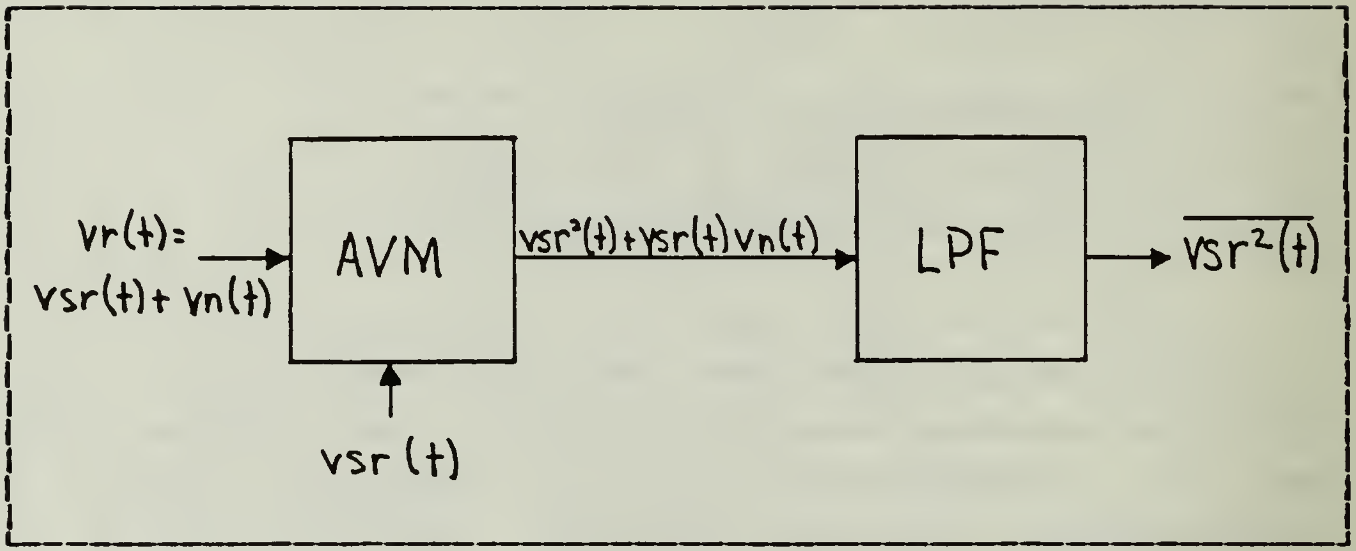


Figure 3.15 Rectification through an AVM and LPF

In practice, however, the exact waveform of vsr(t) may not be known or it may be a time delayed or distorted version of the original signal when it arrives at the receiver. If the distortion or delay is significant enough there will be little agreement or "correlation" in the receiver.

The solution is to multiply the received signal by a series of time delayed approximations of the transmitted signal. The signal is present whenever the output of the series of voltage multipliers or correlators exceeds a certain threshold approaching vsr**2(t). The concept is illustrated in Figure 3.16.

For the concept illustrated in Figure 3.16 to work, the average value of vr(t)•vsr(t-p) must have a DC component.

$$vr(t)\bullet vsr(t-p) = vsr(t)vsr(t-p) + vn(t)vsr(t-p) \qquad \text{(eqn 3.26)}$$

$$\overline{vr(t)\bullet vsr(t-p)} = \overline{vsr(t)vsr(t-p)} + \overline{vn(t)vsr(t-p)} \qquad \text{(eqn 3.27)}$$

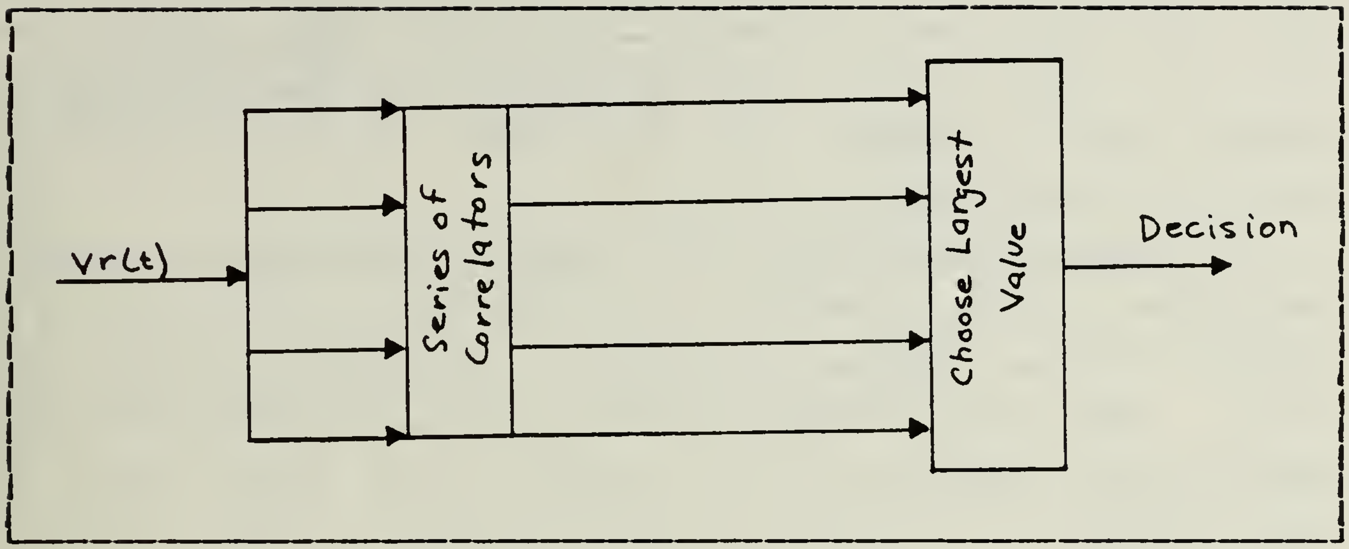


Figure 3.16 Correlation Device

But the average of vn(t)vsr(t-p) = 0 since $\overline{vn(t)}$ is random and the results of equation 3.28 are obtained.

$$\overline{vr(t)\bullet vsr(t-p)} = \overline{vsr(t)vsr(t-p)} \qquad \text{(eqn 3.28)}$$

What is of interest is the average value of vsr(t)vsr(t-p). The autocorrelation function (ACF) will be defined as that average value of vsr(t)vsr(t-p). The mathematical representation of the autocorrelation function for a continuous voltage is represented in equation 3.29 while the autocorrelation function for a pulse voltage is presented as equation 3.30.

$$ACF = Rvv(p) = 1/2T\int_{-T}^{T} v(t)\,v(t-p)\,dt \qquad \text{(eqn 3.29)}$$

$$ACF = Cvv(p) = \int_{-\infty}^{\infty} v(t)\,v(t-p)\,dt \qquad \text{(eqn 3.30)}$$

The autocorrelation function is a measure of the degree to which two identical signals which are corrupted in some manner are alike. The ACF of two signals which are identical, not distorted in any way and occurring at exactly the same time, i.e., p = 0 has a maximum value. On the other hand there will be very little correlation between two identical time variant signals when the time difference between them is great. In this case the autocorrelation function is near zero.

A similar concept is used within the context of signal comparison. This concept is the crosscorrelation which is a measure of the degree to which 2 different signals are alike. When the crosscorrelation between voltage vsr and random noise voltage vn is 0 there is no relationship or correlation.

Again let us assume that the signal at the receiver is a noise disrupted version of the signal originally transmitted.

$$vr(t) = vsr(t) + vn(t) \qquad \text{(eqn 3.31)}$$

In the receiver , the time delayed version of the signal is applied to the incoming signal and the average is formed as before and shown in Figure 3.17.

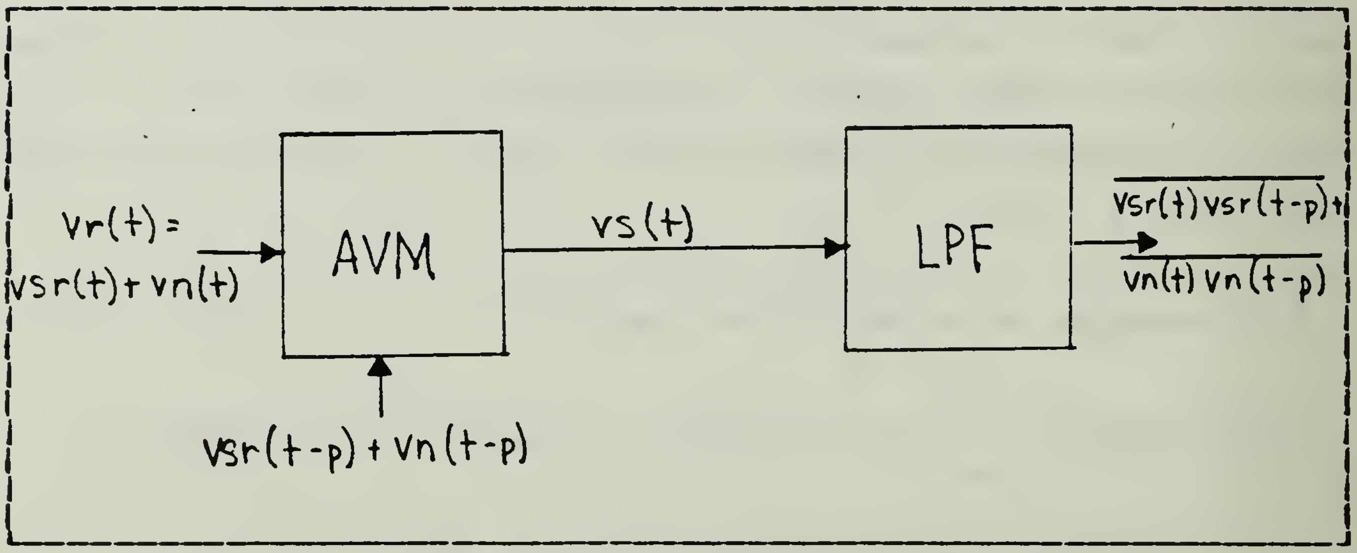


Figure 3.17 Voltage Correlator

$$[\overline{vsr(t) + vn(t)}]\bullet[\overline{vsr(t-p) + vn(t-p)}] = \qquad \text{(eqn 3.32)}$$

$$\overline{vsr(t)vsr(t-p)} + \overline{vn(t)vsr(t-p)} +$$

$$\overline{vsr(t)vn(t-p)} + \overline{vn(t)vn(t-p)} =$$

$$R_{vsr\ vsr}(p) + R_{vn\ vsr}(p) + R_{vsr\ vn}(p) + R_{vn\ vn}(p)$$

$$R_{vn\ vsr}(p) = 0$$

$R_{vsr\ vn}(p) = 0$; because average $vn = 0$

Therefore the result is simply $R_{vsr} = vsr(p) + R_{vn\ vn}(p)$ or the autocorrelation function of the desired signal plus the autocorrelation function of the noise. Assuming the shape of the autocorrelation function of both components (both the original signal and the noise which vary with p, time) is known, what is done in practice is to vary the value of p until the ratio of $R_{vsr\ vsr}(p) / R_{vn\ vn}(p)$ is a maximum or the autocorrelation function of the signal is a maximum while the autocorrelation of the noise is minimum and the signal is recovered.

D. THE MATCHED FILTER

The matched filter is a linear filter which has the characteristic response desired for optimum reception of the desired signal. In other words, we desire the response of the system to the linear filter to be in some way proportional to the autocorrelation function of the desired signal and in no way related to the autocorrelation function of the noise. This system could be illustrated as in Figure 3.18.

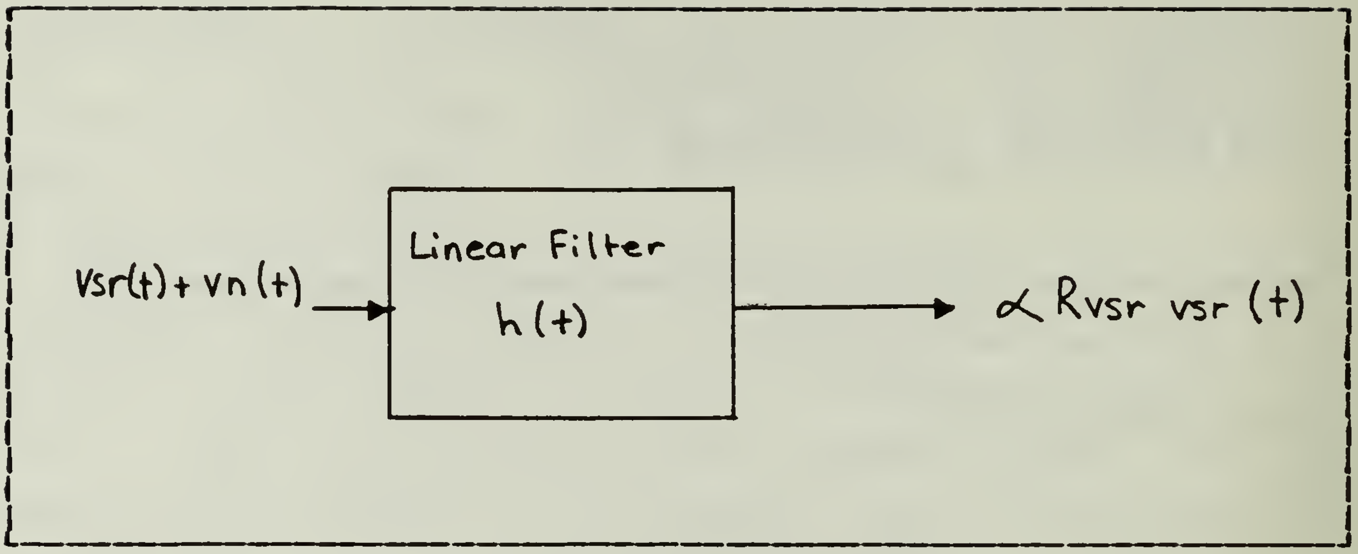


Figure 3.18 Matched Filter Block Representation

The question is what should the makeup or h(t), (i.e., the response of the linear filter) be? The output of a linear system is a convolution so the output of the linear filter, h(t) to an input vsr(t) would be vsr(t) * h(t), where * denotes convolution.

In the previous section it was stated that the autocorrelation function, Rvsr vsr(p), a function of p, is given by

$$\mathrm{Rvsr\ vsr}(p) = \int_{-\infty}^{\infty} \mathrm{vsr}(t)\,\mathrm{vsr}(t-p)\ dt \qquad \text{(eqn 3.33)}$$

By simply changing variables, equation 3.33 can be rewritten as a function of time, t.

$$\mathrm{Rvsr\ vsr}(t) = \int_{-\infty}^{\infty} \mathrm{vsr}(p)\,\mathrm{vsr}(p-t)\ dp \qquad \text{(eqn 3.34)}$$

From convolution theory it is known that the response of a linear filter as above, vsr(t) * h(t) can be expressed mathematically as in equation 3.35.

$$\mathrm{vsr}(t) * h(t) = \int_{-\infty}^{\infty} \mathrm{vsr}(p)\,h(t-p)\ dp \qquad \text{(eqn 3.35)}$$

As stated earlier, the desired output of the linear filter is the autocorrelation function Rvsr vsr(t). Note the similarities between the last two equations. If in equation 3.35 a simple substitution of h(t) = vsr(-t) is performed, the desired results are obtained.

$$vsr(t) * h(t) = \int_{-\infty}^{\infty} vsr(p)\,vsr(p-t)\,dp \qquad \text{(eqn 3.36)}$$

$$= Rvsr\ vsr(t)$$

Therefore, for every signal that is desired to be recovered, the matched filter will do the job very nicely if the response of that filter, h(t) is equal to the inverse of the signal that is desired to be detected.

IV. ANALOG TO DIGITAL CONVERSION

Key to the understanding of digital communications is how the analog information is converted to digital information. As illustrated earlier, each analog voltage or signal can be represented by appropriately spaced sample values. These sample values are still analog in that they can take on any value in the range of the original analog signal. What is desired is to change this infinite set of decimal numbers to a finite set of decimal numbers. This is called analog to digital conversion. Common types of A to D conversion include Pulse Code Modulation (PCM), Differential Pulse Code Modulation (DPCM), Delta Modulation (DM), Pulse Amplitude Modulation (PAM), Pulse Duration Modulation (PDM),and Pulse Position Modulation (PPM). PCM, DPCM, and DM will be examined in this chapter because of their widespread usage and easy application to digital technology.

A. PULSE CODE MODULATION (PCM)

PCM is the most widely used A to D conversion technique. It involves assigning the sample value obtained in sampling to one of several quantization levels within the range of the voltage sampled and then representing those quantization levels by various binary code words.

For example, the highest significant frequency component in human speech is 3300 Hz. In order to capture accurately the signal produced in speech, one would require a sampling rate greater than or equal to 2B or 2(3300) = 6600 samples/sec. The telephone company uses 8000 samples/sec.

$B = 3300$ Hz

$f \geq 2B = 6600$ samples/sec

use $f = 8000$ samples/sec to ensure no aliasing

If a signal is sampled at the rate of 8000 samples/sec, then in the transmission of those samples, assuming the samples are transmitted immediately and not delayed, the transmission rate must be

$Ts = 1/f$

$Ts = 1/8000$ samples/sec

$Ts = 125$ microsec/sample

The number of quantization levels employed to represent the various analog sample values is arbitrary. The greater the number of levels, the more accurate the reconstruction of the original signal but the more rapid the data transmission rate must be(in all cases there will be some error present after recovery). Consider again the example of voice as illustrated in Figure 4.1.

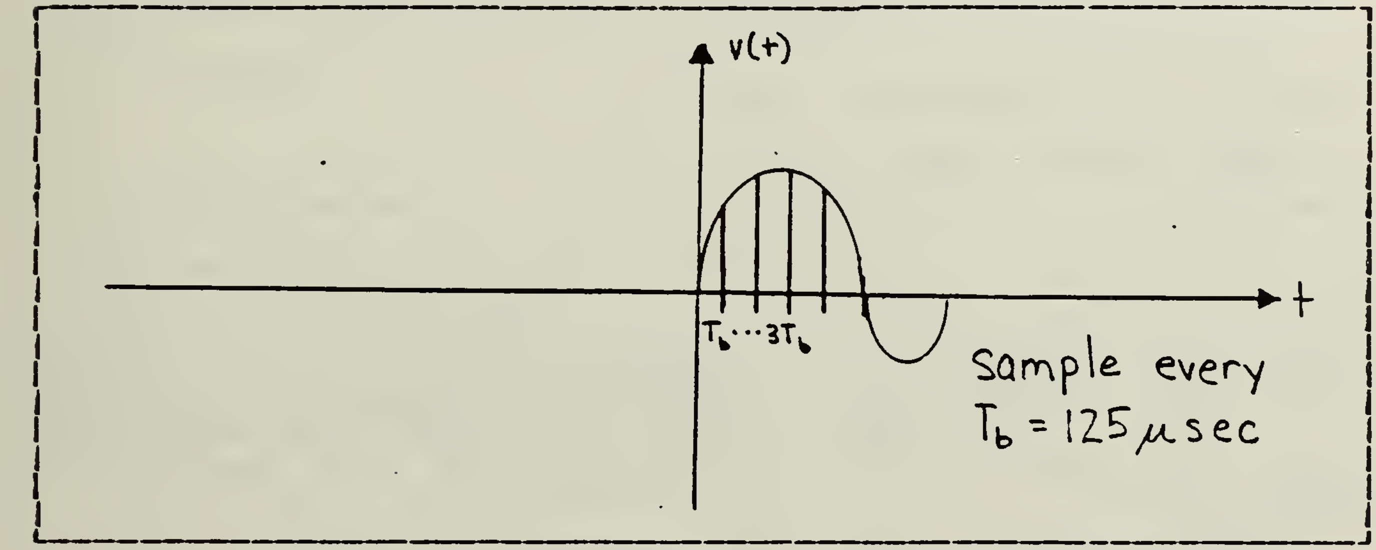


Figure 4.1 Samples of Voltage

Assume it is desired to represent each sample value (decimal number) with an 8 bit binary code word. Then the number of quantization levels is given by equation 4.1.

The spacing between quantization levels is the range of voltages to be represented divided by the number of quantization levels. The analog to digital conversion takes

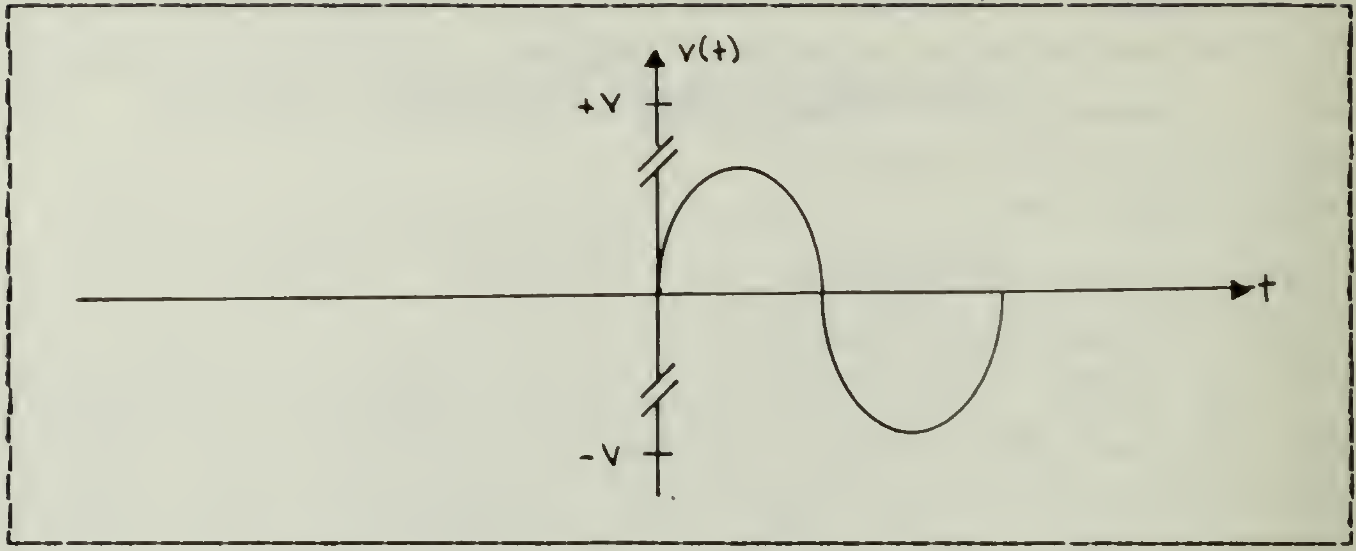


Figure 4.2 Analog Nature of Samples

#quantization levels = 2**n (eqn 4.1)

for n = 8 bits/binary code word
#quantization levels = 2**8
= 256

place by determining into which quantization level the respective sample values fall and assigning that sample value the binary number associated with that quantization level.

Now each sample value is assigned to an eight bit binary code word. For voice transmission it has been shown that the minimum transmission rate was Ts = 125 microsec/sample. The bit rate is then simply equal to the number of bits per sample times the inverse of the transmission rate as illustrated in equations 4.2 and 4.3.

If voice was to be time multiplexed onto a single channel, the bit rate for that channel would be the number of signals per channel times the bit rate for the most time intensive signal as illustrated in equation 4.4.

bit rate = (n bits/sample) (1 sample/T sec) (eqn 4.2)

bit rate = (8 bits/sample) (1 sample/125 microsec)

= 64 kbps

bit duration = 1/bit rate (eqn 4.3)

= 1/64 kbps = 15.6 microsec/bit

(#signals/channel) (bit rate/signal) = (eqn 4.4)

bit rate/channel

In other words, if 24 voice signals are to be multiplexed onto a single channel, the bit rate must be

bit rate/channel ≥ (eqn 4.5)

(24 signals/channel) (64 kbps/signal)

= 1536 Mbps

As can be seen, the data transmission rate increases significantly, necessitating better and better hardware and a wider and wider bandwidth. Advantages should be readily apparent for A to D conversion techniques or modulation techniques that reduce the bit rate required.

Recovery of the analog signal is by a process called Digital to Analog Conversion. All that will be said about D to A conversion is that it is the inverse process of A to D conversion and that a slight error is always introduced during the process due to the discrete nature of the quantization process during A to D and D to A conversion.

B. DIFFERENTIAL PULSE CODE MODULATION (DPCM)

In DPCM, what is converted to binary numbers is not the quantization level (decimal number) which each sample value is represented by but the successive differences between quantization levels. The idea is that the range of maximum difference values will be smaller than the range of actual sample values. It is therefore possible to represent that range of delta values with fewer bits/binary word and therefore fewer quantization levels and ultimately a lower bit rate. [Ref. 11]

In actual practice, in a DPCM conversion technique, it is a statistical estimate of each successive sample value which is subtracted from the actual value that is converted to binary code words. The result is the same in that the range of amplitudes is reduced and therefore fewer bits/word are required to represent the sample thereby lowering the data transmission rate required to transmit the signal. [Ref. 11]

C. DELTA MODULATION (DM)

Delta modulation is a form of DPCM where successive quantization levels of the output differ by only 1 bit. That is to say that any successive quantization level can be represented by varying only one bit of successive output binary code words. In other words a type of gray code is employed. This A to D technique is implemented through the use of a DM coder or linear delta modulator. This DM coder approximates a given input signal with a series of linear segments of uniform slope. A comparison is made between the value of this approximation and the input signal at each sample increment. The sign of this difference value is what is encoded and is used to increment the DM coder in the direction of the input signal. By using the differential sign value of the input signal and the incremented approximation from the DM coder the linear approximation from the linear delta modulator is said to "track" the input signal. [Ref. 8] Slope overload of this type of modulation technique occurs when the slope of the incoming signal exceeds the ability of the DM system to follow the source at the sampling rate being utilized. [Ref. 11].

V. DIGITAL SIGNAL MODULATION TECHNIQUES

Digital signal modulation techniques are the methods of encoding information for transmission utilizing digital technology. Factors affecting digital modulation include, but are not limited to, the physics of the method, hardware requirements, bandwidth considerations, power requirements, data transmission rates and error probabilities. It is these aspects which will be explored in the following sections.

A. DIGITAL MODULATION FORMATS

Modulation is the technique by which the characteristics of one waveform (called the carrier) are varied or modified by the characteristics of another (called the source). The carrier waveform of interest is the sinusoid. It should be obvious that the attributes of a particular sinusoid that differentiate it from every other sinusoid are its amplitude, phase and frequency. It follows that the characteristics of the carrier waveform to be varied by the source are its amplitude, phase, frequency or any combination of the three. This gives rise to the broad general formats of Amplitude Shift Keying (ASK), Phase Shift Keying (PSK) and Frequency Shift Keying (FSK). All other digital modulation techniques are variations of or combinations of these basic formats. Other factors involved in the description of the digital modulation technique being employed include the number of bits being encoded at one time, the employment of error correction techniques and the baseband (source) waveform.

When each bit of the baseband waveform is individually encoded by any of the techniques previously mentioned (ASK, PSK, FSK), the technique being utilized is referred to as binary encoding. When more than 1 bit of the source code is modulated onto the carrier at one time it is called block encoding. Block encoding allows for one of m = 2**k waveforms where k = number of bits.

This paper will not go deeply into signal detection or demodulation techniques, however, a basic understanding of what is involved is necessary and again further defines the digital modulation format being employed. In general terms, signal detection is referred to as either coherent or noncoherent detection of the transmitted signal. Coherent detection, perhaps the easiest to understand, is when all possible waveforms of the modulated carrier waveform are available at the receiver and the waveform at the receiver is in phase with the transmitted carrier. Noncoherent detection is involved when the receiver does not have knowledge of the phase of the transmitted information and one of a number of phase estimation techniques must be employed for signal recovery.

B. HARDWARE

Although significant advances have been made in recent years to improve the quality of hardware associated with satellite communications, most components are not what would be considered "off the shelf items". The hardware components most commonly referred to with regard to digital communications include the sampler, encoder, modulator, multiplexer and transmitter. There are variations of the above hardware requirements necessary for certain types of digital formatting, however, those exceptions will be addressed separately when the individual modulation techniques are examined.

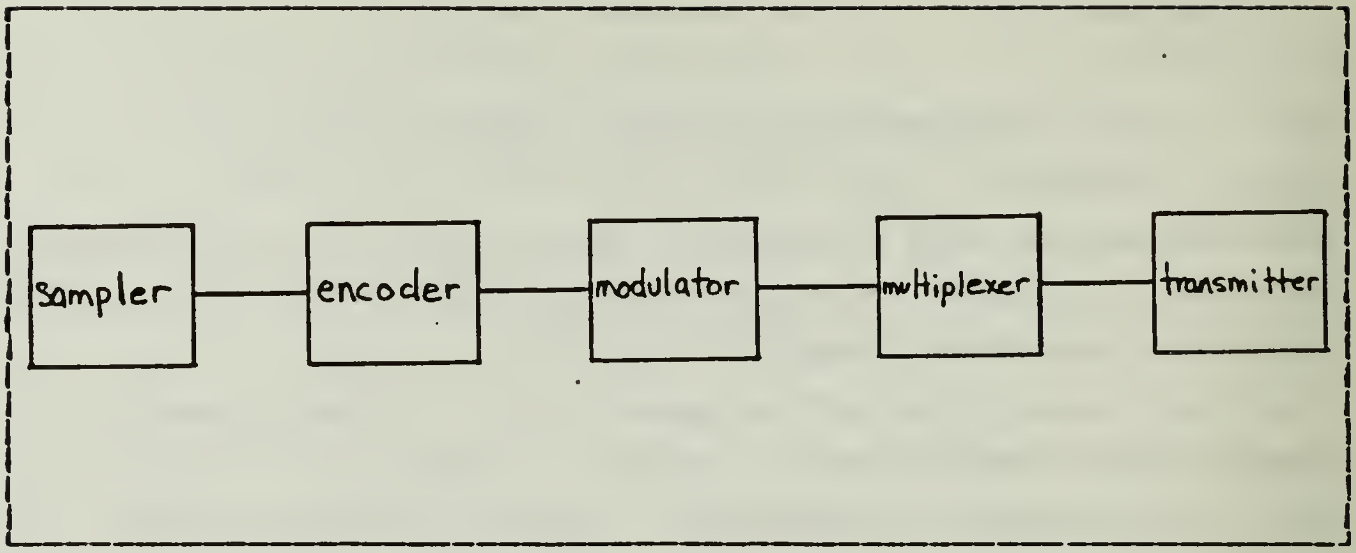


Figure 5.1 Basic Hardware Component Block Diagram

1. Sampler

The sampler is the device or component which samples or extracts those single characteristic values of a naturally occurring analog signal which are ultimately encoded into a digital word by the encoder. The frequency at which this sampler must operate was derived in the discussion of the Sampling Theorem. It was determined that the sampler must operate at a frequency greater than 2 times the highest significant Fourier frequency component of the source voltage. Modern solid state devices capable of taking thousands of samples/sec are available at modest costs.

2. Encoder

Often referred to as the A to D converter (analog to digital converter), the encoder transforms the samples of the analog signal derived from the sampler into a digital format through one of the analog to digital conversion techniques described in the chapter on A to D conversion. These digital bits can be stored for later use, coded, delayed or used immediately either individually or in groups to modify one of the characteristic qualities of the carrier waveform. When sample values of the analog source signal are converted into digital bits of information, they are simply that, digital bits of information. The carrier can only be modified to represent the source information by interaction with another voltage. Therefore the value of the digital bit (binary), either 0 or 1, is used to generate a baseband waveform or voltage which does the actual modulation of the carrier waveform.

a. Common Baseband Waveforms

It should be obvious that since it is desired to represent binary code words with a representative baseband waveform what is required is two levels of voltage. There are two basic logic schemes for representation of the baseband waveform. They are bipolar or unipolar logic. Bipolar logic involves representing the 0's or 1's of the binary codeword as either +V or -V as illustrated in Figure 5.2.

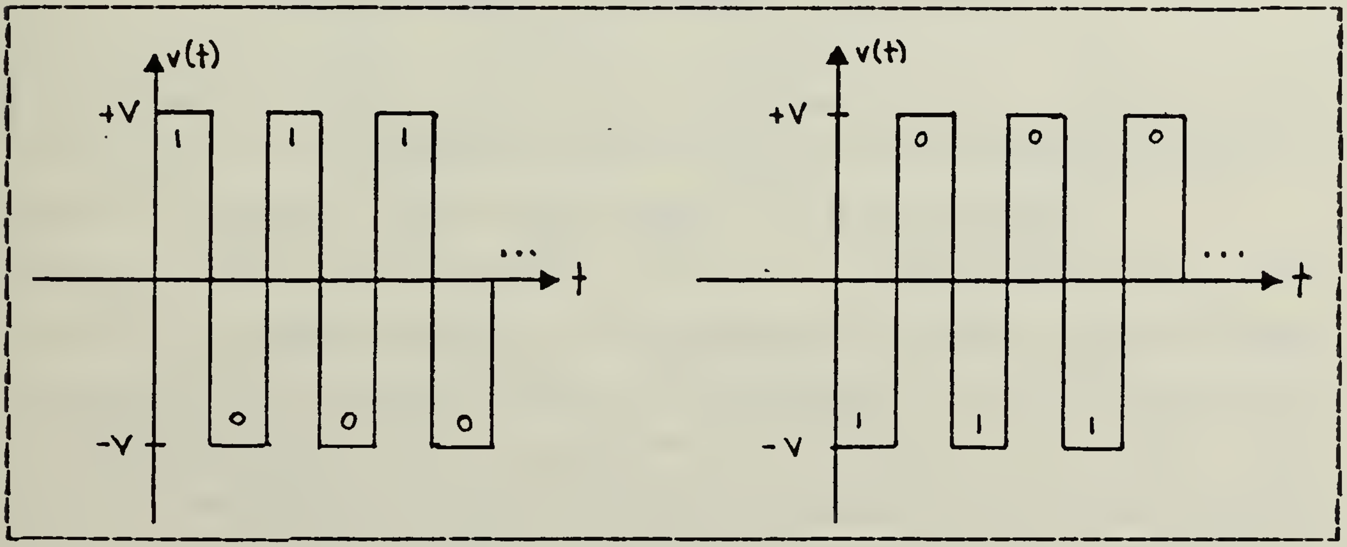


Figure 5.2 Bipolar Logic

The 0 or the 1 of the binary code word can be represented either as +V, -V or -V, +V respectively. This is a matter of convention but must be clearly understood in the various component designs in order to ensure compatibility between parts of the system.

Unipolar logic utilizes a voltage to represent either of the possible binary digits and the absence of voltage to represent the other. Two common conventions of unipolar logic are represented in Figures 5.3 and 5.4.

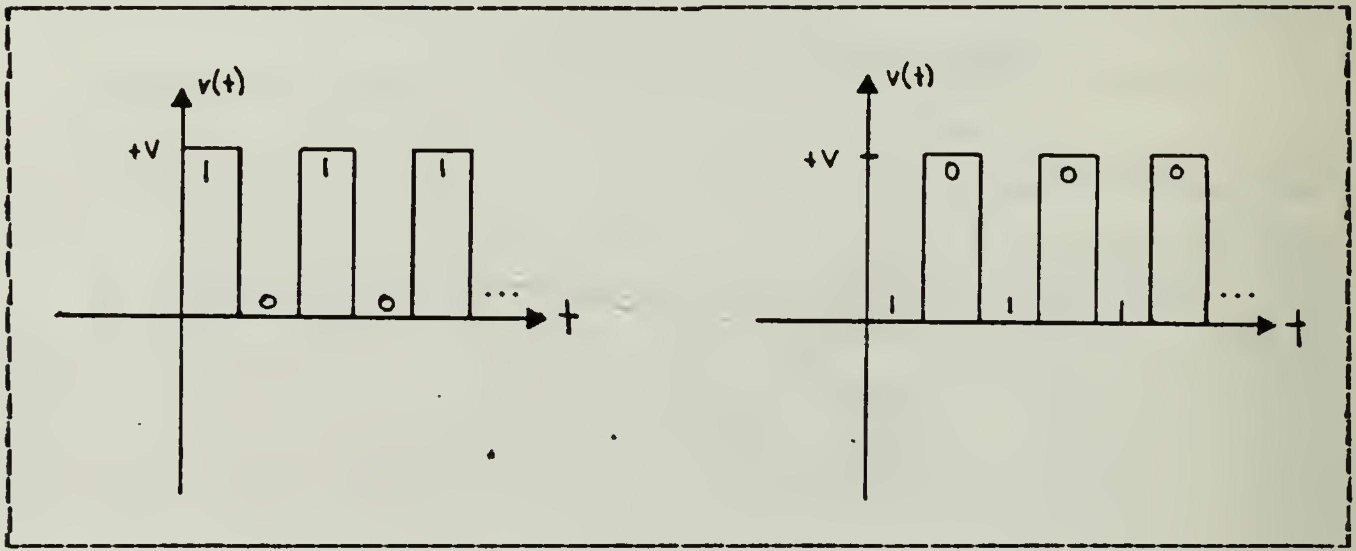


Figure 5.3 Unipolar Positive Logic

Again, which form of unipolar logic might be employed in the A to D converter is a matter of convention.

Variations of these two basic encoding formats have the advantages of ease of generation and improved decoding and clock recoverability. Two variations commonly used in satellite communications are the Non Return to Zero (NRZ) and the Manchester waveforms. The NRZ waveforms is simply the voltage representation which corresponds to the stream of bits represented in the logic scheme chosen. There is no transition as long as the same bit is present. Choosing bipolar logic as an example, a NRZ waveform can be described schematically as in Figure 5.5.

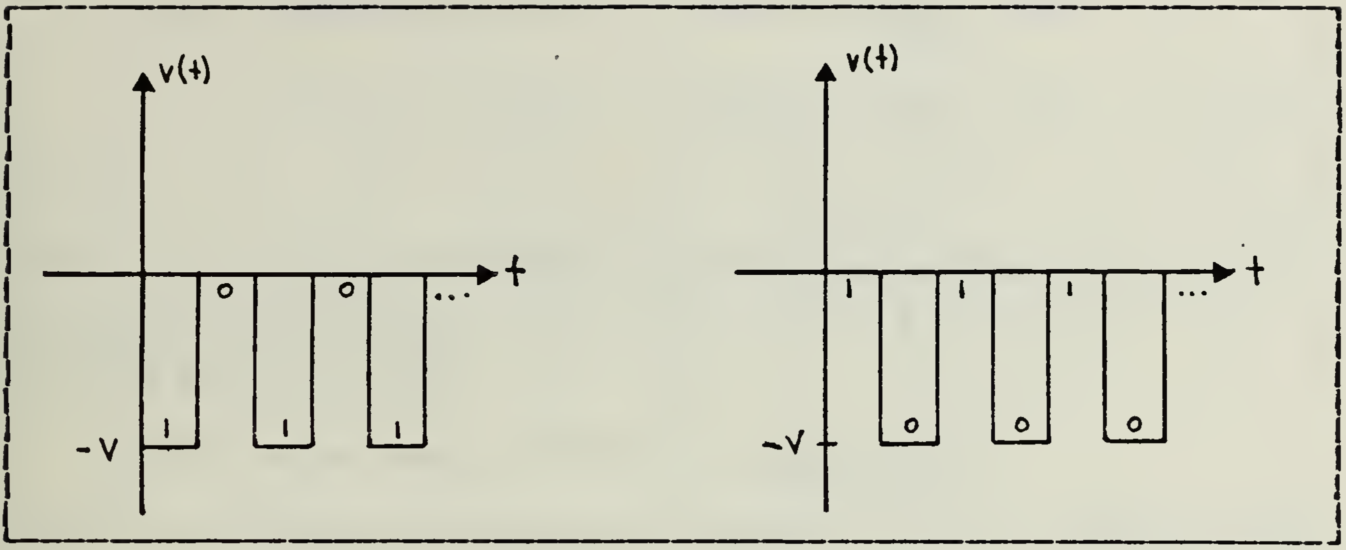


Figure 5.4 Unipolar Negative Logic

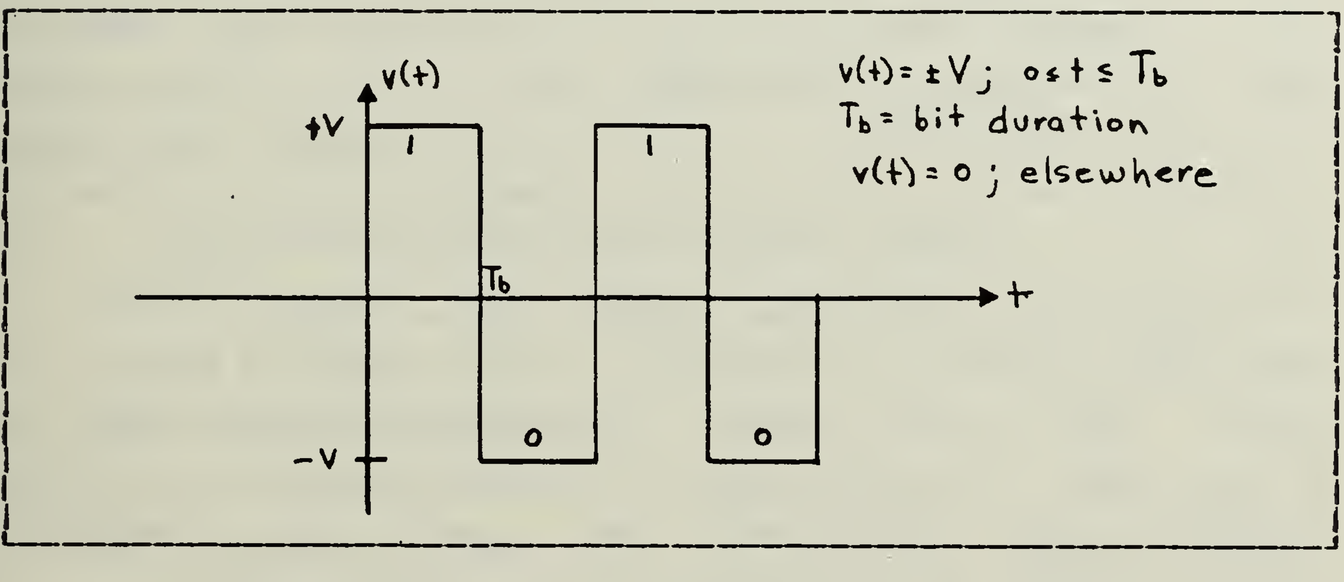


Figure 5.5 Non Return to Zero Waveform

The Manchester waveform of the same source voltage is represented with a transition at the midpoint of the bit duration from either +V to -V or -V to +V. This form of coding has the advantage of clock synchronization in all cases of digital encoding. Schematically, the Manchester code can be represented as in Figure 5.6.

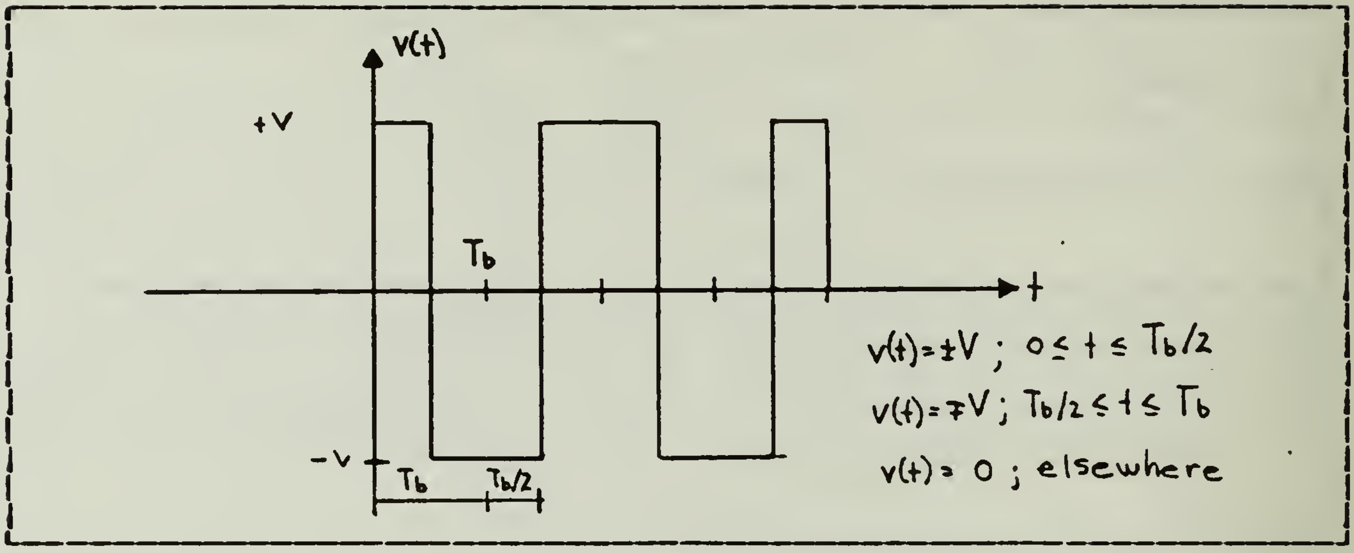


Figure 5.6 Manchester Waveform

3. Modulator

The modulator in a digital communications system is more commonly referred to as a modem (modulator/demodulator). This device does the actual transformation of the digital information into a waveform that can be transmitted from one point to another. The modulation as mentioned earlier can modify either the amplitude, phase or frequency of the carrier wave. In simple terms, the digital information derived from the analog source is mapped into the carrier wave. It is this mapping that determines the power and bandwidth characteristics of the modem.

4. Multiplexer

Multiplexing is a common method for increasing the utility of a given communications channel. Variations in multiplexing techniques give rise to the multiple access techniques employed in satellite communications.

a. Frequency-Division Multiplexing (FDM)

Frequency-Division Multiplexing is a technique whereby the capacity of a communications channel is increased by adding one signal to another. These signals occupy discrete nonoverlapping frequency bands. A specific signal is recovered by use of a band pass filter for the frequency band desired. [Ref. 7]

b. Time-Division Multiplexing (TDM)

Time-Division Multiplexing is a technique used to increase the capacity of a given communication channel by adding signals in time. That is, specific signals or portions of signals are allocated specific time slots or portions of the carrier wave. These time allocations cannot overlap and the signal is recovered through proper synchronization of the recovery hardware with the multiplexer. [Ref. 7]

c. Code-Division Multiplexing (CDM)

Code-Division Multiplexing is a technique for increasing the capacity of a given communications channel through the assignment of a characteristic code to the digital signal before it is multiplexed in the time or frequency domain. Since the code used in multiplexing is known at the demultiplexer, recovery of the digital source code could be accomplished through the use of a matched filter or correlator. [Ref. 7]

C. BANDWIDTH

For purposes of discussion and for uniformity, when examining the various digital signal modulation techniques of interest, the bandwidth will be defined as the highest significant Fourier frequency component of the signal in question. For digital communications, it can be shown that by the above definition, the bandwidth of the baseband waveform is 1/Tb, where Tb is the bit duration. For example:

1. Voice sampled at the rate of 8000 samples/sec
2. Each sample represented by an 8 bit code word
3. Rb = bit rate = (8000 samples/sec)(8 bits/sample)
   Rb = 64 kbps
4. Tb = bit duration = 1/Rb
   Tb = 15.6 microsec

The Fourier transform of the baseband waveform of duration 15.6 microsec is represented in Figure 5.7.

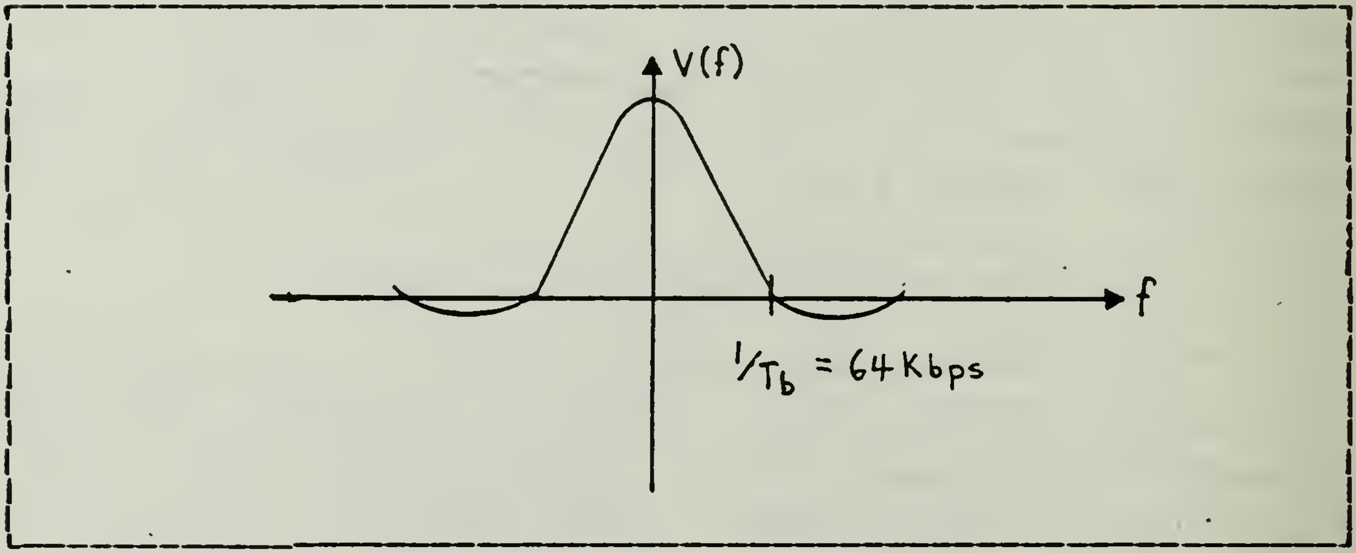


Figure 5.7 Fourier Transform of Baseband Waveform

It should be readily apparent that as the bit rate of the digital baseband waveform increases, so does the bandwidth. It is desireable to keep the bandwidth of the signal to a minimum due to limitations on availability of the electromagnetic spectrum. In addition, interference with signals which occupy adjacent frequency bands is reduced and propogation limitations of the medium and hardware limitations such as self-inductance and capacitance are minimized.

D. SPECIFIC TECHNIQUES

Now with some of the basics of digital signals already introduced it is possible to investigate some of the more significant modulation formats employed in digital satellite communications. The organization of this section will be around the three general types of modulation, i.e., phase, amplitude and frequency. Within each broad category, several techniques will be described under the subareas of binary encoding, where the information is modulated onto the carrier bit by bit, and block encoding, where groups of bits do the modulation. Variations of these areas will be pointed out. The characteristics of the modulation technique will be introduced including, where practical, an analytical description, phasor representation, error probability, spectral efficiency, advantages and disadvantages.

1. Phase Shift Keying (PSK)

Phase shift keying is a generic form of signal modulation where the baseband waveform is used to modify or change the phase of the carrier. Phase, as stated earlier is one of the characteristics which distinguish one sinusoid from another. In general, phase shift keying offers the advantages of power and bandwidth efficiency.

a. Binary Phase Shift Keying (BPSK)

As the name suggests, Binary Phase Shift Keying (BPSK) results in a modulated carrier waveform consisting of two phases of the same sinusoid. The baseband waveform is used to change the phase of the carrier bit by bit from one phase to the other. In the case of bipolar logic, the bit stream consists of ±1. The general waveform of the carrier can be represented as a cosine wave of amplitude A, angular frequency w and initial phase angle delta as in equation 5.1.

$$vc(t) = A \cos(wt + delta) \qquad \text{(eqn 5.1)}$$

Since two phases are represented in vc(t), it is customary to let them differ by pi radians. This can be represented by the modification of equation 5.1 to account for a pi phase shift depending on whether the bit, v(t) to be modulated is either a +1 or -1 as shown in equation 5.2.

$$vc(t) = A \cos(wt + delta + pi/2(1-v(t))) \qquad \text{(eqn 5.2)}$$

Equation 5.2 can be expanded to result in a simplified form showing that the modulated carrier waveform is simply a product of the baseband waveform and the carrier. See equation 5.3 where v(t) represents the baseband waveform.

$$vc(t) = A\, v(t) \cos(wt + delta) \qquad \text{(eqn 5.3)}$$

A phasor diagram can be constructed to represent the modulated carrier waveform in BPSK and is shown in Figure 5.8. As can be seen by the phasor diagram in Figure 5.8, the phase of the modulated waveform depends on the value of the baseband waveform and differs by pi depending on whether the value of the modulated bit is ±1.

Remembering the section on the properties of the Fourier transform, it is possible to analyze the spectral and power efficiency of BPSK. Recall BPSK can be created by multiplication. Multiplication of two voltages is covered by the frequency translation property of the Fourier transform. Frequency translation results in double the bandwidth or spectral requirement of the translated waveform and half the power. In the case of a NRZ baseband waveform,

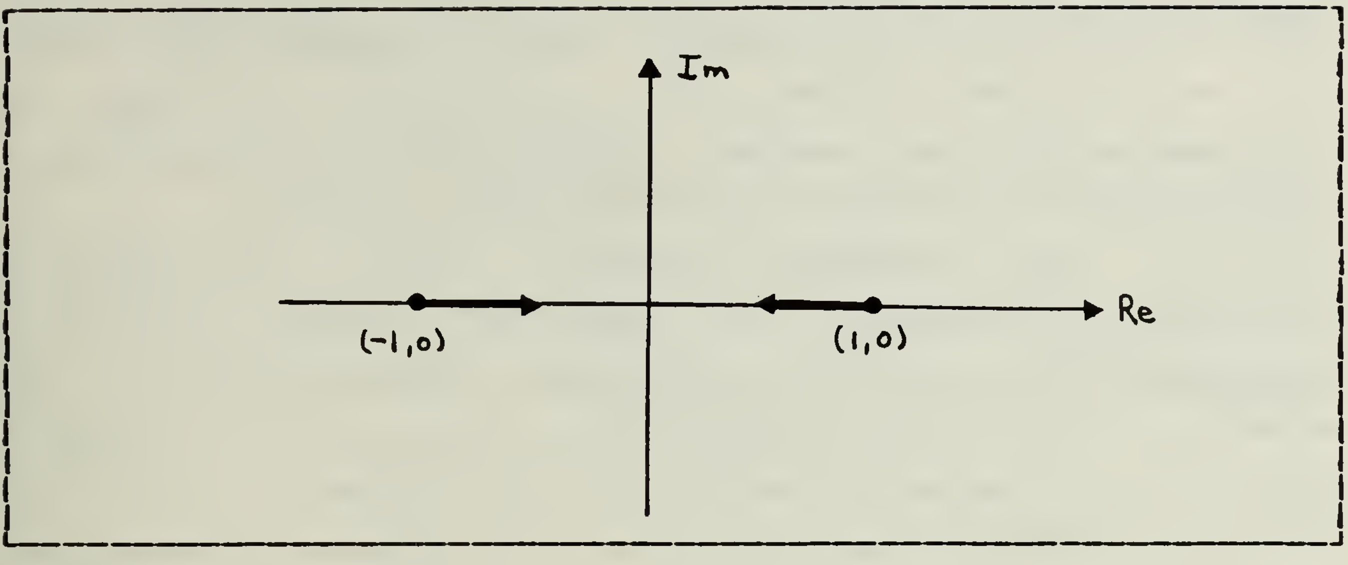


Figure 5.8 Phasor Diagram of BPSK

the bandwidth of the non-translated pulse, determined from the largest significant Fourier frequency component is 1/Tb, where Tb is the bit duration. The bandwidth of the translated voltage (BPSK carrier) is 2/Tb. The power in a sinusoid is $A^2/2$ and none of this power capacity is lost in BPSK since only the phase of the original sinusoid is changed. For a Manchester baseband waveform, the non-translated signal has bandwidth 2/Tb and the translated wave has bandwidth 4/Tb.

The advantage of BPSK is that it is relatively efficient in bandwidth utilization and power capacity. It does have the disadvantage of fairly large sidelobe components which contribute to interference with adjacent frequencies. This usually necessitates some type of filtering before the signal can be transmitted.

b. Differential Binary Phase Shift Keying (DBPSK)

The recovery of a Binary Phase Shift Keyed signal requires the use of a phase coherent reference signal as described in the previous sections on autocorrelation and matched filters. This may not always be practical or possible so a technique called Differential Binary Phase Shift Keying has be developed. DBPSK uses the same carrier type as BPSK and offers many of the same advantages and disadvantages. As stated, the primary difference is the lack of necessity for a phase coherent reference.

The baseband waveform, v(t), for DBPSK is generated by comparing the phase of the next bit to be transmitted to that of the previously transmitted bit. For example, if a +1 is encoded onto the carrier as v(t), it represents a particular phase of the carrier. If the next bit to be sent is also a +1, there is no phase change, i.e., the bit remains the same over two successive bit durations. If, however, the second bit to be sent is a -1, this represents a pi phase change and is decoded as a bit change over successive bit durations. This can be expressed mathematically as in equation 5.4 where bk represents the bit which will be encoded on the carrier and bk-1 represents the previous bit already encoded and ak represents the present bit.

$$bk = bk-1 \bullet ak \qquad \text{(eqn 5.4)}$$

As can be seen when bk = -1, there is a phase change and the bit changes from one bit to the next depending on the logic type being employed. If bk = +1, this represents the phase remaining constant over two successive bit durations, i.e., no bit change. See Figure 5.9 [Ref. 8]. Recovery is effected by correlation of the received bit to the previously received bit.

Differential Binary Phase Shift Keying (DBPSK) differs from Differentially Encoded Binary Phase Shift Keying (DEBPSK) in the recovery step only. DBPSK takes advantage of the modulation of phase shift in the recovery process while DEBPSK still utilizes a phase coherent carrier

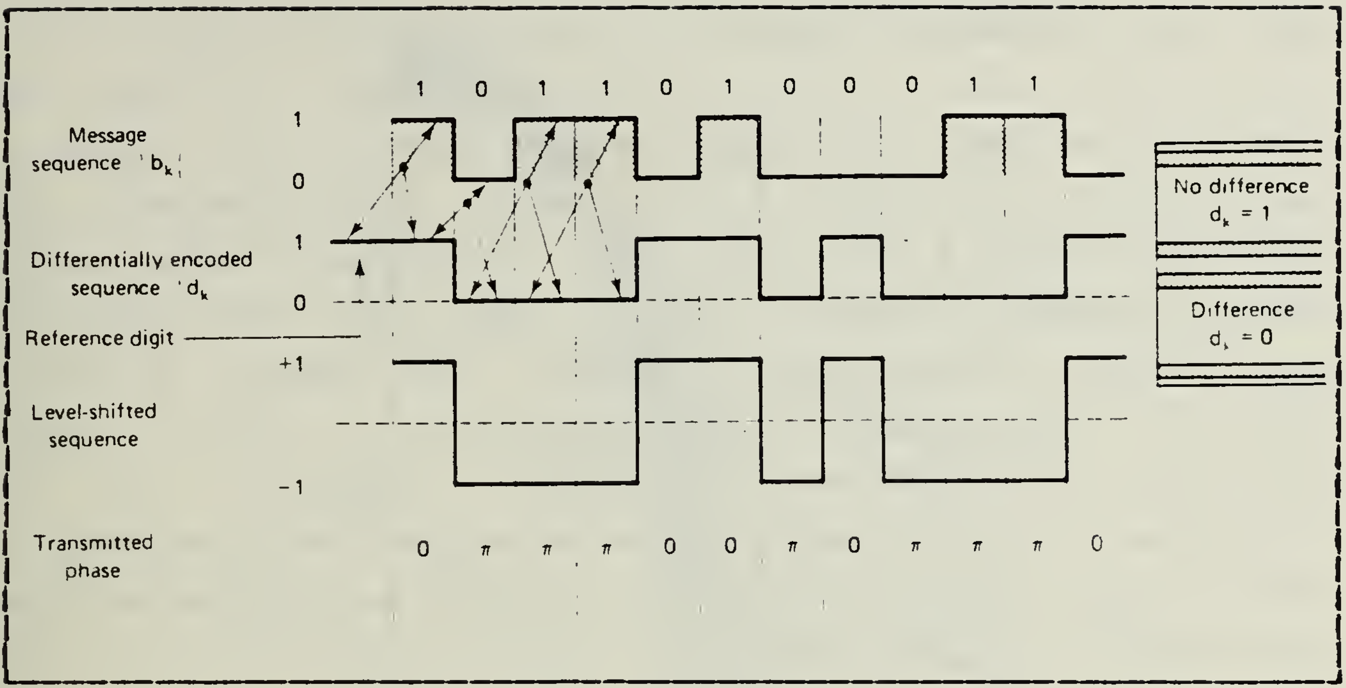


Figure 5.9 Differential Binary Phase Shift Keying

signal in demodulation. Both cases use the same scheme for differential encoding.

c. Orthogonal Binary Phase Shift Keying (Orthogonal BPSK)

In Binary Phase Shift Keying there is always a probability, with the interjection of noise on the transmitted signal that an individual bit will be decoded incorrectly from that which was actually transmitted. In some environments, this probability is so high that special encoding techniques must be employed in order to reduce the probability that a bit or a binary code word will be decoded in error. One such technique is Orthogonal BPSK. Orthogonal BPSK is a type of group encoding scheme where groups or blocks of bits from the original signal are assigned redundant bits according to a predetermined assignment routine. This new expanded sequence of bits is then transmitted as before in BPSK.

For example, assume that it has been determined that the respective values of the original signal will be represented by a k bit binary code word. It has been demonstrated that there exists 2**k binary code words, k bits long in this type of arrangement. With Orthogonal BPSK there also exists 2**k orthogonal sequences of bits (called channel symbols, bauds or chips) [Ref. 6], which represent the k binary code words. However, the number of bits or chips in the sequence is increased to n = 2**k, thereby providing the desired redundancy. Each of the 2**k sequences of n chips is constructed to be orthogonal to every other sequence in order to assure maximum separation. See Figure 5.10 [Ref. 6].

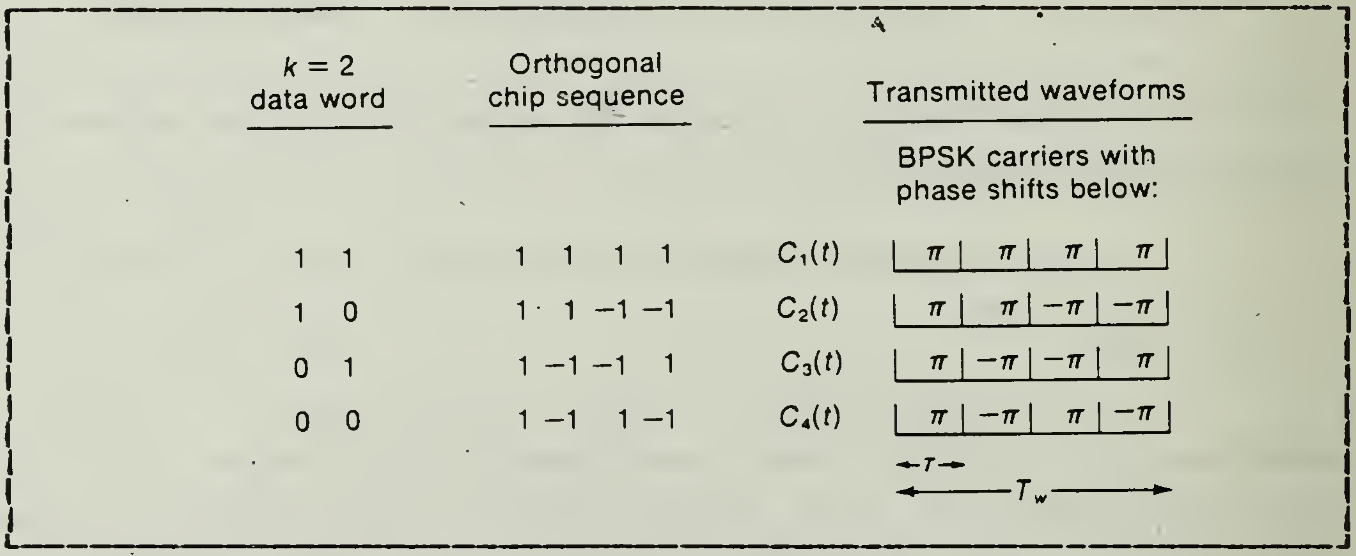


Figure 5.10 Orthogonal Binary Phase Shift Keying

Decoding is also done by blocks through a bank or 2**k correlators. Since the decoding is done in blocks, the probability that the entire transmitted code word will be incorrectly decoded is reduced even though individual bits are incorrectly decoded. This is the major advantage of Orthogonal BPSK. Figure 5.11 [Ref. 6], shows the reduction in error probability with Orthogonal BPSK

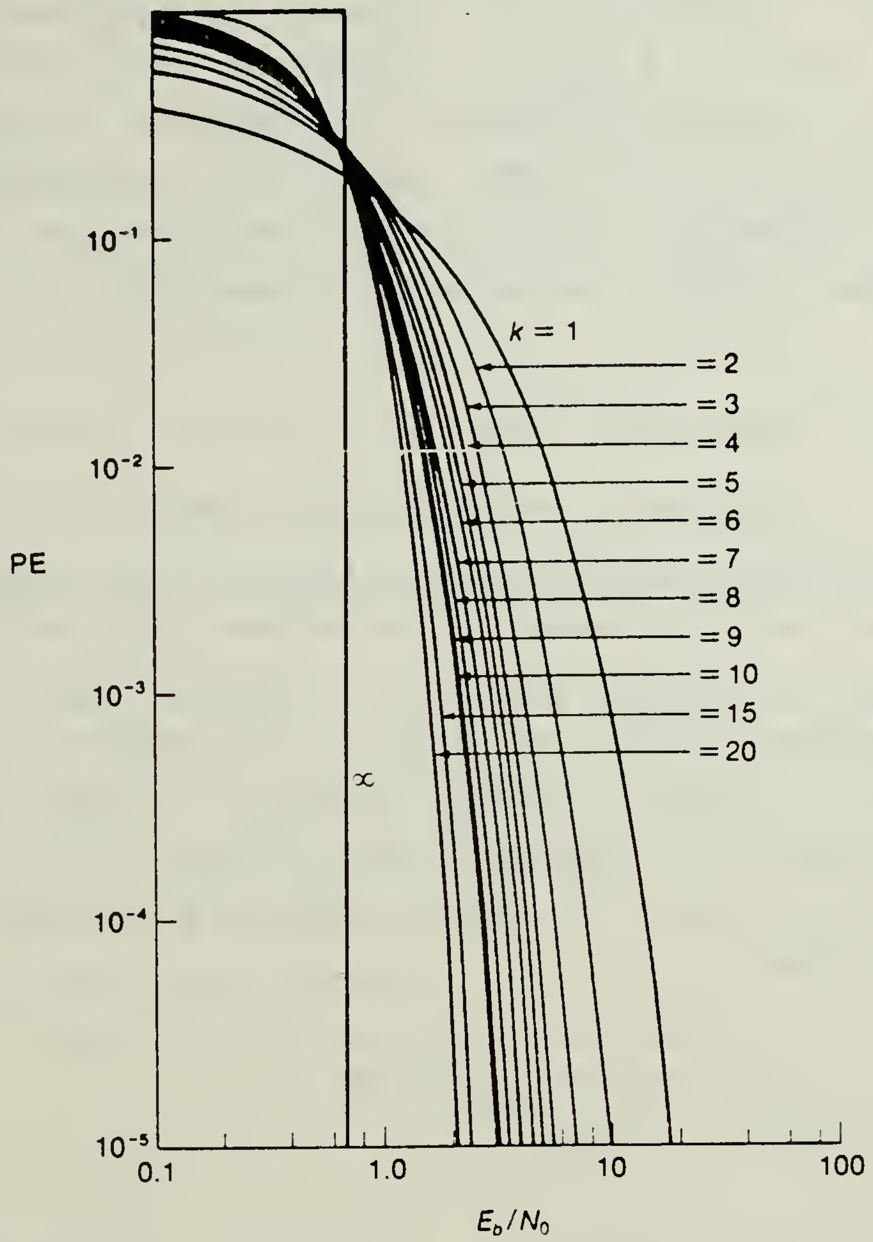


Figure 5.11 Probability of Error for Orthogonal BPSK

The major disadvantage to Orthogonal BPSK is that it results in a reduced data bit rate at a given transmission rate or the necessity for a higher transmission rate if the same bit rate is to be maintained. For example, suppose the bit rate of a PSK signal is R bits/sec. If each of the k bits in the PSK signal are represented by 2**k chips as is the case in Orthogonal BPSK modulation, then the bit rate must be (2**k/k)R if the same data rate is to be maintained. Additionally, since the necessary bit rate increases, the bit duration decreases. It was shown in the section on bandwidth that as bit duration decreases as the result of a higher bit rate, an increase in bandwidth is the result. Therefore, the tradeoff in decreased transmission error comes at the expense of bandwidth and bit rate. [Ref. 6]

d. Quadrature Phase Shift Keying (QPSK)

Quadrature Phase Shift Keying derives its name from a four-phase modulation of the carrier waveform. These modulations are achieved by simultaneously modulating the inputs from two bit streams onto a single carrier. The two bit sequences could be from two separate sources or successive bits from a single source. To take advantage of the orthogonality of the sine and cosine functions, QPSK can be viewed as in equation 5.5 as the sum of a BPSK modulated sine and cosine.

$$\begin{aligned} vc(t) &= A\ v1(t)\ \cos(wt + \text{delta}) + \qquad\qquad \text{(eqn 5.5)} \\ &A\ v2(t)\ \sin(wt + \text{delta}) \end{aligned}$$

The signal can also be represented as in equation 5.6 where the phase angle, theta, of the modulated carrier is shown in equation 5.7.

$$vc(t) = 2{*}{*}.5\ A\ \cos(wt + \text{theta} + \text{delta}) \qquad \text{(eqn 5.6)}$$

$$\text{theta} = \arctan\ (v1(t)/v2(t)) \qquad \text{(eqn 5.7)}$$

The phases possible as a result of substitution of the possible bits in bipolar logic in equation 5.7 are ±45 degrees and ±135 degrees. See Figure 5.12.

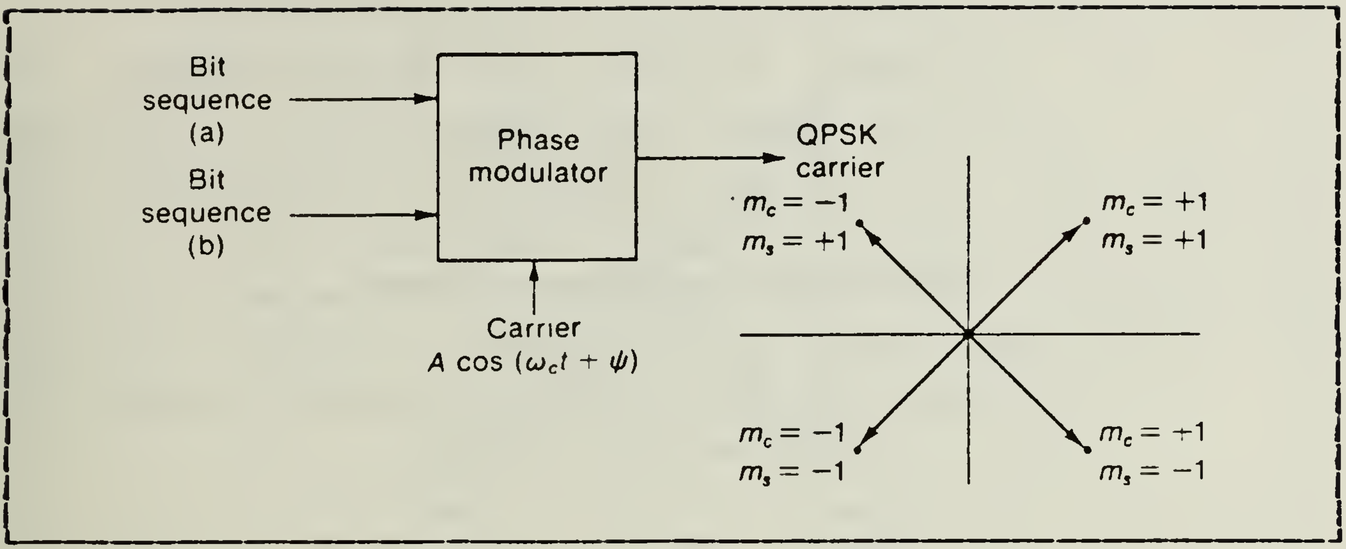


Figure 5.12 Modulation and Phases of QPSK

Since two bits are being encoded at one time for transmission, the bit rate in QPSK is twice that of BPSK. The BPSK bit rate is equal to the QPSK symbol rate, (symbol rate being the time the quadrature bits exist on the carrier). It is the symbol rate in QPSK which determines the bandwidth and since symbol rate is equal to bit rate in BPSK, the bandwidth of the two modulation techniques is identical. The great advantage of QPSK lies in the bandwidth utilization. Two bits of information are transmitted thereby effectively doubling the bit rate at no additional cost in bandwidth. A phasor representation of QPSK is illustrated in Figure 5.13. Each quadrature component of the modulated signal contains half the power of the total carrier or $(A^2/2)/2 = A^2/4$.

e. Offset Quadrature Phase Shift Keying (OQPSK)

In Quadrature Phase Shift Keying, both bits of the two baseband waveforms, which are to be modulated onto the carrier, change at the beginning of the respective symbol time. This allows the phase of the carrier to change up to 180 degrees for each symbol as illustrated in the

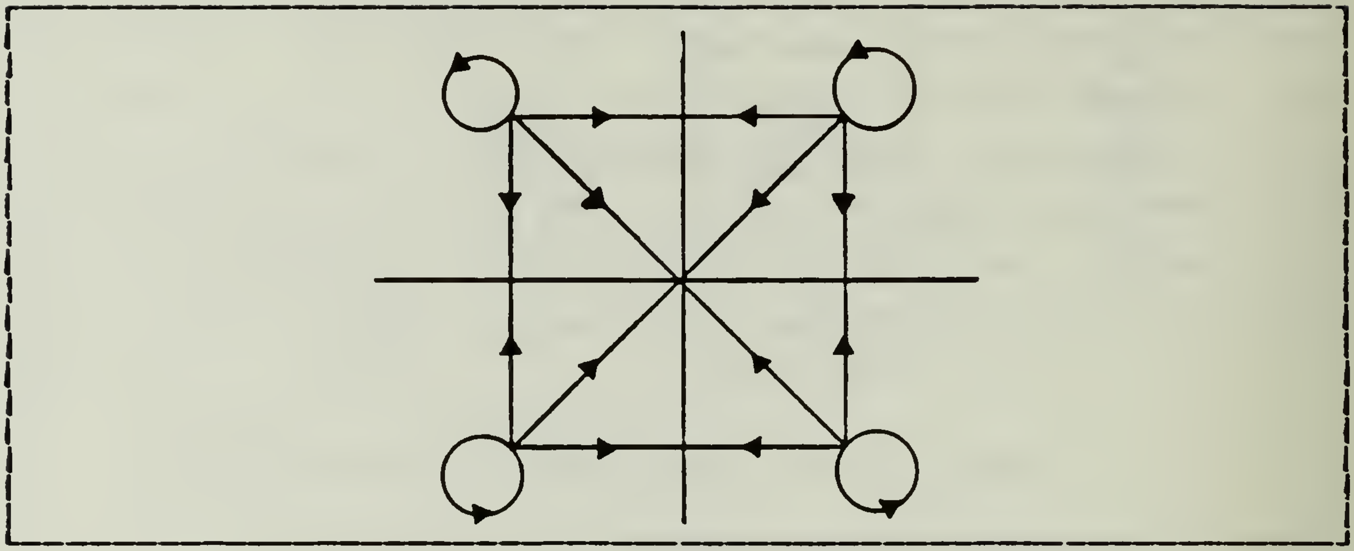


Figure 5.13 Phasor Diagram of QPSK

phasor diagram in Figure 5.13. The phase change of the modulated signal can be limited to 90 degrees through a modulation technique called Offset Quadrature Phase Shift Keying. This is accomplished by delaying the application of the second baseband channel for Ts/2 seconds, where Ts is symbol duration as illustrated in Figure 5.14. Modulation is then accomplished as before in QPSK.

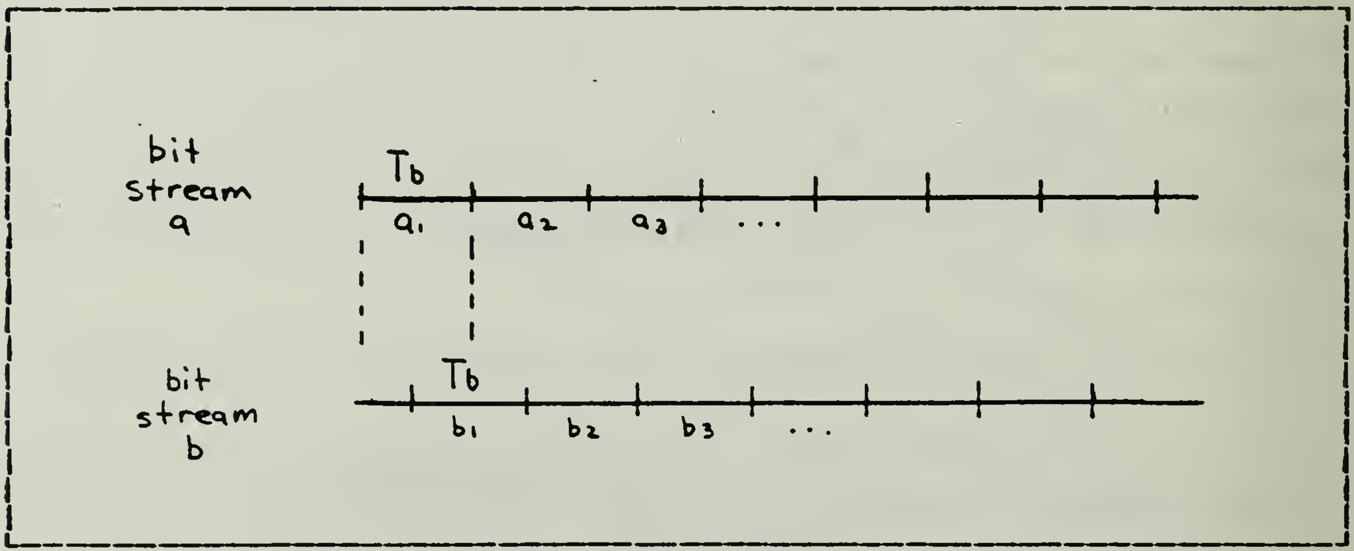


Figure 5.14 Offset Quadrature Phase Shift Keying

The result is a QPSK modulated signal in which the maximum phase shift between successive bits is 90 degrees. The bandwidth and power spectra of an OQPSK modulated signal are the same as that of a QPSK modulated signal. The advantage of OQPSK is in the limit which is placed on phase shift during encoding which simplifies the encoding hardware. Additionally OQPSK has spectral and interference advantages during decoding [Ref. 6].

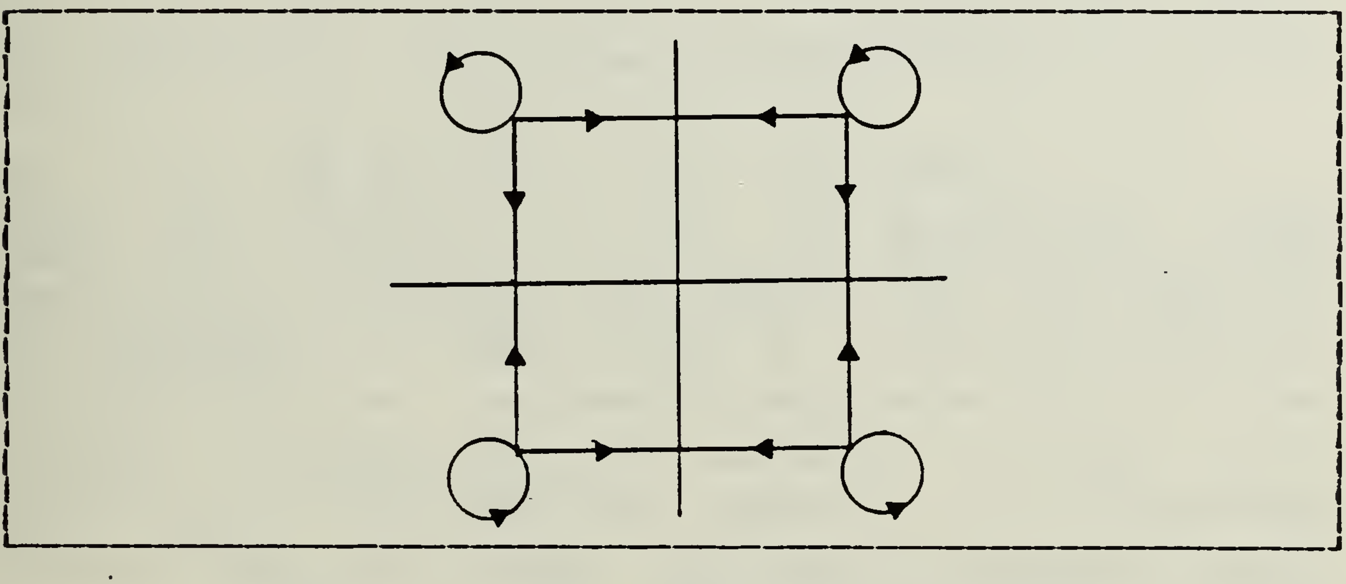


Figure 5.15 Phasor Diagram of OQPSK

f. Multiple Phase Shift Keying (MPSK)

Another form of digital modulation is known as Multiple or M-ary Phase Shift Keying (MPSK). Once again, as in Orthogonal Binary Phase Shift Keying, k data bits are transmitted. The k bits represent the word length and there are m = 2**k different binary words, k bits long, for this type of modulation. In MPSK, the binary code word is used to vary the phase of the carrier. There are therefore m = 2**k different phases in MPSK. These sequences of binary digits need not be orthogonal as in Orthogonal Binary Phase

Shift Keying. The length of the transmitted symbol is only k bits long as compared to 2**k bits for Orthogonal BPSK. The phases therefore are not all orthogonal leading to greater difficulty in decoding and a higher probability that an individual code word will be incorrectly decoded, especially as m becomes large.

As in other types of Phase Shift Keying, MPSK can be represented as in equation 5.8 where theta = phase = (2pi/m) i; i=0,1,...m-1.

$$vc(t) = A \cos (wt + \text{theta} + \text{delta}) \qquad \text{(eqn 5.8)}$$

An advantage of MPSK is that as long as the symbol transmission rate does not increase, the carrier bandwidth does not increase even as the size of the binary code word increases. The disadvantage, as stated earlier, has to do with error rates in decoding. Decoding requires a phase coherent reference of considerable stability especially as m increases and respective phases become closer together. Practical limits for this type of modulation is m = 8 or a 3 bit binary code word due to the complexity of the encoding and decoding hardware.

2. Amplitude Shift Keying (ASK)

Amplitude Shift Keying, as the name implies is modulation of the carrier through variation of its amplitude due to variations in the baseband waveform. The information in the baseband waveform is thereby imparted to the carrier through this modulation. Since the amplitude of the carrier varies between successive symbols or binary code words, the power also varies. Recovery is by comparison of the transmitted power during each symbol to the possible m = 2**k power levels.

a. Multiple Amplitude Shift Keying (MASK)

MASK is a type of group encoding where k bits are combined into a single waveform for transmission and subsequent recovery. Since each symbol or binary code word contains k bits, there are m = 2**k different symbols and consequently m different amplitudes of the carrier possible during the symbol duration time. An assignment scheme which maps the binary code words into the m different amplitudes would be to simply space them Ai = A/mi volts apart, where A is the maximum amplitude and mi represents the decimal equivalent of the binary code word from i = 1 to 2**k.

The analytic form of a MASK waveform is represented in equaticn 5.9 where all the variables are the same a presented earlier except for Ai which is equal to one of i different amplitudes depending on the bit sequence to be transmitted.

$$vc(t) = Ai \cos(wt + delta) \qquad \text{(eqn 5.9)}$$

MASK is not very popular in satellite communications since it depends on a carrier of very stable amplitude. This is not generally practical under actual conditions. However, MASK does have the spectral advantage of a constant bandwidth of 2/Ts, Ts equal to symbol duration, even as the binary code word increases in length.

b. Quadrature Amplitude Shift Keying (QASK)

Quadrature Amplitude Shift Keying (QASK) is a hybrid digital signal modulaticn technique. It represents separate amplitude modulation of the quadrature components of a common carrier. In that sense it is both ASK and PSK. Implementation of QASK involves simultaneous application of M-ary Amplitude Shift Keying to the quadratures. See equation 5.10, where A1 and A2 are derived according to an assignment scheme as in MASK.

$$vc(t) = A1 \cos(wt + delta) + A2 \sin(wt + delta) \qquad \text{(eqn 5.10)}$$

By this method, the effective bit rate is doubled over that of ordinary MASK. In other words, QASK results in the same data rate as modulating 2k bits onto the carrier at the same time or during the same symbol duration with MASK. The advantage to QASK lies in the fact that this increase in bit rate comes at no further increase in bandwidth. The disadvantages associated with MASK are still present with an additional increase in the complexity of the decoding equipment. Decoding of QASK must be done in two steps. First the signal is recovered in phase through a phase-coherent correlator and then each amplitude modulated signal is recovered as before in MASK by comparison of the power levels of the received signal.

3. Frequency Shift Keying (FSK)

Frequency Shift Keying (FSK), is the generic term used to describe a number of digital signal modulation techniques which cause variations in the carrier frequency by interaction with the baseband waveform. Decoding is generally through measurement of the frequency of the received signal.

a. Mimimum Shift Keying or Fast Frequency Shift Keying

Power requirement for the transmission or retransmission of a satellite signal is extremely important. It is desireable to limit power required to accurately transmit a piece of information to the minimum possible consistent with allowable error rates. For this reason, detection of FSK signals is limited to coherent methods as power required increases significantly for non-coherent methods.

MSK or FFSK are identical and represent a modulation technique known as continuous phase FSK. They get their names from the fact that "fast" indicates more bits per second can be transmitted in a given bandwidth than ordinary BPSK and "minimum" refers to the minimum modulation index for which orthogonal signalling occurs [Ref. 7].

Analytically, FFSK can be expressed as in equation 5.11 and equation 5.12.

$$vc(t) = A \cos((wc + deltaw)t) \qquad \text{(eqn 5.11)}$$

$$vc(t) = A \cos(\pm deltaw\ t) \cos(wc\ t) - A \sin(\pm deltaw\ t) \sin(wc\ t) \qquad \text{(eqn 5.12)}$$

As is noted, FFSK can be envisioned as the summation of separately modulated in-phase and quadrature components of the carrier by the baseband waveform. The technique is similar to that used in OQPSK. The frequency variation in the carrier waveform is between wc + deltaw and wc - deltaw. Maximum separation in phase of these two frequency components occurs at pi as noted in equation 5.13, where Tb represents the bit or symbol duration.

$$(w2-w1)Tb = pi \qquad \text{(eqn 5.13)}$$

This can be converted to the modulation index mentioned above simply by converting to frequency as in equation 5.14.

$h = (f2-f1)Tb = .5$ (eqn 5.14)

For FFSK, the frequency deviation or separation between frequencies of the transmitted carrier is exactly 1/2Tb and the deviation from the carrier frequency is 1/4Tb. FFSK can therefore be rewritten from equation 5.12 as in equation 5.15 by substitution for deltaw = 2pi(1/4Tb).

$vc(t) = A \cos(\pm pi\ t/2Tb) \cos(2pi\ fc\ t) -$ (eqn 5.15)
$A \sin(\pm pi\ t/2Tb) \sin(2pi\ fc\ t)$

The error rate in this modulation technique is identical to that of BPSK. Frequency Shift Keying can be implemented to incorporate any given modulation index by simple calculation of the frequency separation with equation 5.14 and substitution into equation 5.15. For M-ary Frequency Shift Keying, the separation between frequencies must be at least 1/Ts, where Ts is the symbol duration, in order to avoid carrier energy from one frequency being incorrectly interpreted as carrier energy from another frequency. This results in a modulation index of 1. Figure 5.16 represents the phasor diagram of an FFSK modulated signal.

4. Quadrature Partial Response Signalling (QPRS)

Quadrature Partial Response Signalling (QPRS) represents a specific type of the general class of digital signal modulation techniques called Partial Response Signalling. Partial Response Signalling is a method in which a controlled amount of intersymbol interference (ISI) is allowed during the encoding process. Previously any overlap in successive signals resulted in aliasing and an increased probability of error in decoding. The idea was

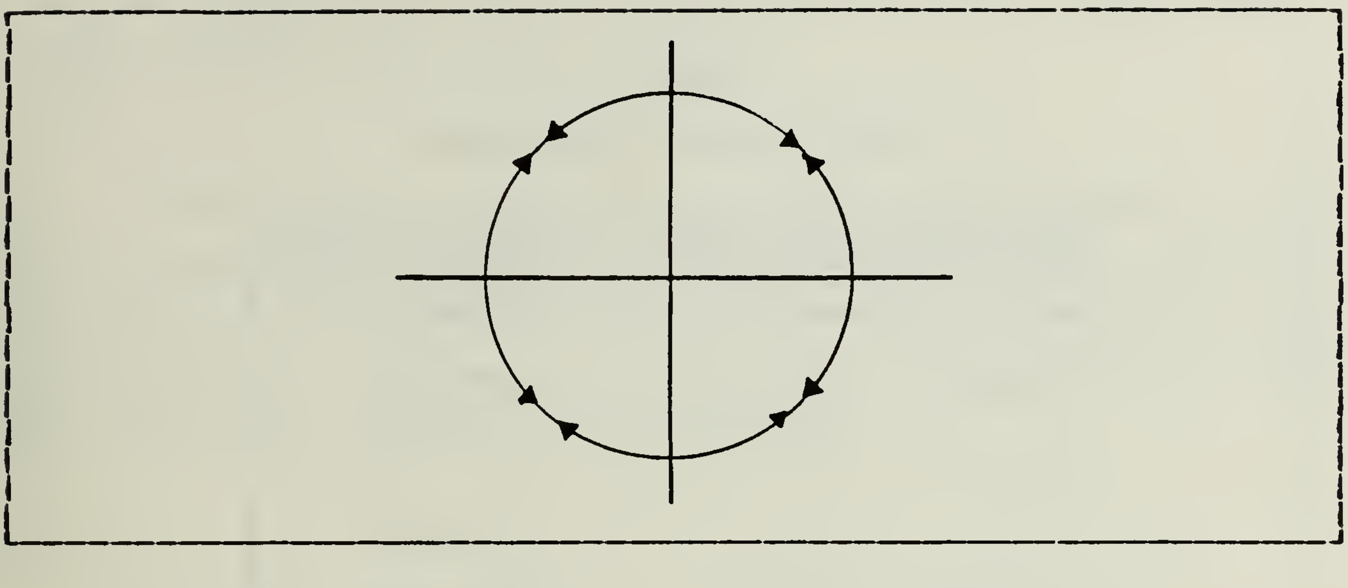


Figure 5.16 Phasor Diagram of FFSK or MSK

first introduced by Lender in 1963 [Ref. 12]. His concept was that in knowing and controlling the amount of interference allowed during the encoding process, compensations can then be made for the ISI at the receiver. Allowing for a limited amount of ISI makes it possible to transmit at rates equal to the Nyquist rate, something that is not possible with many other systems [Ref. 13].

QPRS is implemented, as with previous quadrature systems, through simultaneous modulation of the quadrature components of a common carrier. However, this time the modulation is accomplished with a PRS system. The modulation of the respective quadrature components represents the impulse response of one of a number of linear filters to the bits of the baseband waveform. The linear filter employed depends on the class of the Partial Response Signalling system being used. There are 5 classes of linear filters commonly used in PRS and they are illustrated analytically in Table 1 and graphically in Figure 5.17.

Output of a QPRS system can be represented as in equation 5.16, where an and bn represent the nth bit to be modulated and h(t - nTs) represents the contribution of the

TABLE 1

QPRS SYSTEM POLYNOMIALS

SYSTEM POLYNOMIAL $F(D)$	FREQUENCY RESPONSE $H(\omega)$ for $\lvert\omega\rvert \le \pi/T$	IMPULSE RESPONSE $h(t)$
$1 + D$	$2T \cos \frac{\omega}{2} T$	$\frac{4T^2}{\pi} \frac{\cos(\pi t/T)}{T^2 - 4t^2}$
$1 + 2D + D^2$	$4T \cos^2 \frac{\omega}{2} T$	$\frac{2T^3}{\pi t} \frac{\sin(\pi t/T)}{T^2 - t^2}$
$2 + D - D^2$	$T + T \cos \omega T + j3T \sin \omega T$	$\frac{T^2}{\pi t} \sin(\pi t/T)(\frac{3t - T}{t^2 - T^2})$
$1 - D^2$	$j2T \sin \omega T$	$\frac{2T^2}{\pi} \frac{\sin(\pi t/T)}{t^2 - T^2}$
$1 - 2D^2 + D^4$	$-4T \sin^2 \omega T$	$\frac{8T^3}{\pi t} \frac{\sin(\pi t/T)}{t^2 - 4T^2}$

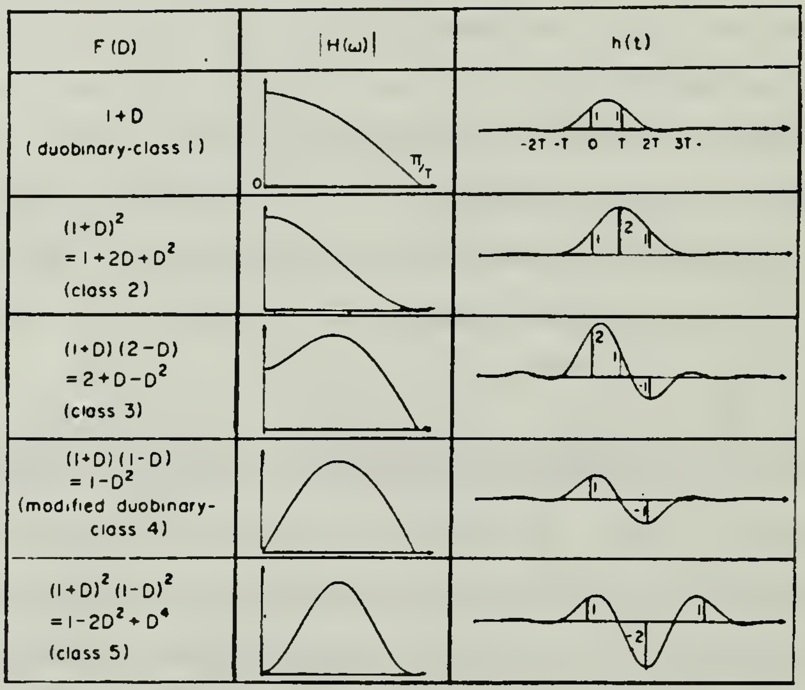


Figure 5.17 QPRS Linear Filter Impulse Responses

impulse response of the linear filter at time t for bit n. [Ref. 14]

$$vc(t) = \sum_{n=-\infty}^{\infty} an\ h(t - n\ Ts)\ \cos(wt + \text{delta}) \qquad \text{(eqn 5.16)}$$
$$\sum_{n=-\infty}^{\infty} bn\ h(t - n\ Ts)\ \sin(wt + \text{delta})$$

QPRS has the advantage of rapid transmission rates with no increase in bandwidth and excellent error handling performance. The cost of such performance improvement comes in the form of a higher required signal to noise (SNR) ratio when compared to other binary systems.

VI. COMPUTER SIMULATION OF DIGITAL SIGNAL MODULATION TECHNIQUES

Due to the nature of digital signal modulation, it is possible to simulate systems through the use of the digital computer. This chapter is a description of the computer simulation included in the Appendix of this thesis.

A. GENERAL DESCRIPTION OF THE PROGRAM

The program was constructed using top-down design and modular programming. FORTRAN was selected as the programming language due to its capabilities in the area of numerical operations and the availability of mathematical routines to be used as modules in the program. Testing was accomplished on each module as the program was developed. The program was designed to be used interactively in order to allow for instructional use. Although the program was made user friendly in that error checking is accomplished on user inputs, care must be taken to insure instructions are followed correctly.

The program consists of twenty modules, sixteen of which were written by the author, three which were taken from the Double Precision International Mathematics and Statistics Library (IMSLDP) and one which was taken from a NON-IMSL library which resides on the IBM 3033 located at the Naval Postgraduate School. The IBM 3033 was used exclusively for development and testing.

The development was accomplished using the WATFIV compiler; however, the program was written to operate with the VS FORTRAN compiler as well. Testing and operation was done using the VS FORTRAN compiler. Figure 6.1 is a block diagram of the relationship of the modules for a representative modulation subroutine.

B. MAIN CONTROL MODULE

MAIN operates as the control module for the entire computer simulation and accomplishes limited output. It introduces the program and allows the user to input various parameters of the digital signal modulation technique to be simulated and various other control functions. These inputs include:

1. Modulation technique
2. Class of QPRS system (when appropriate)
3. Digital logic scheme
4. Baud or symbol rate
5. Bits/binary code word (when appropriate)
6. Carrier frequency
7. Number of samples to be generated
8. Carrier max amplitude
9. Initial phase angle
10. Use of random number generator or no
11. Seed for RNG (when appropriate)
12. Number of repetitions of the simulation

Once the user has input the desired characteristics of the modulation to be simulated, MAIN calls the appropriate module to begin the actual calculation. The values necessary to calculate the time series of the signal are passed to the subroutines as parameters. MAIN calls the required subroutine the number of times the user specifies as repetitions. Each call to a subroutine produces the Discrete Fourier Transform and amplitude spectrum of the signal. It is these respective amplitude spectrums which produce the statistics in the final output after MAIN calls the statistics subroutine the final time.

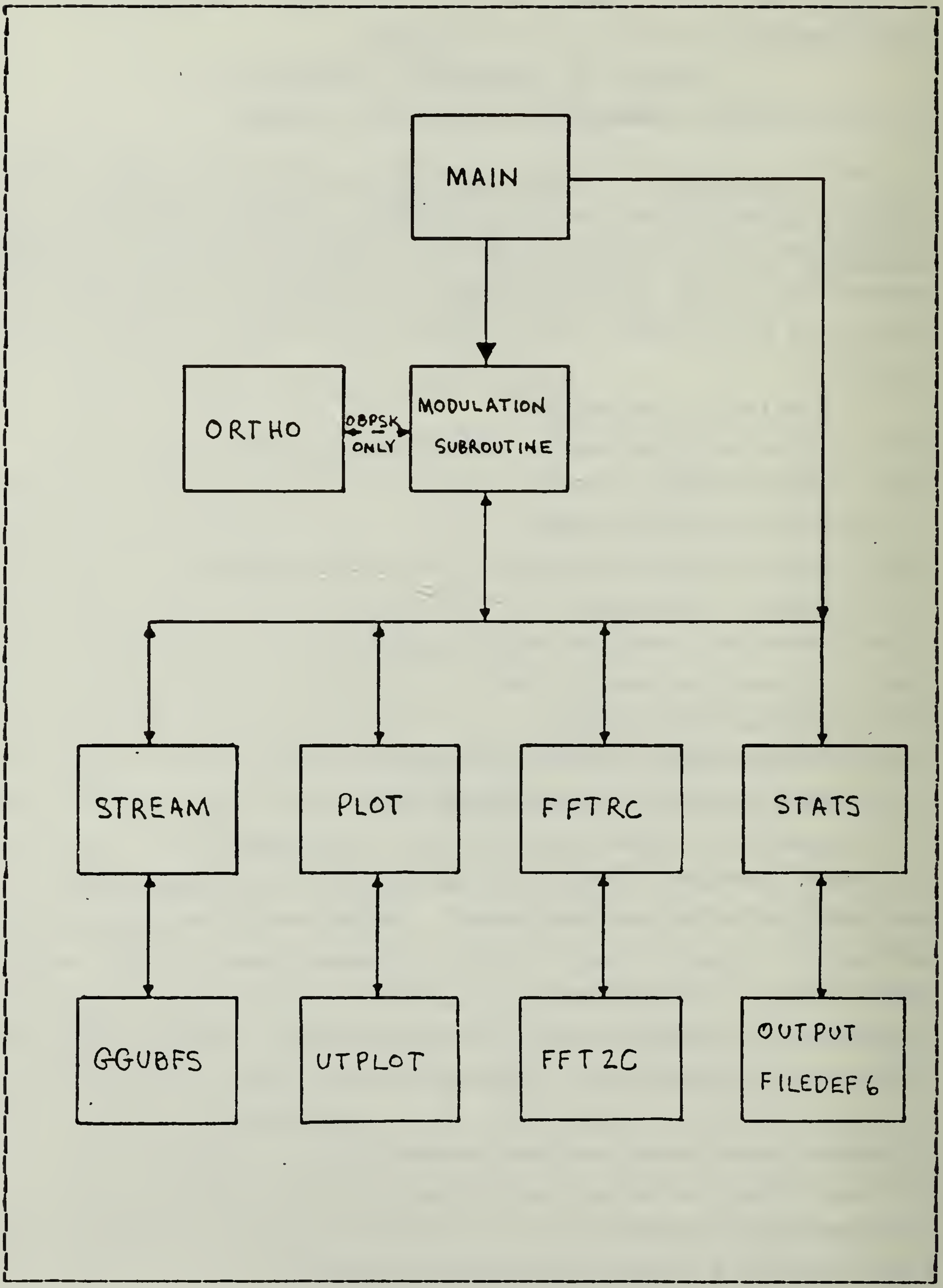


Figure 6.1 Representative Block Diagram

C. SUBROUTINE BPSK

This description of SUBROUTINE BPSK, a module that simulates Binary Phase Shift Keying, will serve as a guide on the construction and operation of subsequent modules involved in the actual signal modulation. A complete description including its interaction with other program subroutines will be included. Since other signal modulation subroutines interact in the same manner within the program, subsequent descriptions will concentrate on differences to this basic module.

SUBROUTINE BPSK begins with variable declarations as with all FORTRAN programs. All variables are declared to be either type integer or double precision. All calculations in the program are carried out in double precision accuracy.

Variable initialization is next. Significant variable initialized at this point are TIME, the time of the first sample which is set to 0. STEP, the delta time between samples is set to the normalized Nyquist sampling rate. OMEGA, the angular frequency and DELTA, the initial phase angle are computed in radians. NBAUD, a variable which keeps track of the number of symbols which have been modulated, is set to 1 or the first symbol is being modulated. NBAUD remains at its present value until total elapsed time exceed 1 symbol duration or BAUDD, the normalized baud rate.

Subsequently, an initial call is made to SUBROUTINE STREAM to receive the value of the first bit to be modulated. The modulation is then carried out according to equation 6.1.

The values of each sample are assigned to an array for storage along with the corresponding time increment. Modulation continues with the first drawn bit until 1 bit or symbol duration is exceeded when STREAM is called to draw vc(t) = A v(t) cos(wt + delta) (eqn 6.1)

A = amplitude
v(t) = bit to be modulated
w = angular frequency
t = time
delta = initial phase angle

another bit. This entire process is repeated until the number of samples specified by the user in MAIN is reached.

At this point, only on the first repetition of the simulation, SUBROUTINE PLOT is called which gives the user the opportunity to plot the time series of the simulated signal. Upon return from PLOT the subroutine calls the IMSL routine FFTRC to generate the Discrete Fourier Transform of the time series produced. This is accomplished on each repetition of the program.

Again on the first repetition only, information on the number of the principle harmonic of the FFT is displayed. Plot is called again to give the user the opportunity to plot the amplitude spectrum. The values of the FFT and the amplitude spectrum are computed on each successive repetition of the program and the amplitude spectrum is added to the statistics being accumulated by a call to SUBROUTINE STATS.

D. SUBROUTINE DBPSK

SUBROUTINE DBPSK simulated Differential Binary Phase Shift Keying and is essentially the same as SUBROUTINE BPSK. The difference lies in the fact that what is encoded during the modulation process is the product of the random bit drawn and the value of the bit previously modulated. A reference bit equal to +1 is used to determine the first bit to be modulated. In this manner, modulation of +1 means no change occurs between successive bits and the phase of the carrier remains the same. Modulation of a -1 indicates a change of bits has occurred and is indicated by a change of phase of the carrier between successive bit durations. The rest of the module remains unchanged.

E. SUBROUTINE OBPSK

Orthogonal Binary Phase Shift Keying is accomplished in this module. Again SUBROUTINE OBPSK is constructed essentially the same as SUBROUTINE BPSK. In Orthogonal BPSK the only bit streams that are modulated are n bits long representing each binary code word, where n = 2**k (k = number of bits per word is limited to 6 bits in MAIN). Each sequence of n bits is orthogonal to every other allowed sequence.

The way this is accomplished in this module is first to draw a series of k random bits from SUBROUTINE STREAM. This series of k 1's and 0's is then changed to its decimal equivalent from 0 to 2**k-1 and saved for later use.

The program continues with a call to SUBROUTINE ORTHO which generates an n X n orthogonal matrix of +1's and -1's through the use of the Hadamard matrix and the Kronecker product [Ref. 15]. The Hadamard matrix is a 2 X 2 orthogonal matrix of 1's and -1's. The Kronecker product is the matrix which is formed when a matrix is expanded to twice its original size by replacing each element of the Hadamard matrix by the product of the Hadamard matrix and the original matrix. The value of the decimal equivalent to the k random bits is used to identify the row of the matrix and the respective columns represent the value of the binary digit which is modulated onto the carrier by BPSK. This sequence continues until either one bit duration is exceeded, when another orthogonal bit is received from ORTHO or when all the orthogonal bits in a row are modulated. Then another sequence of k random bits is converted to its decimal equivalent and a new row and column of the orthogonal matrix is identified. Execution continues in this manner until all required samples have been produced. It should be noted that the bit rate for Orthogonal BPSK is n times the baud rate. This significantly increases the signal bandwidth requirement and decreases the time increment between successive samples in the simulation. The rest of the module is the same as those previously presented.

F. SUBROUTINE QPSK

Quadrature Phase Shift Keying, simulated in SUBROUTINE QPSK, is accomplished through simultaneous BPSK modulation of the quadrature components of the carrier. Two random bits are drawn from successive calls of SUBROUTINE STREAM and each bit is in turn modulated onto the carrier components and the sum formed. This process is repeated at time intervals equal to the normalized Nyquist sampling rate until TIME exceeds one symbol duration, BAUDD. At this time two new random bits are drawn and the modulation continues until all required samples are produced. The rest of the modules is the same as those before. Equation 6.2 represents the analytical expression used to simulate

G. SUBROUTINE OQPSK

SUBROUTINE OQPSK is essentially the same as SUBROUTINE QPSK with these minor deviations. The time of the first sample is artificially initialized as TIME = .5(BAUDD) or 1/2 the symbol duration. In this manner, the two random

vc(t) = A v1(t) cos(wt + delta) + (eqn 6.2)
A v2(t) sin (wt + delta)

v1(t) = in-phase bit
v2(t) = quadrature bit

bits first being modulated are both known to have existed on the carrier for 1/2 the symbol duration. The first of thest two bits only remains on the carrier until TIME = 1(BAUDD) when a third random bit is drawn and modulation begins with this bit. The second random bit is allowed to remain until TIME = 1.5(BAUDD) when a fourth random bit is drawn to replace it and so on. In this manner the two bits being modulated are offset in the time they change by 1/2 the symbol duration. This necessitates keeping track of the number of bits modulated on both the in-phase and quadrature component of the carrier. The remaining portion of the module is the same as SUBROUTINE QPSK.

H. SUBROUTINE MPSK

This module simulates M-ary Phase Shift Keying. This is accomplished by changing the phase of the carrier to any one of n =2**k phases where k is the number of bits in the binary code word. The max length of the binary code word is limited to 10 in the MAIN program. This modulation is accomplished by use of equation 6.3 to simulate the MPSK system.

The program first draws k random bits and converts them to the decimal equivalent. At this point modulation begins at TIME = 0 according to equation 6.3. Modulation continues until one symbol duration is exceeded when a new set of k random bits is drawn, conversion to decimal takes place and vc(t) = A cos[wt + (2pi m)/n + delta] (eqn 6.3)

m = decimal equivalent of binary code word
n = 2**k; k = bits in binary code word

modulation continues or until all desired samples have been produced. The program continues as in previous subroutines.

I. SUBROUTINE MASK

The principles of operation of SUBROUTINE MASK is similar to SUBROUTINE MPSK which also involves a group encoding system. SUBROUTINE MASK allows for M-ary Amplitude Shift Keying. The analytic expression used in the simulation is provided in equation 6.4 Ai is one of 2**k equally spaced amplitudes.

vc(t) = Ai cos(wt + delta) (eqn 6.4)

Once again a set of k random bits is drawn from SUBROUTINE STREAM. The decimal equivalent of the k bits is computed and used to adjust the amplitude Ai according to the assignment routine expressed in equation 6.5.

Ai = A/m (eqn 6.5)

A = max amplitude
m = 1 to n; n = 2**k

This process is repeated at each symbol duration until all desired samples have been produced. The rest of the module remains unchanged.

J. SUBROUTINE QASK

SUBROUTINE QASK combines the elements of the previously described amplitude modulation technique with the now familiar quadrature modulation technique. Two separate streams of random numbers are generated and converted to their decimal form. These numbers are used to produce two separate amplitudes with the same assignment scheme used in MASK. These amplitudes modulate the quadrature components of a common carrier and the output is formed by the sum of the quadratures. Modulation continues in the above manner until a symbol duration elapses when two new amplitudes are calculated. Processing terminates when all required samples are computed.

K. SUBROUTINE MSK

Minimum Shift Keying is frequency shift keying in which the modulation index is 1/2. The modulation index is represented in equation 6.6

$$h = .5 = (\text{deltaf})\,Tb \qquad \text{(eqn 6.6)}$$

deltaf = frequency separation
Tb = bit duration

The frequency deviation from the carrier is .5(deltaf) = 1/4Tb. Converting this frequency deviation to radians yields pi/2Tb. This angular frequency deviation from the central carrier is either ±pi/1Tb depending on the value of the bit to be modulated.

The simulation in SUBROUTINE MSK is accomplished by drawing a random bit and generating the signal according to equation 6.7.

$vc(t) = A \cos[(w \pm pi/2Tb)t + delta]$ (eqn 6.7)

Once again modulation continues until one bit duration is elapsed when another bit is drawn. Modulation stops when all required samples are produced. The rest of the subroutine remains unchanged.

L. SUBROUTINE MFSK

This subroutine modulates a signal simulating M-ary Frequency Shift Keying. The separation between adjacent frequencies is established as 1/Ts, where Ts is the symbol duration. This amounts to a modulation index equal to 1. Initially the entire range of frequency deviation from the carrier is calculated as (n-1)Ts. The mean frequency deviation is then calculated. In other words the range of frequencies of the modulated signal is the frequency of the central carrier ±1/2 the magnitude of the entire range of frequency deviation. The minimum frequency is used as the base for computing the frequency to be used to modulate the signal during each respective symbol duration.

At this point in the subroutine a series of k random bits ($k \leq 10$) is drawn and converted to decimal. This decimal number is multiplied by the frequency separation and added to the minimum frequency and converted to radians. The analytical expression of the signal produced with this subroutine is illustrated in equation 6.8.

$vc(t) = A \cos[(w + 2pi\ mf)t + delta]$ (eqn 6.8)

mf = modulation frequency

This modulation continues until a symbol duration elapses when a new frequency deviation or mf is calculated or modulation stops do to completion of all required samples.

H. SUBROUTINE QPRS

This module simulates 5 different classes of Quadrature Partial Response Signalling systems. The technique employed involves the summation, at each time increment, of all responses to the linear filter representing the class. This is accomplished for all of the bits being modulated during the duration of the simulation.

Initally, two arrays of random bits are generated representing those bits which would be modulated onto the quadrature components of the carrier during the length of time the signal is to be simulated. The the impulse response to each of these n bits is calculated for the time of the respective sample. These impulse responses represent the modulation for the bit in question onto the respective portions of the carrier and the sum is formed according to equation 6.9.

$$vc(t) = \sum_{n=-\infty}^{\infty} A\ h(t - nTs)\ \cos(wt + delta) + \sum_{n=-\infty}^{\infty} A\ h(t - nTs)\ \sin(wt + delta) \qquad \text{(eqn 6.9)}$$

$h(t - nTs)$ = impulse response of nth bit at time t

The time of the first sample is initialized at 6(BAUDD) in order to ensure that when the first sample is taken, contributions from bits modulated at time 0 are also summed do to the overlapping nature of the QPR signals. The value of the last sample is also formed by the sum of the quadrature components existing at 6(BAUDD) after it is produced. The rest of the program operation remains the same as previous modules.

N. SUBROUTINE STREAM

This subroutine interacts with the IMSL random number generator SUBROUTINE GGUBFS to produce a random number between 0 and 1 and make assignment on the basis of the value of this random number to random bits according to the digital logic scheme specified in the MAIN program. It also enables the user to manually insert binary digits if that option was specified previously in MAIN.

O. SUBROUTINE ORTHO

ORTHO produces an n X n orthogonal matrix from the Hadamard matrix by forming successive Kronecker products [Ref. 15]. It also selects the appropriate row and column of the orthogonal bit to be modulated and passes this bit back to SUBROUTINE OBPSK. Point of entry to SUBROUTINE ORTHO is controlled by a flag set in OBPSK.

P. SUBROUTINE PLOT

PLOT is an interactive module that allows the user to determine whether or not a graph of the output of program calculations is to be produced. The user is also able to selectively vary certain parameters associated with the plot. PLOT calls SUBROUTINE UTPLOT which actually produces the graph and performs the output. UTPLOT is a NON-IMSL library routine from the Naval Postgraduate School.

Q. SUBROUTINE STATS

The statistical calculations associated with the amplitude spectrums of the various functions generated on successive repetitions of the program are computed in SUBROUTINE STATS. Upon completion of each repetition, each module calls STATS where the sum, sum of the squares, sum of the cubes and sum of the quartics of each element of the amplitude spectrum of the signal produced are computed and stored. When the last repetition of the program is complete, MAIN instructs STATS to compute and output the final statistics, i.e., mean, variance, skewness and kurtosis of each component of the amplitude spectrum according to the estimations contained in [Ref. 16]. Additionally the mean variance and variance of the variance is calculated and output. Point of entrance to this subroutine is controlled by flags set in the individual modulation subroutines or in MAIN.

VII. STATISTICS OF THE FAST FOURIER TRANSFORMS

A. DESCRIPTION OF THE PROBLEM

As stated in Chapter II, if it can be shown that the statistics of the FFT can be somehow linked to a particular digital signal modulation technique, then the modulation technique can be identified on the basis of those statistics alone. Although it is beyond the scope of this thesis to actually derive those relationships if they exist, it seem prudent to attempt to determine if there is statistical differences between the components of the FFT's as they are derived in the enclosed computer simulations.

The statistic chosen to do the hypothesis testing is the F-test since the true mean and variance of the distribution need not be known [Ref. 17]. In addition, the information necessary to calculate the F-statistic is readily accumulated in SUBROUTINE STATS. Calculation of the F-statistic necessitated the writing of a small computer program to be used for that purpose once the output from the main program was generated and reformatted.

B. ANALYSIS-OF-VARIANCE

If there were no differences attributable to the modulation technique, then it would be reasonable to assume that for a certain set of characteristics, the components of successive FFT's would be the same. In other words, if a signal was modulated by BPSK and a statistically significant number of FFT's were generated of the signal, then the statistics of those FFT's would be assumed to be related. On the other hand, if it can be shown that the statistics are not related (i.e., not from the same distribution), then significance can be placed in the variation among modulation techniques.

1. The F-Distribution

The assumptions necessary to use the F-distribution are:

1. Normal distribution
2. Random samples
3. Independent samples

These assumptions are not too difficult to intuitively accept in the model that will be proposed. Once again it would be expected that the FFT's of successive identically modulated signals to be related. For the simulations conducted as part of this test, they were all generated using bits from a random number generator for which it can be shown that each sequence of bits passes statistical tests for randomness and independence. The assumption of normality could also be argued on the basis of the central limit theorem.

The value of the F-statistic with which comparison will be made is 1.51 for 14 degrees of freedom in the numerator, an infinite number of degrees of freedom in the denominator and a 90% confidence region. How these values were obtained will be detailed under the design of the experiment.

2. Design of the Experiment

The experimental data used in the computation of the statistics was chosen to minimize the random contributions of variables other than the modulation technique. The computer simulations included in this thesis were used to generate the statistics and a separate program also included in the appendix was used to calculate the F-statistic. The variables in the experiment include:

1. Modulation technique
2. Logic type
3. Baud rate
4. Bits per binary code word
5. Carrier frequency
6. Carrier amplitude
7. Initial phase angle
8. Number of samples generated
9. Time between samples
10. Seed for random number generator
11. Number of repetitions or trials

Fifteen different modulation techniques were compared. In all cases bipolar logic was simulated, the baud rate was held constant at 1200 baud and the maximum carrier amplitude was established at 1 volt. Additionally the phase angle of all simulations was 0 degrees and the seed for the random number generator was 1 thereby ensuring the same random sequence of bits. The number of bits per binary code word did vary among the modulation techniques. When the modulation technique was M-ary, the bits per code word was always 3 so it is possible to infer that bits per code word is a function of the modulation technique. The time between samples was the normalized Nyquist sampling rate. This did vary between modulation techniques but was necessary to derive an accurate FFT. Carrier frequency also varied between simulations but was always twice the lowest carrier frequency recommended in the computer simulation. In most cases this was 2400 Hz, or twice the baud rate. Finally each simulation was repeated 100 times and the statistics of the FFT's based on those 100 repetitions. The number of samples produced was always 64 so there are 33 components of the FFT.

What this amounts to can be illustrated through an Analysis-of-Variance table as shown in Table 2 [Ref. 17].

TABLE 2

ANALYSIS-OF-VARIANCE TABLE

n Observations in Each of r Groups

		Observations	Sum	Mean
Group	1	Y_{11} Y_{12} Y_{13} ...... Y_{1n}	$Y_{1.}$	$\overline{Y}_{1.}$
	2	Y_{21} Y_{22} Y_{23} ...... Y_{2n}	$Y_{2.}$	$\overline{Y}_{2.}$
	3	Y_{31} Y_{32} Y_{33} ...... Y_{3n}	$Y_{3.}$	$\overline{Y}_{3.}$
	⋮			
	r	Y_{r1} Y_{r2} Y_{r3} ...... Y_{rn}	$Y_{r.}$	$\overline{Y}_{r.}$

In the case of the simulation described above, this amounts to 100 observations (repetitions or trials) from each of 15 groups (modulation techniques) for each of the 33 components of the FFT. The degrees of freedom in the numerator is equal to (15-1) or 14 while the degrees of freedom in the denominator is equal to 15(100-1) or 1485. Table values for the F-distribution use infinity as the degree of freedom for values greater than 120.

An F-test was also performed to determine if there is a relationship among the mean variance, mean skewness or mean kurtosis of the 15 different modulation techniques. Again the assumption is made that these statistics would be normally distributed from modulation techniques which had the same or statistically similar components of their FFT's. In this case there were again 15 modulation techniques to compare (14 degrees of freedom) but only 33 observations (the variance, skewness or kurtosis of the respective elements of the FFT). This number of observations yields 15(33-1) = 480 degrees of freedom in the denominator.

3. Hypothesis and Hypothesis Testing

The hypothesis posed for the model is that the means of the individual components of the FFT's from the 15 modulation techniques are from the same distribution. Therefore, the respective means must be equal. Also tested is that the mean variance, mean skewness and mean kurtosis of all components of the FFT's of each modulation technique are equal. These hypothesis are illustrated in equations 7.1 through equation 7.4. Each hypothesis is tested and compared to the F-distribution selecting a rejection region or level of significance of .9. This equates to an F-statistic of 1.51 for 14 degrees of freedom in the numerator and an infinite number of degrees of freedom in the denominator.

4. Results

The means of the 33 components of the FFT for each of the 15 modulation techniques were compared using the F-distribution. The results are shown in Table 3. Table 4 shows the F-statistics associated with the comparison of the mean of the variance, mean of the skewness and mean of the kurtosis for the respective groups. In addition a complete summation of the results of the F-test are included in the appendix.

C. CONCLUSION

The results of the F-test indicate that the null hypothesis must be rejected at the .9 significance level and the alternate hypothesis accepted that the means are not equal for FFT components 9-14. In addition the F-statistic for the comparison of mean variance, mean skewness and mean kurtosis all fall in the rejection area.

$$Ho: XBAR11 = XBAR21 = \bullet \bullet \bullet = XBARij \qquad \text{(eqn 7.1)}$$

$$H1: XBAR11 \neq XBAR21 \neq \bullet \bullet \bullet \neq XBARij$$

i = ith modulation technique
j = jth component of the FFT

$$Ho: MVAR1 = MVAR2 = \bullet \bullet \bullet = MVAR15 \qquad \text{(eqn 7.2)}$$

$$H1: MVAR1 \neq MVAR2 \neq \bullet \bullet \bullet \neq MVAR\ 15$$

$$HO: MSKEW1 = MSKEW2 = \bullet \bullet \bullet = MSKEW15 \qquad \text{(eqn 7.3)}$$

$$H1: MSKEW1 \neq MSKEW2 \neq \bullet \bullet \bullet \neq MSKEW15$$

$$Ho: MKUR1 = MKUR2 = \bullet \bullet \bullet = MKUR15 \qquad \text{(eqn 7.4)}$$

$$H1: MKUR1 \neq MKUR2 \neq \bullet \bullet \bullet \neq MKUR15$$

This indicates that there is a difference between the statistics of of the FFT's of the respective modulation technique. Since all the parameters used in the generation of these statistics were held essentially constant among the trials, it can be assumed that these differences are due to the modulation technique employed. It has not been established yet what those differences may be. This is an area where future research and study is warranted.

The results of this test would seem to point to those components of the FFT which offer the best opportunity to develop those relationships or differences. FFT components 9-14 have obvious differences; however, FFT components 20, 24 and 25 also have large F-statistics but do not fall in the rejection area. These components may also be

TABLE 3

F-STATISTICS OF FFT COMPONENTS

FFT COMPONENT	AMONG GROUP SUM	WITHIN GROUP SUM	TOTAL OF SQUARES	F-STAT
1	0.121	17.69	17.81	0.727
2	0.112	18.48	18.59	0.642
3	0.108	20.65	20.76	0.557
4	0.135	25.40	25.54	0.562
5	0.172	32.74	32.91	0.558
6	0.254	41.72	41.98	0.647
7	0.422	50.10	50.52	0.893
8	0.962	82.83	83.79	1.231
9	7.591	390.2	397.8	2.063
10	49.09	1681.0	1730.1	3.097
11	53.01	1732.1	1785.1	3.246
12	61.56	2071.7	2133.3	3.152
13	45.73	1832.8	1878.6	2.646
14	3.864	250.5	254.4	1.636
15	0.539	98.13	98.67	0.582
16	0.366	110.1	110.5	0.353
17	0.504	151.0	151.5	0.354
18	0.943	140.3	141.2	0.713
19	1.299	158.5	159.8	0.870
20	2.671	200.7	203.4	1.412
21	1.853	226.3	228.2	0.868
22	2.277	232.1	234.3	1.041
23	1.712	197.6	199.3	0.919
24	2.512	181.9	184.4	1.476
25	2.144	171.3	173.5	1.327
26	1.257	143.7	145.0	0.928
27	1.233	113.9	115.1	1.149

TABLE 3
F-STATISTICS OF FFT COMPONENTS (con't)

28	0.858	115.8	116.7	0.785
29	0.547	63.72	64.27	0.911
30	0.356	55.77	56.13	0.677
31	0.183	41.41	51.59	0.469
32	0.051	13.79	13.84	0.389
33	0.031	10.92	10.96	0.304

TABLE 4

F-STATISTICS OF THE MEAN VARIANCES, MEAN SKEWNESS AND MEAN KURTOSIS

	AMONG GROUP SUM	WITHIN GROUP SUM	TOTAL OF SQUARES	F-STAT
VARIANCE	3.144 E5	3.755 E6	4.070 E6	2.870
SKEWNESS	5.307 E10	7.031 E11	7.562 E11	2.588
KURTOSIS	8.280 E11	1.262 E13	1.344 E13	2.250

interesting to examine. In addition, it should be noted that the statistics of the FFT associated with each respective modulation technique also display some striking differences. These statistics may prove in some way to be a fingerprint of the modulation techniques themselves.

APPENDIX A

FORTRAN PROGRAM FOR DIGITAL SIGNAL MODULATION

```
C     *****************************************************************MAI00020
C     *                                                               *MAI00030
C     * TITLE:  DIGITAL SIGNAL MODULATION TECHNIQUES                  *MAI00040
C     *                                                               *MAI00050
C     * PURPOSE:  THIS PROGRAM GENERATES A SIMULATED WAVEFORM WHICH IS *MAI00060
C     * CHARACTERISTIC OF ONE OF A VARIETY OF DIGITAL SIGNAL MODULATION*MAI00070
C     * TECHNIQUES.  THE PROGRAM IS INTERACTIVE AND DESIGNED TO BE AS *MAI00080
C     * USER FRIENDLY AS POSSIBLE.  THE PROGRAM ALLOWS THE USER TO    *MAI00090
C     * SPECIFY ANY ONE OF A NUMBER OF PARAMETERS OR VARIABLES WHICH  *MAI00100
C     * ARE CHARACTERISTIC OF THE INDIVIDUAL MODULATION TECHNIQUE.    *MAI00110
C     * THE PROGRAM ALSO ALLOWS THE USER TO DEVELOP A PLOT OF THE     *MAI00120
C     * SIMULATED WAVEFORM, GENERATE THE FAST FOURIER TRANSFORM,      *MAI00130
C     * OR DO LIMITED STATISTICAL ANALYSIS.                           *MAI00140
C     *                                                               *MAI00150
C     * WRITTEN BY:  CRAIG CARLSON, LCDR, USN                         *MAI00160
C     * IN PARTIAL FULFILLMENT OF MASTER OF SCIENCE, SYSTEMS TECHNOLOGY*MAI00170
C     *                                                               *MAI00180
C     * THIS PROGRAM WAS WRITTEN FOR EXECUTION ON AN IBM 3033 COMPUTER *MAI00190
C     * UTILIZING THE VMS/CMS OPERATING SYSTEM.  WITHIN THE CMS SYSTEM *MAI00200
C     * THERE IS A ROUTINE TO CLEAR THE SCREEN WHEN DESIRED.  THIS    *MAI00210
C     * FUNCTION IS CALLED THROUGH USE OF THE CCMMAND *                MAI00220
C     * CALL FRTCMS('CLRSCRN ').  IF THE PROGRAM IS TO BEUSED ON THIS* MAI00230
C     * OPERATING SYSTEM, REMOVAL OF THE COMMENT C BEFORE LINES OF    *MAI00240
C     * CODE CONTAINING THIS COMMAND WILL IMPROVE THE INTERACTIVE     *MAI00250
C     * PORTION OF THE PROGRAM.*                                       MAI00260
C     *                                                               *MAI00270
C     *****************************************************************MAI00280
C                                                                      MAI00290
C     *** MAIN CONTROL MODULE ***                                      MAI00300
C                                                                      MAI00310
C     *** PURPOSE ***                                                  MAI00320
C                                                                      MAI00330
C     THIS PROGRAM IS THE MAIN BODY OF THE SIGNAL GENERATOR.  IT       MAI00340
C     CONTROLS INPUT AND OUTPUT AND CALLS VARIOUS SUBROUTINES DURING   MAI00350
C     ITS OPERATION.                                                   MAI00360
C                                                                      MAI00370
C     *** VARIABLE DEFINITIONS ***                                     MAI00380
C                                                                      MAI00390
C     ANS=        A INTEGER REPRESENTING THE RESPONSE TO AN INQUIRY    MAI00400
C     TYPE1=      AN INTEGER TO CONTROL INPUT                          MAI00410
C     TYPE2=      AN INTEGER TO CONTROL INPUT                          MAI00420
C     TYPE3=      AN INTEGER TO CONTROL INPUT                          MAI00430
C     ANS2=       AN INTEGER USED TO SPECIFY HOW BIT STREAM IS TO BE   MAI00440
```

```
C                 GENERATED                                             MAI00450
C     IBAUD=      INTEGER VALUE OF BAUD RATE                            MAI00460
C     BAUD=       SYMBOL RATE OR BAUD RATE                              MAI00470
C     BAUDD=      BAUD DURATION                                         MAI00480
C     IBITS=      INTEGER VALUE OF BITS IN A BINARY CODE WORD           MAI00490
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD               MAI00500
C     BITR=       BIT RATE                                              MAI00510
C     IFREQ=      INTEGER VALUE OF CARRIER FREQUENCY                    MAI00520
C     FREQ=       CARRIER FREQUENCY                                     MAI00530
C     IIPHAS=     INTEGER VALUE OF INITIAL PHASE ANGLE IN DEGREES       MAI00540
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        MAI00550
C     IAMP=       INTEGER VALUE OF IN-PHASE AMPLITUDE                   MAI00560
C     AMP=        AMPLITUDE                                             MAI00570
C     ISEED=      INTEGER VALUE OF SEED FOR RANDOM NUMBER GENERATOR     MAI00580
C     DSEED=      SEED FOR RANDOM NUMBER GENERATOR                      MAI00590
C     ARRAY=      A TWO DIMENTIONAL ARRAY                               MAI00600
C     R=          AN INTEGER REPRESENTING THE ROW OF ARRAY              MAI00610
C     IN=         INTEGER OF NUMBER OF POSITIONS TO BE USED IN ARRAY    MAI00620
C     N=          REAL VALUE OF IN                                      MAI00630
C     REPS=       INTEGER VALUE OF NUMBER OF TIMES THE PROGRAM IS TO BE MAI00640
C                 REPEATED                                              MAI00650
C     REP=        INTEGER VALUE OF THE NUMBER OF THE REPETITION OF THE  MAI00660
C                 PROGRAM AND PASSED TO THE SUBPROGRAM FOR THE          MAI00670
C                 MODULATION TECHNIQUE BEING EMPLOYED                   MAI00680
C     FLAG=       INTEGER TO CONTROL POINT OF ENTRANCE TO SUBROUTINE    MAI00690
C                 STATS                                                 MAI00700
C     FC=         RECOMMENDED MINIMUM CARRIER FREQUENCY                 MAI00710
C     STEP=       TIME INTERVAL BETWEEN SAMPLES                         MAI00720
C                                                                       MAI00730
C     *** VARIABLE DECLARATIONS ***                                     MAI00740
C                                                                       MAI00750
      INTEGER ANS,TYPE1,TYPE2,TYPE3,ANS2,IBAUD,IBITS,IFREQ,             MAI00760
     *IIPHAS,IAMP,ISEED,R,IN,REPS,REP,FLAG                              MAI00770
C                                                                       MAI00780
      DOUBLE PRECISION BAUD,BITS,BITR,FREQ,IPHAS,AMP,BAUDD,STEP,FC,     MAI00790
     *DSEED,N,PI                                                        MAI00800
C                                                                       MAI00810
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  MAI00820
     *SUMX4(513)                                                        MAI00830
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              MAI00840
C                                                                       MAI00850
C     *** VARIABLE INITIALIZATIONS ***                                  MAI00860
C                                                                       MAI00870
      R=1                                                               MAI00880
      PI=3.141592653589793D0                                            MAI00890
      TYPE3=0                                                           MAI00900
C                                                                       MAI00910
C     *** INTRODUCE THE PROGRAM ***                                     MAI00920
C                                                                       MAI00930
C     CALL FRTCMS('CLRSCRN ')                                           MAI00940
```

```
C                                                                       MAI00950
10    WRITE(10,20)                                                      MAI00960
20    FORMAT(' HELLO!  YOU HAVE INITIATED A PROGRAM WHICH WILL ALLOW',/,MAI00970
     *' YOU TO PRODUCE ONE OF A NUMBER OF SIMULATED COMMUNICATIONS',/,  MAI00980
     *' SIGNALS UTILIZING VARIOUS DIGITAL SIGNAL MODULATION TECHNIQUES.'MAI00990
     *,/,' YOU WILI BE ASKED TO PROVIDE CERTAIN INFORMATION ABOUT THE', MAI01000
     */,' SIGNAL YOU WISH TO SIMULATE.  ADDITIONALLY YOU WILL BE',      MAI01010
     */,' GIVEN THE OPPORTUNITY TO PLOT THE RESULTS, GENERATE THE FFT'  MAI01020
     *,/,' OF THE SIGNAL OR TO DO CERTAIN STATISTICAL ANALYSIS OF THE'  MAI01030
     *,/,' FFT.  IF YOU ARE READY TO PROCEED, TYPE 1 <CR>.',//,' :')    MAI01040
C                                                                       MAI01050
      READ(5,21)ANS                                                     MAI01060
21    FORMAT(I1)                                                        MAI01070
C                                                                       MAI01080
      IF(ANS.NE.1)THEN                                                  MAI01090
C        CALL FRTCMS('CLRSCRN ')                                        MAI01100
         GO TO 10                                                       MAI01110
      END IF                                                            MAI01120
C                                                                       MAI01130
C     *** DISPLAY MODULATION TECHNIQUES AVAILABLE AND INQUIRE WHICH     MAI01140
C     TECHNIQUE IS TO BE SIMULATED ***                                  MAI01150
C                                                                       MAI01160
C     CALL FRTCMS('CLRSCRN ')                                           MAI01170
C                                                                       MAI01180
29    WRITE(10,30)                                                      MAI01190
30    FORMAT(' THIS PROGRAM IS CAPABLE OF SIMULATING THE FOLLOWING',/,  MAI01200
     *' DIGITAL SIGNAL MODULATION TECHNIQUES:',//,                      MAI01210
     *' 1.  BINARY PHASE SHIFT KEYING (BPSK)',/,                        MAI01220
     *' 2.  DIFFERENTIAL BINARY PHASE SHIFT KEYING (DBPSK)',/,          MAI01230
     *' 3.  ORTHOGONAL BINARY PHASE SHIFT KEYING (ORTHOGONAL BPSK)',/,  MAI01240
     *' 4.  QUADRATURE PHASE SHIFT KEYING (QPSK)',/,                    MAI01250
     *' 5.  OFFSET QUADRATURE PHASE SHIFT KEYING (OQPSK)',/,            MAI01260
     *' 6.  MULTIPLE PHASE SHIFT KEYING (MPSK)',/,                      MAI01270
     *' 7.  MULTIPIE AMPLITUDE SHIFT KEYING (MASK)',/,                  MAI01280
     *' 8.  QUADRATURE AMPLITUDE SHIFT KEYING (QASK)',/,                MAI01290
     *' 9.  MINIMUM SHIFT KEYING (MSK) OR',/,                           MAI01300
     *'     FAST FREQUENCY SHIFT KEYING (FFSK)',/,                      MAI01310
     *' 10. MULTIPLE FREQUENCY SHIFT KEYING (MFSK)',/,                  MAI01320
     *' 11. QUADRATURE PARTIAL RESPONSE (QPRS)',//,                     MAI01330
     *' ENTER THE NUMBER (1-11) WHICH CORRESPONDS TO THE DIGITAL SIGNAL'MAI01340
     *,/,' SIGNAL MODULATION TECHNIQUE YOU WISH TO SIMULATE',//,' :')   MAI01350
C                                                                       MAI01360
      READ(5,*)TYPE1                                                    MAI01370
C                                                                       MAI01380
      IF(TYPE1.LT.1.OR.TYPE1.GT.11)THEN                                 MAI01390
C        CALL FRTCMS('CLRSCRN ')                                        MAI01400
         WRITE(10,40)                                                   MAI01410
40       FORMAT(' ERROR',/)                                             MAI01420
         GO TO 29                                                       MAI01430
      END IF                                                            MAI01440
```

```
C                                                                       MAI01450
C     *** DETERMINE THE CLASS OF THE QUADRATURE PARTIAL RESPONE SYSTEM *MAI01460
C                                                                       MAI01470
      IF(TYPE1.EQ.11)THEN                                               MAI01480
C                                                                       MAI01490
         CALL FRTCMS('CLRSCRN ')                                        MAI01500
C                                                                       MAI01510
41       WRITE(10,42)                                                   MAI01520
42       FORMAT(' ENTER THE CLASS OF THE QUADRATURE PARTIAL RESPONSE',  MAI01530
     *   /,' SYSTEM TO BE SIMULATED FROM 1-5.',//,' :')                 MAI01540
C                                                                       MAI01550
         READ(5,*)TYPE3                                                 MAI01560
C                                                                       MAI01570
         IF(TYPE3.LT.1.OR.TYPE3.GT.5)THEN                               MAI01580
C           CALL FRTCMS('CLRSCRN ')                                     MAI01590
            WRITE(10,43)                                                MAI01600
43          FORMAT(' ERROR',/)                                          MAI01610
            GO TO 41                                                    MAI01620
         END IF                                                         MAI01630
C                                                                       MAI01640
      END IF                                                            MAI01650
C                                                                       MAI01660
C     *** DETERMINE THE LOGIC SCHEME TO BE EMPLOYED DURING MODULATION **MAI01670
C                                                                       MAI01680
C     CALL FRTCMS('CLRSCRN ')                                           MAI01690
C                                                                       MAI01700
49    WRITE(10,50)                                                      MAI01710
50    FORMAT(' ENTER THE NUMBER (1-3) WHICH CORRESPONDS TO THE',/,      MAI01720
     *' DESIRED DIGITAL LOGIC SCHEME:',//,                              MAI01730
     *' 1.  BIPOLAR',/,                                                 MAI01740
     *' 2.  UNIPOLAR POSITIVE',/,                                       MAI01750
     *' 3.  UNIPOLAR NEGATIVE',//,' :')                                 MAI01760
C                                                                       MAI01770
      READ(5,51)TYPE2                                                   MAI01780
51    FORMAT(I1)                                                        MAI01790
C                                                                       MAI01800
      IF(TYPE2.LT.1.OR.TYPE2.GT.3)THEN                                  MAI01810
C        CALL FRTCMS('CLRSCRN ')                                        MAI01820
         WRITE(10,60)                                                   MAI01830
60       FORMAT(' ERROR',/)                                             MAI01840
         GO TO 49                                                       MAI01850
      END IF                                                            MAI01860
C                                                                       MAI01870
C     *** HAVE THE USER ENTER THE BAUD OR SYMBOL RATE ***               MAI01880
C                                                                       MAI01890
C     CALL FRTCMS('CLRSCRN ')                                           MAI01900
C                                                                       MAI01910
69    WRITE(10,70)                                                      MAI01920
70    FORMAT(' ENTER THE BAUD RATE OR SYMBOL RATE AT THIS TIME.',//,    MAI01930
     *' :')                                                             MAI01940
```

```
C                                                                       MAI01950
      READ(5,*)IBAUD                                                    MAI01960
C                                                                       MAI01970
      BAUD=IBAUD                                                        MAI01980
C                                                                       MAI01990
      BAUDD=1.D0/BAUD                                                   MAI02000
C                                                                       MAI02010
C     *** DETERMINE THE BITS EITHER BY THE TYPE OF DIGITAL              MAI02020
C     MODULATION SPECIFIED OR BY USER INPUT ***                         MAI02030
C                                                                       MAI02040
C     CALL FRTCMS('CLRSCRN ')                                           MAI02050
C                                                                       MAI02060
      IF(TYPE1.EQ.1.OR.TYPE1.EQ.2.OR.TYPE1.EQ.9)THEN                    MAI02070
          IBITS=1                                                       MAI02080
          BITS=IBITS                                                    MAI02090
C                                                                       MAI02100
      ELSE IF(TYPE1.EQ.3)THEN                                           MAI02110
79        WRITE(10,80)                                                  MAI02120
80        FORMAT(' ENTER THE NUMBER OF BITS IN EACH SYMBOL.',/,         MAI02130
     *    ' CAUTION!  THE NUMBER OF BITS PER SYMBOL MUST BE 6 OR LESS'  MAI02140
     *    ,//,' :')                                                     MAI02150
C                                                                       MAI02160
          READ(5,*)IBITS                                                MAI02170
C                                                                       MAI02180
          IF(IBITS.LT.1.OR.IBITS.GT.6)THEN                              MAI02190
C             CALL FRTCMS('CLRSCRN ')                                   MAI02200
              WRITE(10,90)                                              MAI02210
90            FORMAT(' ERROR',/)                                        MAI02220
              GO TO 79                                                  MAI02230
          ELSE                                                          MAI02240
              BITS=IBITS                                                MAI02250
          END IF                                                        MAI02260
C                                                                       MAI02270
      ELSE IF(TYPE1.EQ.4.OR.TYPE1.EQ.5.OR.TYPE1.EQ.11)THEN              MAI02280
          IBITS=2                                                       MAI02290
          BITS=IBITS                                                    MAI02300
C                                                                       MAI02310
      ELSE IF(TYPE1.GE.6.OR.TYPE1.LE.8.OR.TYPE1.EQ.10)THEN              MAI02320
99        WRITE(10,100)                                                 MAI02330
100       FORMAT(' ENTER THE NUMBER OF BITS IN EACH SYMBOL.',/,         MAI02340
     *    ' CAUTION!  THE NUMBER OF BITS PER SYMBOL MUST BE 10 OR LESS' MAI02350
     *    ,//,' :')                                                     MAI02360
C                                                                       MAI02370
          READ(5,*)IBITS                                                MAI02380
C                                                                       MAI02390
          IF(IBITS.LT.1.OR.IBITS.GT.11)THEN                             MAI02400
C             CALL FRTCMS('CLRSCRN ')                                   MAI02410
              WRITE(10,110)                                             MAI02420
110           FORMAT(' ERROR',/)                                        MAI02430
              GO TO 99                                                  MAI02440
```

```
          ELSE
              BITS=IBITS
          END IF
C
      END IF
C
C     *** DETERMINE AND DISPLAY THE BIT RATE ***
C
      IF(TYPE1.EQ.3)THEN
          BITR=(2.D0**IBITS)*BAUD
      ELSE
          BITR=BITS*BAUD
      END IF
C
C     CALL FRTCMS('CLRSCRN ')
      WRITE(10,120)BITR
120   FORMAT(' THE BIT RATE FOR THE SPECIFIED SIGNAL IS',F9.0,' BITS/SEC
     *')
C
C     *** HAVE THE USER ENTER THE CARRIER FREQUENCY ***
C
      IF(TYPE1.EQ.3)THEN
          FC=BITR
      ELSE IF(TYPE1.EQ.9)THEN
          FC=1.25D0*BAUD
      ELSE IF(TYPE1.EQ.10)THEN
          FC=BAUD+(((2.D0**IBITS)-1.D0)*(BAUD/2.D0))
      ELSE
          FC=BAUD
      END IF
C
129   WRITE(10,130)FC
130   FORMAT(' ENTER THE CARRIER FREQUENCY AT THIS TIME.',//,
     *' NOTE:  CARRIER FREQ SHOULD BE GREATER THAN',F9.0,' HZ.',//,
     *' :')
C
      READ(5,*)IFREQ
C
      FREQ=IFREQ
C
      IF(FREQ.LT.FC)THEN
          CALL FRTCMS('CLRSCRN ')
C         WRITE(10,140)
140       FORMAT(' THE CARRIER FREQUENCY IS LESS THAN RECOMMENDED.',/)
          GO TO 149
      END IF
C
C     *** HAVE THE USER ENTER THE NUMBER OF SAMPLES TO BE GENERATED ***
C
C     CALL FRTCMS('CLRSCRN ')
```

```
C                                                                       MAI02950
149   WRITE(10,150)                                                     MAI02960
150   FORMAT(' ENTER THE NUMBER OF SAMPLES OF THE MODULATED SIGNAL',    MAI02970
     */,' TO BE PRODUCED.  THIS NUMBER MUST BE EQUAL TO 2**N,',/,       MAI02980
     *' WHERE N IS A POSITIVE INTEGER EQUAL TO OR LESS THAN 10.',/,     MAI02990
     *' I.E., 2, 4, 8, ... , 1024',//,' :')                             MAI03000
C                                                                       MAI03010
      READ(5,*)IN                                                       MAI03020
      N=IN                                                              MAI03030
C                                                                       MAI03040
      IF(IN.EQ.2.OR.IN.EQ.4.OR.IN.EQ.8.OR.IN.EQ.16.OR.IN.EQ.32.OR.      MAI03050
     *IN.EQ.64.OR.IN.EQ.128.OR.IN.EQ.256.OR.IN.EQ.512.OR.IN.EQ.1024)THENMAI03060
         GO TO 170                                                      MAI03070
      ELSE                                                              MAI03080
C        CALL FRTCMS('CLRSCRN ')                                        MAI03090
         WRITE(10,160)                                                  MAI03100
160      FORMAT(' ERROR',/)                                             MAI03110
         GO TO 149                                                      MAI03120
      END IF                                                            MAI03130
C                                                                       MAI03140
C     *** DETERMINE AND DISPLAY INFO ABOUT THE RECORD LENGTH ***        MAI03150
C                                                                       MAI03160
170   IF(TYPE1.EQ.2)THEN                                                MAI03170
         STEP=1.D0/(2.D0*(FREQ+BITR))                                   MAI03180
      ELSE IF(TYPE1.EQ.9)THEN                                           MAI03190
         STEP=1.D0/(2.D0*(FREQ+(1.25D0*BAUD)))                          MAI03200
      ELSE IF(TYPE1.EQ.10)THEN                                          MAI03210
         STEP=1.D0/(2.D0*(FREQ+(((2.D0**IBITS)-1.)*(BAUD/2.D0))+BAUD))  MAI03220
      ELSE IF(TYPE1.EQ.11)THEN                                          MAI03230
         STEP=1.D0/(2.D0*(FREQ+((PI+1.D0)*BAUD)))                       MAI03240
      ELSE                                                              MAI03250
         STEP=1.D0/(2.D0*(FREQ+BAUD))                                   MAI03260
      END IF                                                            MAI03270
C                                                                       MAI03280
      IF(TYPE1.EQ.3.AND.((N-1.)*STEP).LE.1./BITR)THEN                   MAI03290
C        CALL FRTCMS('CLRSCRN ')                                        MAI03300
         WRITE(10,180)                                                  MAI03310
180      FORMAT(' ELAPSED TIME FOR SIGNAL GENERATION WILL BE LESS THAN'MAI03320
     *   ,/,' 1 BIT DURATION.  IF YOU WISH TO CHANGE THIS BY',/,        MAI03330
     *   ' INCREASING THE NUMBER OF SAMPLES TO BE PRODUCED, BY',/,      MAI03340
     *   ' DECREASING CARRIER FREQUENCY, BY DECREASING THE BAUD',/,     MAI03350
     *   ' RATE OR BY DECREASING THE SIZE OF THE BINARY CODE WORD,',/,  MAI03360
     *   ' ENTER A 1.  ENTER ANY OTHER INTEGER VALUE TO CONTINUE',/     MAI03370
     *   ' WITH THE SIMULATION AS SPECIFIED.',//,' :')                  MAI03380
C                                                                       MAI03390
         READ(5,*)ANS                                                   MAI03400
C                                                                       MAI03410
         IF(ANS.EQ.1)THEN                                               MAI03420
            GO TO 29                                                    MAI03430
         END IF                                                         MAI03440
```

```
C                                                                       MAI03450
      ELSE IF(((N-1.D0)*STEP).LE.BAUDD)THEN                             MAI03460
C        CALL FRTCMS('CLRSCRN ')                                        MAI03470
         WRITE(10,190)                                                  MAI03480
190      FORMAT(' ELAPSED TIME FOR SIGNAL GENERATION WILL BE LESS THAN'MAI03490
     *   ,/,' 1 SYMBOL DURATION.  IF YOU WISH TO CHANGE THIS BY',/,     MAI03500
     *   ' INCREASING THE NUMBER OF SAMPLES TO BE PRODUCED, BY',/,      MAI03510
     *   ' DECREASING CARRIER FREQUENCY, BY DECREASING THE BAUD',/,     MAI03520
     *   ' RATE OR BY DECREASING THE SIZE OF THE BINARY CODE WORD,',/,  MAI03530
     *   ' ENTER A 1.  ENTER ANY OTHER INTEGER VALUE TO CONTINUE',/     MAI03540
     *   ' WITH THE SIMULATION AS SPECIFIED.',//,' :')                  MAI03550
C                                                                       MAI03560
         READ(5,*)ANS                                                   MAI03570
C                                                                       MAI03580
         IF(ANS.EQ.1)THEN                                               MAI03590
            GO TO 29                                                    MAI03600
         END IF                                                         MAI03610
C                                                                       MAI03620
      END IF                                                            MAI03630
C                                                                       MAI03640
C     *** HAVE THE USER ENTER THE AMPLITUDE OF THE CARRIER WAVE ***     MAI03650
C                                                                       MAI03660
C     CALL FRTCMS('CLRSCRN ')                                           MAI03670
C                                                                       MAI03680
199   WRITE(10,200)                                                     MAI03690
200   FORMAT(' ENTER THE AMPLITUDE OF THE CARRIER.',//,' :')            MAI03700
C                                                                       MAI03710
      READ(5,*)IAMP                                                     MAI03720
C                                                                       MAI03730
      AMP=IAMP                                                          MAI03740
C                                                                       MAI03750
C     *** HAVE THE USER ENTER THE INITIAL PHASE ANGLE ***               MAI03760
C                                                                       MAI03770
C     CALL FRTCMS('CLRSCRN ')                                           MAI03780
C                                                                       MAI03790
209   WRITE(10,210)                                                     MAI03800
210   FORMAT(' ENTER THE INITIAL PHASE ANGLE FROM 0 TO 360 DEGREES.',//,MAI03810
     *' :')                                                             MAI03820
C                                                                       MAI03830
      READ(5,*)IIPHAS                                                   MAI03840
C                                                                       MAI03850
      IF(IIPHAS.LT.0.OR.IIPHAS.GT.360)THEN                              MAI03860
C        CALL FRTCMS('CLRSCRN ')                                        MAI03870
         WRITE(10,220)                                                  MAI03880
220      FORMAT(' ERROR',/)                                             MAI03890
         GO TO 209                                                      MAI03900
      ELSE                                                              MAI03910
         IPHAS=IIPHAS                                                   MAI03920
      END IF                                                            MAI03930
C                                                                       MAI03940
```

```
C     *** DETERMINE IF A RANDOM BIT STREAM IS TO BE GENERATED ***       MAI03950
C                                                                       MAI03960
C     CALL FRTCMS('CLRSCRN ')                                           MAI03970
C                                                                       MAI03980
229   WRITE(10,230)                                                     MAI03990
230   FORMAT(' ENTER 1 IF YOU DESIRE TO HAVE THE COMPUTER GENERATE A',/,MAI04000
     *' RANDOM BIT STREAM OR ENTER 2 IF YOU WISH TO ENTER YOUR OWN BIT',MAI04010
     */,' STREAM.',//,' :')                                             MAI04020
C                                                                       MAI04030
      READ(5,240) ANS2                                                  MAI04040
240   FORMAT(I1)                                                        MAI04050
C                                                                       MAI04060
      IF(ANS2.LT.1.OR.ANS2.GT.2) THEN                                   MAI04070
C        CALL FRTCMS('CLRSCRN ')                                        MAI04080
         WRITE(10,250)                                                  MAI04090
250      FORMAT(' ERROR',/)                                             MAI04100
         GO TO 229                                                      MAI04110
      END IF                                                            MAI04120
C                                                                       MAI04130
C     *** HAVE THE USER ENTER THE SEED FOR THE RANDOM NUMBER GENERATOR**MAI04140
C                                                                       MAI04150
C     CALL FRTCMS('CLRSCRN ')                                           MAI04160
C                                                                       MAI04170
      IF(ANS2.EQ.1)THEN                                                 MAI04180
         WRITE(10,260)                                                  MAI04190
260      FORMAT(' ENTER THE SEED (A REAL NUMBER BETWEEN 1 AND 2**31)',/ MAI04200
     *   ,' FOR THE RANDOM NUMBER GENERATOR',//,' :')                   MAI04210
C                                                                       MAI04220
         READ(5,*)ISEED                                                 MAI04230
C                                                                       MAI04240
         DSEED=ISEED                                                    MAI04250
      END IF                                                            MAI04260
C                                                                       MAI04270
C     *** HAVE THE USER SPECIFY THE NUMBER OF TRIALS TO BE USED ***     MAI04280
C                                                                       MAI04290
C     CALL FRTCMS('CLRSCRN ')                                           MAI04300
C                                                                       MAI04310
      WRITE(10,270)                                                     MAI04320
270   FORMAT(' ENTER THE NUMBER OF TIMES YOU WOULD LIKE THE SIMULATION',MAI04330
     */,' TO REPEAT.',//,' :')                                          MAI04340
C                                                                       MAI04350
      READ(5,*)REPS                                                     MAI04360
C                                                                       MAI04370
C     *** CALL THE APPROPRIATE SUBROUTINE FOR THE MODULATION TECHNIQUE  MAI04380
C     SPECIFIED, THE APPROPRIATE NUMBER OF TIMES ***                    MAI04390
C                                                                       MAI04400
      DO 280 REP=1,REPS                                                 MAI04410
C                                                                       MAI04420
      IF(TYPE1.EQ.1)THEN                                                MAI04430
         CALL BPSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)         MAI04440
```

```
C
      ELSE IF(TYPE1.EQ.2)THEN
          CALL DBPSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)
C
      ELSE IF(TYPE1.EQ.3)THEN
          CALL OBPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)
C
      ELSE IF(TYPE1.EQ.4)THEN
          CALL QPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)
C
      ELSE IF(TYPE1.EQ.5)THEN
          CALL OQPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,
     *    REP)
C
      ELSE IF(TYPE1.EQ.6)THEN
          CALL MPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,
     *    REP)
C
      ELSE IF(TYPE1.EQ.7)THEN
          CALL MASK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,
     *    REP)
C
      ELSE IF(TYPE1.EQ.8)THEN
          CALL QASK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,
     *    REP)
C
      ELSE IF(TYPE1.EQ.9)THEN
          CALL MSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)
C
      ELSE IF(TYPE1.EQ.10)THEN
          CALL MFSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,IN,REP)
C
      ELSE IF(TYPE1.EQ.11)THEN
          CALL QPRS(TYPE2,TYPE3,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,DSEED,
     *    IN,REP)
C
      END IF
C
280   CONTINUE
C
C     *** OUTPUT A FINGERPRINT OF THE MODULATION ACCOMPLISHED ***
C
      IF(TYPE1.EQ.1)THEN
          WRITE(6,281)
281       FORMAT('1',' MODULATION TECHNIQUE = BPSK')
      ELSE IF(TYPE1.EQ.2)THEN
          WRITE(6,282)
282       FORMAT('1',' MODULATION TECHNIQUE = DBPSK')
      ELSE IF(TYPE1.EQ.3)THEN
          WRITE(6,283)
```

```
283       FORMAT('1',' MODULATION TECHNIQUE = ORTHOGONAL BPSK')          MAI04950
      ELSE IF(TYPE1.EQ.4) THEN                                           MAI04960
          WRITE(6,284)                                                   MAI04970
284       FORMAT('1',' MODULATION TECHNIQUE = QPSK')                     MAI04980
      ELSE IF(TYPE1.EQ.5) THEN                                           MAI04990
          WRITE(6,285)                                                   MAI05000
285       FORMAT('1',' MODULATION TECHNIQUE = OQPSK')                    MAI05010
      ELSE IF(TYPE1.EQ.6) THEN                                           MAI05020
          WRITE(6,286)                                                   MAI05030
286       FORMAT('1',' MODULATION TECHNIQUE = MPSK')                     MAI05040
      ELSE IF(TYPE1.EQ.7) THEN                                           MAI05050
          WRITE(6,287)                                                   MAI05060
287       FORMAT('1',' MODULATION TECHNIQUE = MASK')                     MAI05070
      ELSE IF(TYPE1.EQ.8) THEN                                           MAI05080
          WRITE(6,288)                                                   MAI05090
288       FORMAT('1',' MODULATION TECHNIQUE = QASK')                     MAI05100
      ELSE IF(TYPE1.EQ.9) THEN                                           MAI05110
          WRITE(6,289)                                                   MAI05120
289       FORMAT('1',' MODULATION TECHNIQUE = MSK')                      MAI05130
      ELSE IF(TYPE1.EQ.10) THEN                                          MAI05140
          WRITE(6,290)                                                   MAI05150
290       FORMAT('1',' MODULATION TECHNIQUE = MFSK')                     MAI05160
      ELSE IF(TYPE1.EQ.11) THEN                                          MAI05170
          WRITE(6,291)                                                   MAI05180
291       FORMAT('1',' MODULATION TECHNIQUE = QPRS')                     MAI05190
      END IF                                                             MAI05200
C                                                                        MAI05210
      IF(TYPE1.EQ.11.AND.TYPE3.EQ.1) THEN                                MAI05220
          WRITE(6,292)                                                   MAI05230
292       FORMAT(' QPRS CLASS 1 FILTER')                                 MAI05240
      ELSE IF(TYPE1.EQ.11.AND.TYPE3.EQ.2) THEN                           MAI05250
          WRITE(6,293)                                                   MAI05260
293       FORMAT(' QPRS CLASS 2 FILTER')                                 MAI05270
      ELSE IF(TYPE1.EQ.11.AND.TYPE3.EQ.3) THEN                           MAI05280
          WRITE(6,294)                                                   MAI05290
294       FORMAT(' QPRS CLASS 3 FILTER')                                 MAI05300
      ELSE IF(TYPE1.EQ.11.AND.TYPE3.EQ.4) THEN                           MAI05310
          WRITE(6,295)                                                   MAI05320
295       FORMAT(' QPRS CLASS 4 FILTER')                                 MAI05330
      ELSE IF(TYPE1.EQ.11.AND.TYPE3.EQ.5) THEN                           MAI05340
          WRITE(6,296)                                                   MAI05350
296       FORMAT(' QPRS CLASS 5 FILTER')                                 MAI05360
      END IF                                                             MAI05370
C                                                                        MAI05380
      IF(TYPE2.EQ.1)THEN                                                 MAI05390
          WRITE(6,297)                                                   MAI05400
297       FORMAT(' BIPOLAR LOGIC')                                       MAI05410
      ELSE IF(TYPE2.EQ.2) THEN                                           MAI05420
          WRITE(6,298)                                                   MAI05430
298       FORMAT(' UNIPOLAR POSITIVE LOGIC')                             MAI05440
```

```
      ELSE IF(TYPE2.EQ.3)THEN                                           MAI05450
         WRITE(6,299)                                                   MAI05460
299      FORMAT(' UNIPOLAR NEGATIVE LOGIC')                             MAI05470
      END IF                                                            MAI05480
C                                                                       MAI05490
      WRITE(6,300)IBAUD                                                 MAI05500
300   FORMAT(' BAUD OR SYMBOL RATE = ',I10,' HZ')                       MAI05510
C                                                                       MAI05520
      WRITE(6,301)IBITS                                                 MAI05530
301   FORMAT(' BITS PER BINARY CODE WORD = ',I10)                       MAI05540
C                                                                       MAI05550
      WRITE(6,302)BITR                                                  MAI05560
302   FORMAT(' BIT RATE = ',E23.16)                                     MAI05570
C                                                                       MAI05580
      WRITE(6,303)IFREQ                                                 MAI05590
303   FORMAT(' CARRIER FREQUENCY = ',I10,' HZ')                         MAI05600
C                                                                       MAI05610
      WRITE(6,304)IAMP                                                  MAI05620
304   FORMAT(' MAXIMUM CARRIER AMPLITUDE = ',I10,' VOLT(S)')            MAI05630
C                                                                       MAI05640
      WRITE(6,305)IIPHAS                                                MAI05650
305   FORMAT(' INITIAL PHASE ANGLE = ',I10,' DEGREES')                  MAI05660
C                                                                       MAI05670
      WRITE(6,306)STEP                                                  MAI05680
306   FORMAT(' TIME BETWEEN SAMPLES = ',E23.16,' SEC')                  MAI05690
C                                                                       MAI05700
      WRITE(6,307)IN                                                    MAI05710
307   FORMAT(' NUMBER OF SAMPLES GENERATED = ',I10)                     MAI05720
C                                                                       MAI05730
      IF(ANS2.EQ.1)THEN                                                 MAI05740
         WRITE(6,308)ISEED                                              MAI05750
308      FORMAT(' SEED FOR RANDOM NUMBER GENERATOR = ',I10)             MAI05760
      END IF                                                            MAI05770
C                                                                       MAI05780
      WRITE(6,309)REPS                                                  MAI05790
309   FORMAT(' NUMBER OF TIMES SIMULATION REPEATS = ',I10)              MAI05800
C                                                                       MAI05810
C     *** CALL THE STATISTICS SUBROUTINE FOR FINAL CALCULATIONS ***     MAI05820
C                                                                       MAI05830
      FLAG=1                                                            MAI05840
      CALL STATS(IN,REP,FLAG)                                           MAI05850
C                                                                       MAI05860
      IF(TYPE1.EQ.3.AND.((N-1.D0)*STEP).LE.1./BITR)THEN                 MAI05870
         WRITE(6,310)                                                   MAI05880
310      FORMAT(' LESS THAN 1 BIT WAS MODULATED DURING EACH REPETITION MAI05890
     *   ')                                                             MAI05900
      ELSE IF(((N-1.D0)*STEP).LE.BAUDD)THEN                             MAI05910
         WRITE(6,320)                                                   MAI05920
320      FORMAT(' LESS THAN 1 BAUD WAS MODULATED DURING EACH REPETITIONMAI05930
     *   ')                                                             MAI05940
```

```
      END IF
C
C     *** DETERMINE IF ANOTHER SIMULATION IS TO BE RUN ***
C
      WRITE(10,330)
330   FORMAT(' ENTER A 1 IF YOU DESIRE TO SIMULATE ANOTHER SIGNAL.',/,
     *' ENTER ANY CTHER INTEGER IF YOU ARE READY TO QUIT.',//,' :')
C
      READ(5,*)ANS
C
      IF(ANS.EQ.1) THEN
C         CALL FRTCMS('CLRSCRN ')
          GC TO 29
      END IF
C
      STOP
      END
```

```
      SUBROUTINE BPSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,                   BPS00110
     *DSEED,IN,REP)                                                     BPS00120
C                                                                       BPS00130
C     *** PURPOSE ***                                                   BPS00140
C                                                                       BPS00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING BINARY PHASE SHIFT    BPS00160
C     KEYING AS THE MODULATION TECHNIQUE.                               BPS00170
C                                                                       BPS00180
C     *** PARAMETER DEFINITIONS ***                                     BPS00190
C                                                                       BPS00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   BPS00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              BPS00220
C     FREQ=       CARRIER FREQUENCY                                     BPS00230
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        BPS00240
C     AMP=        AMPLITUDE                                             BPS00250
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               BPS00260
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     BPS00270
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED           BPS00280
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF   BPS00290
C                 THE CALL THE THIS SUBROUTINE                          BPS00300
C                                                                       BPS00310
C     *** VARIABLE DEFINITIONS ***                                      BPS00320
C                                                                       BPS00330
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       BPS00340
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     BPS00350
C                 AND THE FFT                                           BPS00360
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         BPS00370
C     TIME=       TIME VARIABLE                                         BPS00380
C     MT=         VALUE OF THE BINARY DIGIT                             BPS00390
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            BPS00400
C     PI=         NUMERICAL CONSTANT                                    BPS00410
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             BPS00420
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       BPS00430
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED              BPS00440
C     BAUDD=      BAUD DURATION                                         BPS00450
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   BPS00460
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC          BPS00470
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           BPS00480
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           BPS00490
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE               BPS00500
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                       BPS00510
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM       BPS00520
C                 SUBPROGRAM STATS                                      BPS00530
C     IND2P1=     ARRAY LENGTH DIVIDED BY 2 PLUS 1                      BPS00540
C                                                                       BPS00550
C     *** VARIABLE DECLARATIONS ***                                     BPS00560
C                                                                       BPS00570
      INTEGER R,ANS2,TYPE2,IN,RMAX,REP,FLAG,IND2P1                      BPS00580
C                                                                       BPS00590
      DOUBLE PRECISION BAUD,FREQ,IPHAS,AMP,TIME,MT,                     BPS00600
```

```
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                  BPS00610
     *DSEED,MAXY,MINY,INT                                               BPS00620
C                                                                       BPS00630
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  BPS00640
     *SUMX4(513)                                                        BPS00650
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              BPS00660
C                                                                       BPS00670
      COMPLEX*16 X(513)                                                 BPS00680
C                                                                       BPS00690
      INTEGER IWK(10)                                                   BPS00700
C                                                                       BPS00710
C     *** VARIABLE INITIALIZATION ***                                   BPS00720
C                                                                       BPS00730
      R=1                                                               BPS00740
      TIME=0.D0                                                         BPS00750
      STEP=1.D0/(2.D0*(FREQ+BAUD))                                      BPS00760
      PI=3.141592653589793D0                                            BPS00770
      OMEGA=2.D0*PI*FREQ                                                BPS00780
      DELTA=IPHAS*PI/180.D0                                             BPS00790
      NBAUD=1.D0                                                        BPS00800
      BAUDD=1.D0/BAUD                                                   BPS00810
      MAXY=0.D0                                                         BPS00820
      IND2P1=IN/2+1                                                     BPS00830
C                                                                       BPS00840
C     *** DO THE MODULATION AND ASSIGN THE VALUES TO ARRAY ***          BPS00850
C                                                                       BPS00860
      CALL STREAM(DSEED,ANS2,TYPE2,MT)                                  BPS00870
C                                                                       BPS00880
      DO 10 I=1,IN                                                      BPS00890
         ARRAY(R,1)=AMP*MT*DCOS((OMEGA*TIME)+DELTA)                     BPS00900
         ARRAY(R,2)=TIME                                                BPS00910
         IF(DABS(ARRAY(R,1)).GT.MAXY)THEN                               BPS00920
            MAXY=DABS(ARRAY(R,1))                                       BPS00930
         END IF                                                         BPS00940
         R=R+1                                                          BPS00950
         TIME=TIME+STEP                                                 BPS00960
         IF(TIME.GT.NBAUD*BAUDD)THEN                                    BPS00970
            CALL STREAM(DSEED,ANS2,TYPE2,MT)                            BPS00980
            NBAUD=NBAUD+1.D0                                            BPS00990
         END IF                                                         BPS01000
10    CONTINUE                                                          BPS01010
C                                                                       BPS01020
C     *** PLOT THE TIME SERIES IF DESIRED ***                           BPS01030
C                                                                       BPS01040
      IF(REP.EQ.1)THEN                                                  BPS01050
         MINY=-MAXY                                                     BPS01060
C                                                                       BPS01070
         CALL PLOT(MAXY,MINY,STEP,IN)                                   BPS01080
      END IF                                                            BPS01090
C                                                                       BPS01100
```

```
C     *** GENERATE THE FFT ***                                          BPS01110
C                                                                       BPS01120
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   BPS01130
C                                                                       BPS01140
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          BPS01150
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       BPS01160
C                                                                       BPS01170
      N=0.D0                                                            BPS01180
      R=1                                                               BPS01190
      MAXY=0.D0                                                         BPS01200
      DO 20 I=1,IND2P1                                                  BPS01210
         ARRAY(R,1)=CDABS(X(R))                                         BPS01220
         ARRAY(R,2)=N/STEP                                              BPS01230
         IF(ARRAY(R,1).GT.MAXY) THEN                                    BPS01240
            MAXY=ARRAY(R,1)                                             BPS01250
            RMAX=R-1                                                    BPS01260
         END IF                                                         BPS01270
         R=R+1                                                          BPS01280
         N=N+1.D0                                                       BPS01290
20    CONTINUE                                                          BPS01300
C                                                                       BPS01310
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH SUBPROGRAM *** .       BPS01320
C                                                                       BPS01330
      IF(REP.EQ.1) THEN                                                 BPS01340
C                                                                       BPS01350
29    WRITE(10,30)RMAX                                                  BPS01360
30    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,  BPS01370
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,   BPS01380
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,   BPS01390
     *' CONTINUE WITH THE PROGRAM.',//,' :')                            BPS01400
C                                                                       BPS01410
      READ(5,*)L                                                        BPS01420
C                                                                       BPS01430
      IF(L.NE.1)THEN                                                    BPS01440
C        CALL FRTCMS('CLRSCRN ')                                        BPS01450
         WRITE(10,40)                                                   BPS01460
40       FORMAT(' ERROR',/)                                             BPS01470
         GO TO 29                                                       BPS01480
      END IF                                                            BPS01490
C                                                                       BPS01500
      END IF                                                            BPS01510
C                                                                       BPS01520
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***   BPS01530
C                                                                       BPS01540
      IF(REP.EQ.1)THEN                                                  BPS01550
         MINY=0.D0                                                      BPS01560
         INT=1.D0/STEP                                                  BPS01570
C                                                                       BPS01580
         CALL PLOT(MAXY,MINY,INT,IND2P1)                                BPS01590
      END IF                                                            BPS01600
```

```
C                                                                              BPS01610
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***          BPS01620
C                                                                              BPS01630
      FLAG=0                                                                   BPS01640
      CALL STATS(IN,REP,FLAG)                                                  BPS01650
C                                                                              BPS01660
      RETURN                                                                   BPS01670
      END                                                                      BPS01680
```

```
      SUBROUTINE DBPSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,                  DBP00110
     *DSEED,IN,REP)                                                     DBP00120
C                                                                       DBP00130
C     *** PURPOSE ***                                                   DBP00140
C                                                                       DBP00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING DIFFERENTIAL BINARY   DBP00160
C     SHIFT KEYING AS THE MODULATION TECHNIQUE.                         DBP00170
C                                                                       DBP00180
C     *** PARAMETER DEFINITIONS ***                                     DBP00190
C                                                                       DBP00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   DBP00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              DBP00220
C     FREQ=       CARRIER FREQUENCY                                     DBP00230
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        DBP00240
C     AMP=        AMPLITUDE                                             DBP00250
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               DBP00260
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     DBP00270
C     IN=         NUMBER OF POSITIONS OF ARRAY TO BE UTILIZED           DBP00280
C                 THE CALL THE THIS SUBROUTINE                          DBP00290
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM       DBP00300
C                                                                       DBP00310
C     *** VARIABLE DEFINITIONS ***                                      DBP00320
C                                                                       DBP00330
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       DBP00340
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     DBP00350
C                 AND THE FFT                                           DBP00360
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         DBP00370
C     TIME=       TIME VARIABLE                                         DBP00380
C     MT=         VALUE OF THE BINARY DIGIT                             DBP00390
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            DBP00400
C     PI=         NUMERICAL CONSTANT                                    DBP00410
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             DBP00420
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       DBP00430
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED              DBP00440
C     BAUDD=      BAUD DURATION                                         DBP00450
C     REF=        REFERENCE VOLTAGE                                     DBP00460
C     BK=         VALUE OF DIFFERENTIAL BIT TO BE MODULATED             DBP00470
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   DBP00480
C     IWK=        INTEGER ARRAY USED IN SUBROUTINE FFTRC                DBP00490
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           DBP00500
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           DBP00510
C     RMAX=       PRINCIPLE HARMONIC                                    DBP00520
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF   DBP00530
C                 SUBPROGRAM STATS                                      DBP00540
C     IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1                      DBP00550
C                                                                       DBP00560
C     *** VARIABLE DECLARATIONS ***                                     DBP00570
C                                                                       DBP00580
      INTEGER R,ANS2,TYPE2,IN,RMAX,REP,FLAG,IND2P1                      DBP00590
C                                                                       DBP00600
```

```
      DOUBLE PRECISION BAUD,FREQ,IPHAS,AMP,TIME,MT,                     DBP00610
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                  DBP00620
     *DSEED,REF,BK,MAXY,MINY,INT                                        DBP00630
C                                                                       DBP00640
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  DBP00650
     *SUMX4(513)                                                        DBP00660
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              DBP00670
C                                                                       DBP00680
      COMPLEX*16 X(513)                                                 DBP00690
C                                                                       DBP00700
      INTEGER IWK(10)                                                   DBP00710
C                                                                       DBP00720
C     *** VARIABLE INITIALIZATION ***                                   DBP00730
C                                                                       DBP00740
      R=1                                                               DBP00750
      TIME=0.D0                                                         DBP00760
      STEP=1.D0/(2.D0*(FREQ+BAUD))                                      DBP00770
      PI=3.141592653589793D0                                            DBP00780
      OMEGA=2.D0*PI*FREQ                                                DBP00790
      DELTA=IPHAS*PI/180.D0                                             DBP00800
      NBAUD=1.D0                                                        DBP00810
      BAUDD=1.D0/BAUD                                                   DBP00820
      REF=1.D0                                                          DBP00830
      MAXY=0.D0                                                         DBP00840
      IND2P1=IN/2+1                                                     DBP00850
C                                                                       DBP00860
C     *** DO THE MODULATION AND ASSIGN THE VALUES TO ARRAY ***          DBP00870
C                                                                       DBP00880
      CALL STREAM(DSEED,ANS2,TYPE2,MT)                                  DBP00890
C                                                                       DBP00900
      BK=REF*MT                                                         DBP00910
C                                                                       DBP00920
      DO 10 I=1,IN                                                      DBP00930
         ARRAY(R,1)=AMP*BK*DCOS((OMEGA*TIME)+DELTA)                     DBP00940
         ARRAY(R,2)=TIME                                                DBP00950
         IF(ARRAY(R,1).GT.MAXY) THEN                                    DBP00960
            MAXY=ARRAY(R,1)                                             DBP00970
         END IF                                                         DBP00980
         R=R+1                                                          DBP00990
         TIME=TIME+STEP                                                 DBP01000
         IF(TIME.GT.NBAUD*BAUDD) THEN                                   DBP01010
            CALL STREAM(DSEED,ANS2,TYPE2,MT)                            DBP01020
            BK=BK*MT                                                    DBP01030
            NBAUD=NBAUD+1.D0                                            DBP01040
         END IF                                                         DBP01050
10    CONTINUE                                                          DBP01060
C                                                                       DBP01070
C     *** ALLOW FOR THE PLOT OF THE TIME SERIES ***                     DBP01080
C                                                                       DBP01090
      IF(REP.EQ.1) THEN                                                 DBP01100
```

```
            MINY=-MAXY                                                  DBP01110
C                                                                       DBP01120
            CALL PLOT(MAXY,MINY,STEP,IN)                                DBP01130
         END IF                                                         DBP01140
C                                                                       DBP01150
C        *** GENERATE THE FFT ***                                       DBP01160
C                                                                       DBP01170
         CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                DBP01180
C                                                                       DBP01190
C        *** PRODUCE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***         DBP01200
C        *** FIND THE NUMBER AND MAGNITUDE OF THE PRINCIPLE HARMONIC ***DBP01210
C                                                                       DBP01220
         N=0.D0                                                         DBP01230
         R=1                                                            DBP01240
         MAXY=0.D0                                                      DBP01250
         DO 20 I=1,IND2P1                                               DBP01260
            ARRAY(R,1)=CDABS(X(R))                                      DBP01270
            ARRAY(R,2)=N/STEP                                           DBP01280
            IF(ARRAY(R,1).GT.MAXY) THEN                                 DBP01290
               MAXY=ARRAY(R,1)                                          DBP01300
               RMAX=R-1                                                 DBP01310
            END IF                                                      DBP01320
            R=R+1                                                       DBP01330
            N=N+1.D0                                                    DBP01340
20       CONTINUE                                                       DBP01350
C                                                                       DBP01360
C        *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***  DBP01370
C                                                                       DBP01380
         IF(REP.EQ.1) THEN                                              DBP01390
C                                                                       DBP01400
29       WRITE(10,30)RMAX                                               DBP01410
30       FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,DBP01420
        *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,DBP01430
        *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,DBP01440
        *' CONTINUE WITH THE PROGRAM.',//,' :')                         DBP01450
C                                                                       DBP01460
         READ(5,*)L                                                     DBP01470
C                                                                       DBP01480
         IF(L.NE.1)THEN                                                 DBP01490
C           CALL FRTCMS('CLRSCRN ')                                     DBP01500
            WRITE(10,40)                                                DBP01510
40          FORMAT(' ERROR',/)                                          DBP01520
            GO TO 29                                                    DBP01530
         END IF                                                         DBP01540
C                                                                       DBP01550
         END IF                                                         DBP01560
C                                                                       DBP01570
C        *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM ***           DBP01580
C                                                                       DBP01590
         IF(REP.EQ.1)THEN                                               DBP01600
```

```
          MINY=0.D0                                                     DBP01610
          INT=1.D0/STEP                                                 DBP01620
C                                                                       DBP01630
          CALL PLOT(MAXY,MINY,INT,IND2P1)                               DBP01640
      END IF                                                            DBP01650
C                                                                       DBP01660
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***   DBP01670
C                                                                       DBP01680
      FLAG=0                                                            DBP01690
      CALL STATS(IN,REP,FLAG)                                           DBP01700
C                                                                       DBP01710
      RETURN                                                            DBP01720
      END                                                               DBP01730
```

```
      SUBROUTINE OBPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,             OBP00110
     *DSEED,IN,REP)                                                     OBP00120
C                                                                       OBP00130
C     *** PURPOSE ***                                                   OBP00140
C                                                                       OBP00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING M-ARY PHASE SHIFT     OBP00160
C     KEYING AS THE MODULATION TECHNIQUE.                               OBP00170
C                                                                       OBP00180
C     *** PARAMETER DEFINITIONS ***                                     OBP00190
C                                                                       OBP00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   OBP00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              OBP00220
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD               OBP00230
C     FREQ=       CARRIER FREQUENCY                                     OBP00240
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        OBP00250
C     AMP=        AMPLITUDE                                             OBP00260
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               OBP00270
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     OBP00280
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED           OBP00290
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF   OBP00300
C                 THE CALL THE THIS SUBROUTINE                          OBP00310
C                                                                       OBP00320
C     *** VARIABLE DEFINITIONS ***                                      OBP00330
C                                                                       OBP00340
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       OBP00350
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     OBP00360
C                 AND THE FFT                                           OBP00370
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         OBP00380
C     TIME=       TIME VARIABLE                                         OBP00390
C     MT=         VALUE OF THE BINARY DIGIT                             OBP00400
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            OBP00410
C     PI=         NUMERICAL CONSTANT                                    OBP00420
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             OBP00430
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       OBP00440
C     NBIT=       A COUNT OF THE NUMBER OF BITS MODULATED               OBP00450
C     BITR=       BIT RATE                                              OBP00460
C     BITD=       BIT DURATION                                          OBP00470
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   OBP00480
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC          OBP00490
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           OBP00500
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           OBP00510
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE               OBP00520
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                       OBP00530
C     K=          INTEGER VALUE OF THE NUMBER OF BITS IN A BINARY WORD  OBP00540
C     KM1=        INTEGER VALUE OF K MINUS 1                            OBP00550
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K           OBP00560
C     NDP=        DOUBLE PRECISION OF N                                 OBP00570
C     ND2=        NDP DIVIDED BY 2                                      OBP00580
C     SUM1=       VARIABLE USED TO HOLD THE DECIMAL EQUIVALENT TO A     OBP00590
C                 BINARY CODE WORD OF LENGTH K                          OBP00600
```

```
C     SUM2=          VARIABLE USED TO HOLD THE DECIMAL CONVERSION OF SUM1  OBP00610
C     FLAG=          AN INTEGER WHICH CCNTROL ENTRANCE AND EXIT FROM       OBP00620
C                    SUBPROGRAM STATS AND ORTHO                            OBP00630
C     IND2P1=        LENGTH OF ARRAY DIVIDED BY 2 + 1                      OBP00640
C                                                                          OBP00650
C     *** VARIABLE DECLARATIONS ***                                        OBP00660
C                                                                          OBP00670
      INTEGER R,ANS2,TYPE2,IN,RMAX,K,KM1,REP,FLAG,IND2P1,N,C               OBP00680
C                                                                          OBP00690
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT,                   OBP00700
     *STEP,PI,OMEGA,DELTA,NBIT,BITD,BITR,                                  OBP00710
     *DSEED,MAXY,MINY,INT,NDP,ND2,SUM1,SUM2                                OBP00720
C                                                                          OBP00730
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),     OBP00740
     *SUMX4(513)                                                           OBP00750
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                                 OBP00760
C                                                                          OBP00770
      COMPLEX*16 X(513)                                                    OBP00780
C                                                                          OBP00790
      INTEGER IWK(10)                                                      OBP00800
C                                                                          OBP00810
C     *** VARIABLE INITIALIZATION ***                                      OBP00820
C                                                                          OBP00830
      R=1                                                                  OBP00840
      K=BITS                                                               OBP00850
      N=2**K                                                               OBP00860
      NDP=N                                                                OBP00870
      NBIT=1.D0                                                            OBP00880
      BITR=N*BAUD                                                          OBP00890
      BITD=1.D0/BITR                                                       OBP00900
      TIME=0.D0                                                            OBP00910
      STEP=1.D0/(2.D0*(FREQ+BITR))                                         OBP00920
      PI=3.141592653589793D0                                               OBP00930
      OMEGA=2.D0*PI*FREQ                                                   OBP00940
      DELTA=IPHAS*PI/180.D0                                                OBP00950
      MAXY=0.D0                                                            OBP00960
      IND2P1=IN/2+1                                                        OBP00970
C                                                                          OBP00980
C     *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY     OBP00990
C     VARIABLE IN DECIMAL FORM ***                                         OBP01000
C                                                                          OBP01010
      SUM1=0.D0                                                            OBP01020
      KM1=K-1                                                              OBP01030
      DO 10 I=1,K                                                          OBP01040
         CALL STREAM(DSEED,ANS2,TYPE2,MT)                                  OBP01050
         IF(TYPE2.EQ.1.AND.MT.EQ.-1.D0)THEN                                OBP01060
            MT=0.D0                                                        OBP01070
         ELSE IF (TYPE2.EQ.3.AND.MT.EQ.-1.D0)THEN                          OBP01080
            MT=1.D0                                                        OBP01090
         END IF                                                            OBP01100
```

```
          SUM1=SUM1+(MT*(10.D0**KM1))                                   OBP01110
          KM1=KM1-1                                                     OBP01120
10    CONTINUE                                                          OBP01130
C                                                                       OBP01140
C     *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL     OBP01150
C     EQUIVALENT ***                                                    OBP01160
C                                                                       OBP01170
      SUM2=0.D0                                                         OBP01180
      KM1=K-1                                                           OBP01190
      ND2=NDP/2.D0                                                      OBP01200
      DO 20 I=1,K                                                       OBP01210
          IF(SUM1/10.D0**KM1.GE.1.D0) THEN                              OBP01220
              SUM2=SUM2+ND2                                             OBP01230
              SUM1=SUM1-10.D0**KM1                                      OBP01240
              ND2=ND2/2.D0                                              OBP01250
              KM1=KM1-1                                                 OBP01260
          ELSE                                                          OBP01270
              ND2=ND2/2.D0                                              OBP01280
              KM1=KM1-1                                                 OBP01290
          END IF                                                        OBP01300
20    CONTINUE                                                          OBP01310
C                                                                       OBP01320
C     *** DO THE MODULATION AND ASSIGN TO ARRAY ***                     OBP01330
C                                                                       OBP01340
      C=1                                                               OBP01350
      FLAG=0                                                            OBP01360
      CALL CRTHO(K,MT,SUM2,C,FLAG)                                      OBP01370
      FLAG=2                                                            OBP01380
      DO 30 I=1,IN                                                      OBP01390
          ARRAY(R,1)=AMP*MT*DCOS((OMEGA*TIME)+DELTA)                    OBP01400
          ARRAY(R,2)=TIME                                               OBP01410
          IF(ARRAY(R,1).GT.MAXY) THEN                                   OBP01420
              MAXY=ARRAY(R,1)                                           OBP01430
          END IF                                                        OBP01440
          R=R+1                                                         OBP01450
          TIME=TIME+STEP                                                OBP01460
          IF(TIME.GT.NBIT*BITD) THEN                                    OBP01470
              NBIT=NBIT+1.D0                                            OBP01480
              IF(C.GT.N) THEN                                           OBP01490
C                                                                       OBP01500
C     *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY  OBP01510
C     VARIABLE IN DECIMAL FORM ***                                      OBP01520
C                                                                       OBP01530
                SUM1=0.D0                                               OBP01540
                KM1=K-1                                                 OBP01550
                DO 40 J=1,K                                             OBP01560
                   CALL STREAM(DSEED,ANS2,TYPE2,MT)                     OBP01570
                   IF (TYPE2.EQ.1.AND.MT.EQ.-1.D0) THEN                 OBP01580
                      MT=0.D0                                           OBP01590
                   ELSE IF(TYPE2.EQ.3.AND.MT.EQ.-1.D0)THEN              OBP01600
```

```
                          MT=1.D0                                       OBP01610
                      END IF                                            OBP01620
                      SUM1=SUM1+(MT*(10.D0**KM1))                       OBP01630
                      KM1=KM1-1                                         OBP01640
40                CONTINUE                                              OBP01650
C                                                                       OBP01660
C     *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL     OBP01670
C     EQUIVALENT ***                                                    OBP01680
C                                                                       OBP01690
                  SUM2=0.D0                                             OBP01700
                  KM1=K-1                                               OBP01710
                  ND2=NDP/2.D0                                          OBP01720
                  DO 50 J=1,K                                           OBP01730
                      IF(SUM1/10.D0**KM1.GE.1.D0) THEN                  OBP01740
                          SUM2=SUM2+ND2                                 OBP01750
                          SUM1=SUM1-10.D0**KM1                          OBP01760
                          ND2=ND2/2.D0                                  OBP01770
                          KM1=KM1-1                                     OBP01780
                      ELSE                                              OBP01790
                          ND2=ND2/2.D0                                  OBP01800
                          KM1=KM1-1                                     OBP01810
                      END IF                                            OBP01820
50                CONTINUE                                              OBP01830
                  C=1                                                   OBP01840
                  FLAG=1                                                OBP01850
              END IF                                                    OBP01860
              CALL ORTHO(K,MT,SUM2,C,FLAG)                              OBP01870
              FLAG=2                                                    OBP01880
          END IF                                                        OBP01890
30    CONTINUE                                                          OBP01900
C                                                                       OBP01910
C     *** PLOT THE TIME SERIES IF DESIRED ***                           OBP01920
C                                                                       OBP01930
      IF(REP.EQ.1)THEN                                                  OBP01940
          MINY=-MAXY                                                    OBP01950
C                                                                       OBP01960
          CALL PLOT(MAXY,MINY,STEP,IN)                                  OBP01970
      END IF                                                            OBP01980
C                                                                       OBP01990
C     *** GENERATE THE FFT ***                                          OBP02000
C                                                                       OBP02010
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   OBP02020
C                                                                       OBP02030
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          OBP02040
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       OBP02050
C                                                                       OBP02060
      N=0.D0                                                            OBP02070
      R=1                                                               OBP02080
      MAXY=0.D0                                                         OBP02090
      DO 60 I=1,IND2P1                                                  OBP02100
```

```
            ARRAY(R,1)=CDABS(X(R))                                                    OBP02110
            ARRAY(R,2)=N/STEP                                                         OBP02120
            IF(ARRAY(R,1).GT.MAXY)THEN                                                OBP02130
                MAXY=ARRAY(R,1)                                                       OBP02140
                RMAX=R-1                                                              OBP02150
            END IF                                                                    OBP02160
            R=R+1                                                                     OBP02170
            N=N+1.D0                                                                  OBP02180
60      CONTINUE                                                                      OBP02190
C                                                                                     OBP02200
C       *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***                 OBP02210
C                                                                                     OBP02220
        IF(REP.EQ.1)THEN                                                              OBP02230
C                                                                                     OBP02240
69      WRITE(10,70)RMAX                                                              OBP02250
70      FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,              OBP02260
       *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,               OBP02270
       *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,               OBP02280
       *' CONTINUE WITH THE PROGRAM.',//,' :')                                        OBP02290
C                                                                                     OBP02300
        READ(5,*)L                                                                    OBP02310
C                                                                                     OBP02320
        IF(L.NE.1)THEN                                                                OBP02330
C           CALL FRTCMS('CLRSCRN ')                                                   OBP02340
            WRITE(10,80)                                                              OBP02350
80          FORMAT(' ERROR',/)                                                        OBP02360
            GO TO 69                                                                  OBP02370
        END IF                                                                        OBP02380
C                                                                                     OBP02390
        END IF                                                                        OBP02400
C                                                                                     OBP02410
C       *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***               OBP02420
C                                                                                     OBP02430
        IF(REP.EQ.1)THEN                                                              OBP02440
            MINY=0.D0                                                                 OBP02450
            INT=1.D0/STEP                                                             OBP02460
C                                                                                     OBP02470
            CALL PLOT(MAXY,MINY,INT,IND2P1)                                           OBP02480
        END IF                                                                        OBP02490
C                                                                                     OBP02500
C       *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***               OBP02510
C                                                                                     OBP02520
        FLAG=0                                                                        OBP02530
        CALL STATS(IN,REP,FLAG)                                                       OBP02540
C                                                                                     OBP02550
        RETURN                                                                        OBP02560
        END                                                                           OBP02570
```

```
      SUBROUTINE QPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,                   QPS00110
     *ANS2,DSEED,IN,REP)                                                QPS00120
C                                                                       QPS00130
C     *** PURPOSE ***                                                   QPS00140
C                                                                       QPS00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING QUADRATURE PHASE SHIFTQPS00160
C     KEYING AS THE MODULATION TECHNIQUE.                               QPS00170
C                                                                       QPS00180
C     *** PARAMETER DEFINITIONS ***                                     QPS00190
C                                                                       QPS00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   QPS00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              QPS00220
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD               QPS00230
C     FREQ=       CARRIER FREQUENCY                                     QPS00240
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        QPS00250
C     AMP=        AMPLITUDE                                             QPS00260
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               QPS00270
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     QPS00280
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED           QPS00290
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF   QPS00300
C                 THE CALL THE THIS SUBROUTINE                          QPS00310
C                                                                       QPS00320
C     *** VARIABLE DEFINITIONS ***                                      QPS00330
C                                                                       QPS00340
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       QPS00350
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     QPS00360
C                 AND THE FFT                                           QPS00370
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         QPS00380
C     TIME=       TIME VARIABLE                                         QPS00390
C     MT=         VALUE OF BINARY DIGIT PASSED FROM SUBPROGRAM STREAM   QPS00400
C     MT1=        VALUE OF IN-PHASE BINARY DIGIT                        QPS00410
C     MT2=        VALUE OF QUADRATURE BINARY DIGIT                      QPS00420
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            QPS00430
C     PI=         NUMERICAL CONSTANT                                    QPS00440
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             QPS00450
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       QPS00460
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED              QPS00470
C     BAUDD=      BAUD DURATION                                         QPS00480
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   QPS00490
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC          QPS00500
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           QPS00510
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           QPS00520
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE               QPS00530
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                       QPS00540
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM       QPS00550
C                 SUBPROGRAM STATS                                      QPS00560
C     IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1                      QPS00570
C                                                                       QPS00580
C     *** VARIABLE DECLARATIONS ***                                     QPS00590
C                                                                       QPS00600
```

```
      INTEGER R,ANS2,TYPE2,IN,RMAX,REP,FLAG,IND2P1
C
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT1,MT2,
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,
     *DSEED,MAXY,MINY,INT,MT
C
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),
     *SUMX4(513)
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4
C
      COMPLEX*16 X(513)
C
      INTEGER IWK(10)
C
C     *** VARIABLE INITIALIZATION ***
C
      R=1
      TIME=0.D0
      STEP=1.D0/(2.D0*(FREQ+BAUD))
      PI=3.141592653589793D0
      OMEGA=2.D0*PI*FREQ
      DELTA=IPHAS*PI/180.D0
      NBAUD=1.D0
      BAUDD=1.D0/BAUD
      MAXY=0.D0
      IND2P1=IN/2+1
C
C     *** DO THE MCDULATION AND ASSIGN THE VALUES TO ARRAY***
C
      CALL STREAM(DSEED,ANS2,TYPE2,MT)
      MT1=MT
C
      CALL STREAM(DSEED,ANS2,TYPE2,MT)
      MT2=MT
C
      DO 10 I=1,IN
         ARRAY(R,1)=AMP*MT1*DCOS((OMEGA*TIME)+DELTA)+
     *              AMP*MT2*DSIN((OMEGA*TIME)+DELTA)
         ARRAY(R,2)=TIME
         IF(ARRAY(R,1).GT.MAXY) THEN
            MAXY=ARRAY(R,1)
         END IF
         R=R+1
         TIME=TIME+STEP
         IF(TIME.GT.NBAUD*BAUDD) THEN
            CALL STREAM(DSEED,ANS2,TYPE2,MT)
            MT1=MT
            CALL STREAM(DSEED,ANS2,TYPE2,MT)
            MT2=MT
            NBAUD=NBAUD+1.D0
```

```
          END IF                                                         QPS01110
10    CONTINUE                                                           QPS01120
C                                                                        QPS01130
C     *** PLOT THE TIME SERIES IF DESIRED ***                            QPS01140
C                                                                        QPS01150
      IF(REP.EQ.1)THEN                                                   QPS01160
          MINY=-MAXY                                                     QPS01170
C                                                                        QPS01180
          CALL PLOT(MAXY,MINY,STEP,IN)                                   QPS01190
      END IF                                                             QPS01200
C                                                                        QPS01210
C     *** GENERATE THE FFT ***                                           QPS01220
C                                                                        QPS01230
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                    QPS01240
C                                                                        QPS01250
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***           QPS01260
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***        QPS01270
C                                                                        QPS01280
      N=0.D0                                                             QPS01290
      R=1                                                                QPS01300
      MAXY=0.D0                                                          QPS01310
      DO 20 I=1,IND2P1                                                   QPS01320
          ARRAY(R,1)=CDABS(X(R))                                         QPS01330
          ARRAY(R,2)=N/STEP                                              QPS01340
          IF(ARRAY(R,1).GT.MAXY) THEN                                    QPS01350
              MAXY=ARRAY(R,1)                                            QPS01360
              RMAX=R-1                                                   QPS01370
          END IF                                                         QPS01380
          R=R+1                                                          QPS01390
          N=N+1.D0                                                       QPS01400
20    CONTINUE                                                           QPS01410
C                                                                        QPS01420
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***      QPS01430
C                                                                        QPS01440
      IF(REP.EQ.1)THEN                                                   QPS01450
C                                                                        QPS01460
29    WRITE(10,30)RMAX                                                   QPS01470
30    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,   QPS01480
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,    QPS01490
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,    QPS01500
     *' CONTINUE WITH THE PROGRAM.',//,' :')                             QPS01510
C                                                                        QPS01520
      READ(5,*)L                                                         QPS01530
C                                                                        QPS01540
      IF(L.NE.1)THEN                                                     QPS01550
C         CALL FRTCMS('CLRSCRN ')                                        QPS01560
          WRITE(10,40)                                                   QPS01570
40        FORMAT(' ERROR',/)                                             QPS01580
          GO TO 29                                                       QPS01590
      END IF                                                             QPS01600
```

```
C
      END IF
C
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***
C
      IF(REP.EQ.1)THEN
          MINY=0.D0
          INT=1.D0/STEP
C
          CALL PLOT(MAXY,MINY,INT,IND2P1)
      END IF
C
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***
C
      FLAG=0
      CALL STATS(IN,REP,FLAG)
C
      RETURN
      END
```

```
      SUBROUTINE OQPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,                  OQP00110
     *ANS2,DSEED,IN,REP)                                                OQP00120
C                                                                       OQP00130
C     *** PURPOSE ***                                                   OQP00140
C                                                                       OQP00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING OFFSET QUADRATURE     OQP00160
C     PHASE SHIFT KEYING AS THE MODULATION TECHNIQUE.                   OQP00170
C                                                                       OQP00180
C     *** PARAMETER DEFINITIONS ***                                     OQP00190
C                                                                       OQP00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   OQP00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              OQP00220
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD               OQP00230
C     FREQ=       CARRIER FREQUENCY                                     OQP00240
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        OQP00250
C     AMP=        AMPLITUDE                                             OQP00260
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               OQP00270
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     OQP00280
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED           OQP00290
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF   OQP00300
C                 THE CALL THE THIS SUBROUTINE                          OQP00310
C                                                                       OQP00320
C     *** VARIABLE DEFINITIONS ***                                      OQP00330
C                                                                       OQP00340
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       OQP00350
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     OQP00360
C                 AND THE FFT                                           OQP00370
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         OQP00380
C     TIME=       TIME VARIABLE                                         OQP00390
C     MT=         VALUE OF BINARY DIGIT PASSED FROM SUBPROGRAM STREAM   OQP00400
C     MT1=        VALUE OF IN-PHASE BINARY DIGIT                        OQP00410
C     MT2=        VALUE OF QUADRATURE BINARY DIGIT                      OQP00420
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            OQP00430
C     PI=         NUMERICAL CONSTANT                                    OQP00440
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             OQP00450
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       OQP00460
C     NBAUD1=     A COUNT OF THE NUMBER OF BAUDS MODULATED IN-PHASE     OQP00470
C     NBAUD2=     A COUNT OF THE NUMBER OF BAUDS MODULATED QUADRATURE   OQP00480
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   OQP00490
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC          OQP00500
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           OQP00510
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           OQP00520
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE               OQP00530
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                       OQP00540
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM       OQP00550
C                 SUBPROGRAM STATS                                      OQP00560
C     IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1                      OQP00570
C                                                                       OQP00580
C     *** VARIABLE DECLARATIONS ***                                     OQP00590
C                                                                       OQP00600
```

```
      INTEGER R,ANS2,TYPE2,IN,RMAX,REP,FLAG,IND2P1
C
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT1,MT2,
     *STEP,PI,OMEGA,DELTA,BAUDD,NBAUD1,NBAUD2,
     *DSEED,MAXY,MINY,INT,MT
C
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),
     *SUMX4(513)
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4
C
      COMPLEX*16 X(513)
C
      INTEGER IWK(10)
C
C     *** VARIABLE INITIALIZATION ***
C
      R=1
      STEP=1.D0/(2.D0*(FREQ+BAUD))
      PI=3.141592653589793D0
      OMEGA=2.D0*PI*FREQ
      DELTA=IPHAS*PI/180.D0
      NBAUD1=1.D0
      NBAUD2=1.D0
      BAUDD=1.D0/BAUD
      TIME=.5D0*BAUDD
      MAXY=0.D0
      IND2P1=IN/2+1
C
C     *** DO THE MODULATION AND ASSIGN THE VALUES TO ARRAY ***
C
      CALL STREAM(DSEED,ANS2,TYPE2,MT)
      MT1=MT
C
      CALL STREAM(DSEED,ANS2,TYPE2,MT)
      MT2=MT
C
      DO 10 I=1,IN
         ARRAY(R,1)=AMP*MT1*DCOS((OMEGA*TIME)+DELTA)+
     *              AMP*MT2*DSIN((OMEGA*TIME)+DELTA)
         ARRAY(R,2)=TIME
         IF(ARRAY(R,1).GT.MAXY) THEN
            MAXY=ARRAY(R,1)
         END IF
         R=R+1
         TIME=TIME+STEP
         IF(TIME.GT.NBAUD1*BAUDD) THEN
            CALL STREAM(DSEED,ANS2,TYPE2,MT)
            MT1=MT
            NBAUD1=NBAUD1+1.D0
         END IF
```

```
C                                                                       0QP01110
          IF(TIME.GT.((NBAUD2*BAUDD)+(BAUDD/2.D0)))THEN                 0QP01120
              CALL STREAM(DSEED,ANS2,TYPE2,MT)                          0QP01130
              MT2=MT                                                    0QP01140
              NBAUD2=NBAUD2+1.D0                                        0QP01150
          END IF                                                        0QP01160
10    CONTINUE                                                          0QP01170
C                                                                       0QP01180
C     *** PLOT THE TIME SERIES IF DESIRED ***                           0QP01190
C                                                                       0QP01200
      IF(REP.EQ.1)THEN                                                  0QP01210
          MINY=-MAXY                                                    0QP01220
C                                                                       0QP01230
          CALL PLOT(MAXY,MINY,STEP,IN)                                  0QP01240
      END IF                                                            0QP01250
C                                                                       0QP01260
C     *** GENERATE THE FFT ***                                          0QP01270
C                                                                       0QP01280
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   0QP01290
C                                                                       0QP01300
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          0QP01310
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       0QP01320
C                                                                       0QP01330
      N=0.D0                                                            0QP01340
      R=1                                                               0QP01350
      MAXY=0.D0                                                         0QP01360
      DO 20 I=1,IND2P1                                                  0QP01370
          ARRAY(R,1)=CDABS(X(R))                                        0QP01380
          ARRAY(R,2)=N/STEP                                             0QP01390
          IF(ARRAY(R,1).GT.MAXY)THEN                                    0QP01400
              MAXY=ARRAY(R,1)                                           0QP01410
              RMAX=R-1                                                  0QP01420
          END IF                                                        0QP01430
          R=R+1                                                         0QP01440
          N=N+1.D0                                                      0QP01450
20    CONTINUE                                                          0QP01460
C                                                                       0QP01470
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***     0QP01480
C                                                                       0QP01490
      IF(REP.EQ.1)THEN                                                  0QP01500
C                                                                       0QP01510
29    WRITE(10,30)RMAX                                                  0QP01520
30    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,  0QP01530
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,   0QP01540
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,   0QP01550
     *' CONTINUE WITH THE PROGRAM.',//,' :')                            0QP01560
C                                                                       0QP01570
      READ(5,*)L                                                        0QP01580
C                                                                       0QP01590
      IF(L.NE.1)THEN                                                    0QP01600
```

```
C          CALL FRTCMS('CLRSCRN ')                                           OQP01610
           WRITE(10,40)                                                      OQP01620
40         FORMAT(' ERROR',/)                                                OQP01630
           GO TO 29                                                          OQP01640
      END IF                                                                 OQP01650
C                                                                            OQP01660
      END IF                                                                 OQP01670
C                                                                            OQP01680
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***        OQP01690
C                                                                            OQP01700
      IF(REP.EQ.1)THEN                                                       OQP01710
          MINY=0.D0                                                          OQP01720
          INT=1.D0/STEP                                                      OQP01730
C                                                                            OQP01740
          CALL PLOT(MAXY,MINY,INT,IND2P1)                                    OQP01750
      END IF                                                                 OQP01760
C                                                                            OQP01770
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***        OQP01780
C                                                                            OQP01790
      FLAG=0                                                                 OQP01800
      CALL STATS(IN,REP,FLAG)                                                OQP01810
C                                                                            OQP01820
      RETURN                                                                 OQP01830
      END                                                                    OQP01840
```

```
      SUBROUTINE MPSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,
     *DSEED,IN,REP)
C
C     *** PURPOSE ***
C
C     THIS SUBROUTINE MODULATES THE CARRIER USING M-ARY PHASE SHIFT
C     KEYING AS THE MODULATION TECHNIQUE.
C
C     *** PARAMETER DEFINITIONS ***
C
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED
C     BAUD=       SYMBOL RATE OR BAUD RATE
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD
C     FREQ=       CARRIER FREQUENCY
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES
C     AMP=        AMPLITUDE
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF
C                 THE CALL THE THIS SUBROUTINE
C
C     *** VARIABLE DEFINITIONS ***
C
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION
C                 AND THE FFT
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY
C     TIME=       TIME VARIABLE
C     MT=         VALUE OF THE BINARY DIGIT
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED
C     PI=         NUMERICAL CONSTANT
C     OMEGA=      CARRIER ANGULAR FREQUENCY
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED
C     BAUDD=      BAUD DURATION
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE
C     KMAX=       VALUE OF THE PRINCIPLE HARMONIC
C     K=          INTEGER VALUE OF THE NUMBER OF BITS IN A BINARY WORD
C     KM1=        INTEGER VALUE OF K MINUS 1
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K
C     ND2=        N DIVIDED BY 2
C     SUM1=       VARIABLE USED TO HOLD THE DECIMAL EQUIVALENT TO A
C                 BINARY CODE WORD OF LENGTH K
C     SUM2=       VARIABLE USED TO HOLD THE DECIMAL CONVERSION OF SUM1
C     J=          INTEGER USED TO INDEX A LOOP
```

```
C      FLAG=       AN INTEGER WHICH CCNTROL ENTRANCE AND EXIT FROM          MPS00610
C                  SUBPROGRAM STATS                                         MPS00620
C      IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1                         MPS00630
C                                                                           MPS00640
C      *** VARIABLE DECLARATIONS ***                                        MPS00650
C                                                                           MPS00660
       INTEGER R,ANS2,TYPE2,IN,RMAX,K,KM1,J,REP,FLAG,IND2P1                 MPS00670
C                                                                           MPS00680
       DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT,                   MPS00690
      *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                     MPS00700
      *DSEED,MAXY,MINY,INT,N,ND2,SUM1,SUM2                                  MPS00710
C                                                                           MPS00720
       DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),     MPS00730
      *SUMX4(513)                                                           MPS00740
       COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                                 MPS00750
C                                                                           MPS00760
       CCMPLEX*16 X(513)                                                    MPS00770
C                                                                           MPS00780
       INTEGER IWK(10)                                                      MPS00790
C                                                                           MPS00800
C      *** VARIABLE INITIALIZATION ***                                      MPS00810
C                                                                           MPS00820
       R=1                                                                  MPS00830
       TIME=0.D0                                                            MPS00840
       STEP=1.D0/(2.D0*(FREQ+BAUD))                                         MPS00850
       PI=3.14159265358979 3D0                                              MPS00860
       OMEGA=2.D0*PI*FREQ                                                   MPS00870
       DELTA=IPHAS*PI/180.D0                                                MPS00880
       NBAUD=1.D0                                                           MPS00890
       BAUDD=1.D0/BAUD                                                      MPS00900
       K=BITS                                                               MPS00910
       N=2.D0**K                                                            MPS00920
       MAXY=0.D0                                                            MPS00930
       IND2P1=IN/2+1                                                        MPS00940
C                                                                           MPS00950
9      IF(R.LE.IN) THEN                                                     MPS00960
C                                                                           MPS00970
C      *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY     MPS00980
C      VARIABLE IN DECIMAL FORM ***                                         MPS00990
C                                                                           MPS01000
          SUM1=0.D0                                                         MPS01010
          KM1=K-1                                                           MPS01020
          DO 10 I=1,K                                                       MPS01030
             CALL STREAM(DSEED,ANS2,TYPE2,MT)                               MPS01040
             IF(TYPE2.EQ.1.AND.MT.EQ.-1.D0) THEN                            MPS01050
                MT=0.D0                                                     MPS01060
             ELSE IF(TYPE2.EQ.3.AND.MT.EQ.-1.D0)THEN                        MPS01070
                MT=1.D0                                                     MPS01080
             END IF                                                         MPS01090
             SUM1=SUM1+(MT*(10.D0**KM1))                                    MPS01100
```

```
                  KM1=KM1-1                                                     MPS01110
10            CONTINUE                                                          MPS01120
C                                                                               MPS01130
C         *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL         MPS01140
C         EQUIVALENT ***                                                        MPS01150
C                                                                               MPS01160
              SUM2=0.D0                                                         MPS01170
              KM1=K-1                                                           MPS01180
              ND2=N/2.D0                                                        MPS01190
              DO 20 I=1,K                                                       MPS01200
                  IF(SUM1/10.D0**KM1.GE.1.D0)THEN                               MPS01210
                      SUM2=SUM2+ND2                                             MPS01220
                      SUM1=SUM1-10.D0**KM1                                      MPS01230
                      ND2=ND2/2.D0                                              MPS01240
                      KM1=KM1-1                                                 MPS01250
                  ELSE                                                          MPS01260
                      ND2=ND2/2.D0                                              MPS01270
                      KM1=KM1-1                                                 MPS01280
                  END IF                                                        MPS01290
20            CONTINUE                                                          MPS01300
C                                                                               MPS01310
C         *** DO THE MCDULATION AND ASSIGN TO ARRAY ***                         MPS01320
C                                                                               MPS01330
              J=R                                                               MPS01340
              DO 30 I=J,IN                                                      MPS01350
                  ARRAY(R,1)=AMP*DCOS((OMEGA*TIME)+                             MPS01360
     *                       ((SUM2*2.D0*PI)/N)+DELTA)                          MPS01370
                  ARRAY(R,2)=TIME                                               MPS01380
                  IF(ARRAY(R,1).GT.MAXY)THEN                                    MPS01390
                      MAXY=ARRAY(R,1)                                           MPS01400
                  END IF                                                        MPS01410
                  R=R+1                                                         MPS01420
                  TIME=TIME+STEP                                                MPS01430
                  IF(TIME.GT.NBAUD*BAUDD)THEN                                   MPS01440
                      NBAUD=NBAUD+1.D0                                          MPS01450
                      GO TO 9                                                   MPS01460
                  END IF                                                        MPS01470
30            CONTINUE                                                          MPS01480
          END IF                                                                MPS01490
C                                                                               MPS01500
C         *** PLOT THE TIME SERIES IF DESIRED ***                               MPS01510
C                                                                               MPS01520
          IF(REP.EQ.1)THEN                                                      MPS01530
              MINY=-MAXY                                                        MPS01540
C                                                                               MPS01550
              CALL PLOT(MAXY,MINY,STEP,IN)                                      MPS01560
          END IF                                                                MPS01570
C                                                                               MPS01580
C         *** GENERATE THE FFT ***                                              MPS01590
C                                                                               MPS01600
```

```
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   MPS01610
C                                                                       MPS01620
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          MPS01630
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       MPS01640
C                                                                       MPS01650
      N=0.D0                                                            MPS01660
      R=1                                                               MPS01670
      MAXY=0.D0                                                         MPS01680
      DO 40 I=1,IND2P1                                                  MPS01690
         ARRAY(R,1)=CDABS(X(R))                                         MPS01700
         ARRAY(R,2)=N/STEP                                              MPS01710
         IF(ARRAY(R,1).GT.MAXY) THEN                                    MPS01720
            MAXY=ARRAY(R,1)                                             MPS01730
            RMAX=R-1                                                    MPS01740
         END IF                                                         MPS01750
         R=R+1                                                          MPS01760
         N=N+1.D0                                                       MPS01770
40    CONTINUE                                                          MPS01780
C                                                                       MPS01790
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***     MPS01800
C                                                                       MPS01810
      IF(REP.EQ.1)THEN                                                  MPS01820
C                                                                       MPS01830
49    WRITE(10,50)RMAX                                                  MPS01840
50    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,  MPS01850
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,   MPS01860
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,   MPS01870
     *' CONTINUE WITH THE PROGRAM.',//,' :')                            MPS01880
C                                                                       MPS01890
      READ(5,*)L                                                        MPS01900
C                                                                       MPS01910
      IF(L.NE.1)THEN                                                    MPS01920
C        CALL FRTCMS('CLRSCRN ')                                        MPS01930
         WRITE(10,60)                                                   MPS01940
60       FORMAT(' ERROR',/)                                             MPS01950
         GO TO 49                                                       MPS01960
      END IF                                                            MPS01970
C                                                                       MPS01980
      END IF                                                            MPS01990
C                                                                       MPS02000
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***   MPS02010
C                                                                       MPS02020
      IF(REP.EQ.1)THEN                                                  MPS02030
         MINY=0.D0                                                      MPS02040
         INT=1.D0/STEP                                                  MPS02050
C                                                                       MPS02060
         CALL PLOT(MAXY,MINY,INT,IND2P1)                                MPS02070
      END IF                                                            MPS02080
C                                                                       MPS02090
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***   MPS02100
```

```
C                                                                       MPS02110
      FLAG=0                                                            MPS02120
      CALL  STATS(IN,REP,FLAG)                                          MPS02130
C                                                                       MPS02140
      RETURN                                                            MPS02150
      END                                                               MPS02160
```

```
      SUBROUTINE MASK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,               MAS00110
     *DSEED,IN,REP)                                                      MAS00120
C                                                                        MAS00130
C     *** PURPOSE ***                                                    MAS00140
C                                                                        MAS00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING M-ARY AMPLITUDE SHIFT MAS00160
C     KEYING AS THE MODULATION TECHNIQUE.                                MAS00170
C                                                                        MAS00180
C     *** PARAMETER DEFINITIONS ***                                      MAS00190
C                                                                        MAS00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                    MAS00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                               MAS00220
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD                MAS00230
C     FREQ=       CARRIER FREQUENCY                                      MAS00240
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                         MAS00250
C     AMP=        AMPLITUDE                                              MAS00260
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM                MAS00270
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR      MAS00280
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED            MAS00290
C                 THE CALL THE THIS SUBROUTINE                           MAS00300
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM        MAS00310
C                                                                        MAS00320
C     *** VARIABLE DEFINITIONS ***                                       MAS00330
C                                                                        MAS00340
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY        MAS00350
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION      MAS00360
C                 AND THE FFT                                            MAS00370
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY          MAS00380
C     TIME=       TIME VARIABLE                                          MAS00390
C     MT=         VALUE OF THE BINARY DIGIT                              MAS00400
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED             MAS00410
C     PI=         NUMERICAL CONSTANT                                     MAS00420
C     OMEGA=      CARRIER ANGULAR FREQUENCY                              MAS00430
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                        MAS00440
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED               MAS00450
C     BAUDD=      BAUD DURATION                                          MAS00460
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES    MAS00470
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC           MAS00480
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE            MAS00490
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE            MAS00500
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE                MAS00510
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                        MAS00520
C     K=          INTEGER VALUE OF THE NUMBER OF BITS IN A BINARY WORD   MAS00530
C     KM1=        INTEGER VALUE OF K MINUS 1                             MAS00540
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K            MAS00550
C     ND2=        N DIVIDED BY 2                                         MAS00560
C     SUM1=       VARIABLE USED TO HOLD THE DECIMAL EQUIVALENT TO A      MAS00570
C                 BINARY CODE WORD OF LENGTH K                           MAS00580
C     SUM2=       VARIABLE USED TO HOLD THE DECIMAL CONVERSION OF SUM1   MAS00590
C     J=          INTEGER USED TO INDEX A LOOP                           MAS00600
```

```
C     AMP1=         PORTION OF AMP USED TO MODULATE THE CARRIER DURING
C                   ANY RESPECTIVE BAUD DURATION
C     REP=          AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF
C                   SUBPROGRAM STATS
C     IND2P1=       LENGTH OF ARRAY DIVIDED BY 2 + 1
C
C     *** VARIABLE DECLARATIONS ***
C
      INTEGER R,ANS2,TYPE2,IN,RMAX,K,KM1,J,REP,FLAG,IND2P1
C
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT,
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,
     *DSEED,MAXY,MINY,INT,N,ND2,SUM1,SUM2,AMP1
C
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),
     *SUMX4(513)
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4
C
      COMPLEX*16 X(513)
C
      INTEGER IWK(10)
C
C     *** VARIABLE INITIALIZATION ***
C
      R=1
      TIME=0.D0
      STEP=1.D0/(2.D0*(FREQ+BAUD))
      PI=3.141592653589793D0
      OMEGA=2.D0*PI*FREQ
      DELTA=IPHAS*PI/180.D0
      NBAUD=1.D0
      BAUDD=1.D0/BAUD
      K=BITS
      N=2.D0**K
      MAXY=0.D0
      IND2P1=IN/2+1
C
9     IF(R.LE.IN) THEN
C
C     *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY
C     VARIABLE IN DECIMAL FORM ***
C
         SUM1=0.D0
         KM1=K-1
         DO 10 I=1,K
            CALL STREAM(DSEED,ANS2,TYPE2,MT)
            IF(TYPE2.EQ.1.AND.MT.EQ.-1.D0) THEN
               MT=0.D0
            ELSE IF(TYPE2.EQ.3.AND.MT.EQ.-1.D0) THEN
               MT=1.D0
```

```
              END IF
              SUM1=SUM1+(MT*(10.D0**KM1))
              KM1=KM1-1
10        CONTINUE
C
C     *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL
C     EQUIVALENT ***
C
          SUM2=0.D0
          KM1=K-1
          ND2=N/2.D0
          DO 20 I=1,K
              IF(SUM1/10.D0**KM1.GE.1.D0)THEN
                  SUM2=SUM2+ND2
                  SUM1=SUM1-10.D0**KM1
                  ND2=ND2/2.D0
                  KM1=KM1-1
              ELSE
                  ND2=ND2/2.D0
                  KM1=KM1-1
              END IF
20        CONTINUE
C
C     *** DO THE MODULATION AND ASSIGN TO ARRAY ***
C
          SUM2=SUM2+1.D0
          AMP1=AMP/SUM2
          J=R
          DO 30 I=J,IN
              ARRAY(R,1)=AMP1*DCOS((OMEGA*TIME)+DELTA)
              ARRAY(R,2)=TIME
              IF(ARRAY(R,1).GT.MAXY)THEN
                  MAXY=ARRAY(R,1)
              END IF
              R=R+1
              TIME=TIME+STEP
              IF(TIME.GT.NBAUD*BAUDD)THEN
                  NBAUD=NBAUD+1.D0
                  GO TO 9
              END IF
30        CONTINUE
      END IF
C
C     *** PLOT THE TIME SERIES IF DESIRED ***
C
      IF(REP.EQ.1)THEN
          MINY=-MAXY
C
          CALL PLOT(MAXY,MINY,STEP,IN)
      END IF
```

```
C
C     *** GENERATE THE FFT ***
C
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)
C
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***
C
      N=0.D0
      R=1
      MAXY=0.D0
      DO 40 I=1,IND2P1
          ARRAY(R,1)=CDABS(X(R))
          ARRAY(R,2)=N/STEP
          IF(ARRAY(R,1).GT.MAXY) THEN
              MAXY=ARRAY(R,1)
              RMAX=R-1
          END IF
          R=R+1
          N=N+1.D0
40    CONTINUE
C
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***
C
      IF(REP.EQ.1) THEN
C
49    WRITE(10,50) RMAX
50    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,
     *' CONTINUE WITH THE PROGRAM.',//,' :')
C
      READ(5,*) L
C
      IF(L.NE.1) THEN
          CALL FRTCMS('CLRSCRN ')
C
          WRITE(10,60)
60        FORMAT(' ERROR',/)
          GO TO 49
      END IF
C
      END IF
C
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***
C
      IF(REP.EQ.1) THEN
          MINY=0.D0
          INT=1.D0/STEP
C
          CALL PLCT(MAXY,MINY,INT,IND2P1)
```

```
      END IF                                                            MAS02110
C                                                                       MAS02120
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***   MAS02130
C                                                                       MAS02140
      FLAG=0                                                            MAS02150
      CALL STATS(IN,REP,FLAG)                                           MAS02160
C                                                                       MAS02170
      RETURN                                                            MAS02180
      END                                                               MAS02190
```

```
      SUBROUTINE QASK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,              QAS00110
     *DSEED,IN,REP)                                                     QAS00120
C                                                                       QAS00130
C     *** PURPOSE ***                                                   QAS00140
C                                                                       QAS00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING QUADRATURE AMPLITUDE  QAS00160
C     SHIFT KEYING AS THE MODULATION TECHNIQUE.                         QAS00170
C                                                                       QAS00180
C     *** PARAMETER DEFINITIONS ***                                     QAS00190
C                                                                       QAS00200
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED                   QAS00210
C     BAUD=       SYMBOL RATE OR BAUD RATE                              QAS00220
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD               QAS00230
C     FREQ=       CARRIER FREQUENCY                                     QAS00240
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES                        QAS00250
C     AMP=        AMPLITUDE                                             QAS00260
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM               QAS00270
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR     QAS00280
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED           QAS00290
C                 THE CALL THE THIS SUBROUTINE                          QAS00300
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM       QAS00310
C                                                                       QAS00320
C     *** VARIABLE DEFINITIONS ***                                      QAS00330
C                                                                       QAS00340
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY       QAS00350
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION     QAS00360
C                 AND THE FFT                                           QAS00370
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY         QAS00380
C     TIME=       TIME VARIABLE                                         QAS00390
C     MT=         VALUE OF THE BINARY DIGIT                             QAS00400
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED            QAS00410
C     PI=         NUMERICAL CONSTANT                                    QAS00420
C     OMEGA=      CARRIER ANGULAR FREQUENCY                             QAS00430
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS                       QAS00440
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED              QAS00450
C     BAUDD=      BAUD DURATION                                         QAS00460
C     X=          CCMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES   QAS00470
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC          QAS00480
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           QAS00490
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE           QAS00500
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE               QAS00510
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC                       QAS00520
C     K=          INTEGER VALUE OF THE NUMBER OF BITS IN A BINARY WORD  QAS00530
C     KM1=        INTEGER VALUE OF K MINUS 1                            QAS00540
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K           QAS00550
C     ND2=        N DIVIDED BY 2                                        QAS00560
C     SUM1=       VARIABLE USED TO HOLD THE DECIMAL EQUIVALENT TO A     QAS00570
C                 BINARY CODE WORD OF LENGTH K                          QAS00580
C     SUM2=       VARIABLE USED TO HOLD THE DECIMAL CONVERSION OF SUM1  QAS00590
C     J=          INTEGER USED TO INDEX A LOOP                          QAS00600
```

```
C     AMPA=        PORTION OF AMP USED TO MODULATE THE IN-PHASE                QAS00610
C                  COMPONENT OF THE CARRIER DURING ANY RESPECTIVE BAUD         QAS00620
C                  DURATION                                                    QAS00630
C     AMPB=        PORTION OF AMP USED TO MODULATE THE QUADRATURE              QAS00640
C                  COMPONENT OF THE CARRIER DURING ANY RESPECTIVE BAUD         QAS00650
C                  DURATION                                                    QAS00660
C     SUM2A=       THE VALUE OF THE IN-PHASE CODE WORD                         QAS00670
C     SUM2B=       THE VALUE OF THE QUADRATURE CODE WORD                       QAS00680
C     REP=         AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF         QAS00690
C                  SUBPROGRAM STATS                                            QAS00700
C     IND2P1=      LENGTH OF ARRAY DIVIDED BY 2 + 1                            QAS00710
C                                                                              QAS00720
C     *** VARIABLE DECLARATIONS ***                                            QAS00730
C                                                                              QAS00740
      INTEGER R,ANS2,TYPE2,IN,RMAX,K,KM1,J,M,REP,FLAG,IND2P1                   QAS00750
C                                                                              QAS00760
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT,                       QAS00770
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                         QAS00780
     *DSEED,MAXY,MINY,INT,N,ND2,SUM1,SUM2,AMPA,AMPB,SUM2A,SUM2B                QAS00790
C                                                                              QAS00800
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),         QAS00810
     *SUMX4(513)                                                               QAS00820
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                                     QAS00830
C                                                                              QAS00840
      COMPLEX*16 X(513)                                                        QAS00850
C                                                                              QAS00860
      INTEGER IWK(10)                                                          QAS00870
C                                                                              QAS00880
C     *** VARIABLE INITIALIZATION ***                                          QAS00890
C                                                                              QAS00900
      R=1                                                                      QAS00910
      TIME=0.D0                                                                QAS00920
      STEP=1.D0/(2.D0*(FREQ+BAUD))                                             QAS00930
      PI=3.141592653589793D0                                                   QAS00940
      OMEGA=2.D0*PI*FREQ                                                       QAS00950
      DELTA=IPHAS*PI/180.D0                                                    QAS00960
      NBAUD=1.D0                                                               QAS00970
      BAUDD=1.D0/BAUD                                                          QAS00980
      K=BITS                                                                   QAS00990
      N=2.D0**K                                                                QAS01000
      MAXY=0.D0                                                                QAS01010
      IND2P1=IN/2+1                                                            QAS01020
C                                                                              QAS01030
9     IF(R.LE.IN) THEN                                                         QAS01040
C                                                                              QAS01050
C     *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY         QAS01060
C     VARIABLE IN DECIMAL FORM-DO THIS TWICE, ONCE FOR THE IN-PHASE            QAS01070
C     CODE WORD AND ONCE FOR THE QUADRATURE CODE WORD ***                      QAS01080
C                                                                              QAS01090
         DO 16 M=1,2                                                           QAS01100
```

```
C                                                                       QAS01110
           SUM1=0.D0                                                    QAS01120
           KM1=K-1                                                      QAS01130
           DO 10 I=1,K                                                  QAS01140
              CALL STREAM(DSEED,ANS2,TYPE2,MT)                          QAS01150
              IF(TYPE2.EQ.1.AND.MT.EQ.-1.D0) THEN                       QAS01160
                 MT=0.D0                                                QAS01170
              ELSE IF(TYPE2.EQ.3.AND.MT.EQ.-1.D0)THEN                   QAS01180
                 MT=1.D0                                                QAS01190
              END IF                                                    QAS01200
              SUM1=SUM1+(MT*(10.D0**KM1))                               QAS01210
              KM1=KM1-1                                                 QAS01220
10         CONTINUE                                                     QAS01230
C                                                                       QAS01240
C    *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL      QAS01250
C    EQUIVALENT ***                                                     QAS01260
C                                                                       QAS01270
           SUM2=0.D0                                                    QAS01280
           KM1=K-1                                                      QAS01290
           ND2=N/2.D0                                                   QAS01300
           DO 20 I=1,K                                                  QAS01310
              IF(SUM1/10.D0**KM1.GE.1.D0)THEN                           QAS01320
                 SUM2=SUM2+ND2                                          QAS01330
                 SUM1=SUM1-10.D0**KM1                                   QAS01340
                 ND2=ND2/2.D0                                           QAS01350
                 KM1=KM1-1                                              QAS01360
              ELSE                                                      QAS01370
                 ND2=ND2/2.D0                                           QAS01380
                 KM1=KM1-1                                              QAS01390
              END IF                                                    QAS01400
20         CONTINUE                                                     QAS01410
C                                                                       QAS01420
           IF(M.EQ.1) THEN                                              QAS01430
              SUM2A=SUM2+1.D0                                           QAS01440
           ELSE IF(M.EQ.2) THEN                                         QAS01450
              SUM2B=SUM2+1.D0                                           QAS01460
           END IF                                                       QAS01470
C                                                                       QAS01480
16      CONTINUE                                                        QAS01490
C                                                                       QAS01500
C    *** DO THE MODULATION AND ASSIGN TO ARRAY ***                      QAS01510
C                                                                       QAS01520
        AMPA=AMP/SUM2A                                                  QAS01530
        AMPB=AMP/SUM2B                                                  QAS01540
        J=R                                                             QAS01550
        DO 30 I=J,IN                                                    QAS01560
           ARRAY(R,1)=AMPA*DCOS((OMEGA*TIME)+DELTA)+                    QAS01570
     *                 AMPB*DSIN((OMEGA*TIME)+DELTA)                    QAS01580
           ARRAY(R,2)=TIME                                              QAS01590
           IF(ARRAY(R,1).GT.MAXY)THEN                                   QAS01600
```

```
                    MAXY=ARRAY(R,1)
                 END IF
                 R=R+1
                 TIME=TIME+STEP
                 IF(TIME.GT.NBAUD*BAUDD) THEN
                    NBAUD=NBAUD+1.D0
                    GO TO 9
                 END IF
30            CONTINUE
           END IF
C
C          *** PLOT THE TIME SERIES IF DESIRED ***
C
           IF(REP.EQ.1) THEN
              MINY=-MAXY
C
              CALL PLOT(MAXY,MINY,STEP,IN)
           END IF
C
C          *** GENERATE THE FFT ***
C
           CALL FFTRC(ARRAY(1,1),IN,X,IWK)
C
C          *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***
C          *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***
C
           N=0.D0
           R=1
           MAXY=0.D0
           DO 40 I=1,IND2P1
              ARRAY(R,1)=CDABS(X(R))
              ARRAY(R,2)=N/STEP
              IF(ARRAY(R,1).GT.MAXY) THEN
                 MAXY=ARRAY(R,1)
                 RMAX=R-1
              END IF
              R=R+1
              N=N+1.D0
40         CONTINUE
C
C          *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***
C
           IF(REP.EQ.1) THEN
C
49         WRITE(10,50) RMAX
50         FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,
          *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,
          *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,
          *' CONTINUE WITH THE PROGRAM.',//,' :')
C
```

```
      READ(5,*)L                                                        QAS02110
C                                                                       QAS02120
      IF(L.NE.1)THEN                                                    QAS02130
C         CALL FRTCMS('CLRSCRN ')                                       QAS02140
          WRITE(10,60)                                                  QAS02150
60        FORMAT(' ERROR',/)                                            QAS02160
          GO TO 49                                                      QAS02170
      END IF                                                            QAS02180
C                                                                       QAS02190
      END IF                                                            QAS02200
C                                                                       QAS02210
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***   QAS02220
C                                                                       QAS02230
      IF(REP.EQ.1)THEN                                                  QAS02240
          MINY=0.D0                                                     QAS02250
          INT=1.D0/STEP                                                 QAS02260
C                                                                       QAS02270
          CALL PLOT(MAXY,MINY,INT,IND2P1)                               QAS02280
      END IF                                                            QAS02290
C                                                                       QAS02300
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***   QAS02310
C                                                                       QAS02320
      FLAG=0                                                            QAS02330
      CALL STATS(IN,REP,FLAG)                                           QAS02340
C                                                                       QAS02350
      RETURN                                                            QAS02360
      END                                                               QAS02370
```

```
      SUBROUTINE MSK(TYPE2,BAUD,FREQ,IPHAS,AMP,ANS2,
     *DSEED,IN,REP)
C
C     *** PURPOSE ***
C
C     THIS SUBROUTINE MODULATES THE CARRIER USING MINIMUM SHIFT KEYING
C     OR FAST FREQUENCY SHIFT KEYING AS THE MODULATION TECHNIQUE.
C
C     *** PARAMETER DEFINITIONS ***
C
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED
C     BAUD=       SYMBOL RATE OR BAUD RATE
C     FREQ=       CARRIER FREQUENCY
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES
C     AMP=        AMPLITUDE
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF
C                 THE CALL THE THIS SUBROUTINE
C
C     *** VARIABLE DEFINITIONS ***
C
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION
C                 AND THE FFT
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY
C     TIME=       TIME VARIABLE
C     MT=         VALUE OF THE BINARY DIGIT
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED
C     PI=         NUMERICAL CONSTANT
C     OMEGA=      CARRIER ANGULAR FREQUENCY
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED
C     BAUDD=      BAUD DURATION
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM
C                 SUBPROGRAM STATS
C     IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1
C
C     *** VARIABLE DECLARATIONS ***
C
      INTEGER R,ANS2,TYPE2,IN,RMAX,REP,FLAG,IND2P1
C
      DOUBLE PRECISION BAUD,FREQ,IPHAS,AMP,TIME,MT,
```

```
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                  MSK00610
     *DSEED,MAXY,MINY,INT                                               MSK00620
C                                                                       MSK00630
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  MSK00640
     *SUMX4(513)                                                        MSK00650
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              MSK00660
C                                                                       MSK00670
      COMPLEX*16 X(513)                                                 MSK00680
C                                                                       MSK00690
      INTEGER IWK(10)                                                   MSK00700
C                                                                       MSK00710
C     *** VARIABLE INITIALIZATION ***                                   MSK00720
C                                                                       MSK00730
      R=1                                                               MSK00740
      TIME=0.D0                                                         MSK00750
      STEP=1.D0/(2.D0*(FREQ+(1.25D0*BAUD)))                             MSK00760
      PI=3.141592653589793D0                                            MSK00770
      OMEGA=2.D0*PI*FREQ                                                MSK00780
      DELTA=IPHAS*PI/180.D0                                             MSK00790
      NBAUD=1.D0                                                        MSK00800
      BAUDD=1.D0/BAUD                                                   MSK00810
      MAXY=0.D0                                                         MSK00820
      IND2P1=IN/2+1                                                     MSK00830
C                                                                       MSK00840
      CALL STREAM(DSEED,ANS2,TYPE2,MT)                                  MSK00850
C                                                                       MSK00860
      DO 10 I=1,IN                                                      MSK00870
         ARRAY(R,1)=AMP*DCOS(((OMEGA+((MT*PI)/(2.D0*BAUDD)))*TIME)      MSK00880
     *   +DELTA)                                                        MSK00890
         ARRAY(R,2)=TIME                                                MSK00900
         IF(DABS(ARRAY(R,1)).GT.MAXY) THEN                              MSK00910
            MAXY=DABS(ARRAY(R,1))                                       MSK00920
         END IF                                                         MSK00930
         R=R+1                                                          MSK00940
         TIME=TIME+STEP                                                 MSK00950
         IF(TIME.GT.NBAUD*BAUDD)THEN                                    MSK00960
            CALL STREAM(DSEED,ANS2,TYPE2,MT)                            MSK00970
            NBAUD=NBAUD+1.D0                                            MSK00980
         END IF                                                         MSK00990
   10 CONTINUE                                                          MSK01000
C                                                                       MSK01010
C     *** PLOT THE TIME SERIES IF DESIRED ***                           MSK01020
C                                                                       MSK01030
      IF(REP.EQ.1)THEN                                                  MSK01040
         MINY=-MAXY                                                     MSK01050
C                                                                       MSK01060
         CALL PLOT(MAXY,MINY,STEP,IN)                                   MSK01070
      END IF                                                            MSK01080
C                                                                       MSK01090
C     *** GENERATE THE FFT ***                                          MSK01100
```

```
C                                                                       MSK01110
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   MSK01120
C                                                                       MSK01130
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          MSK01140
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       MSK01150
C                                                                       MSK01160
      N=0.D0                                                            MSK01170
      R=1                                                               MSK01180
      MAXY=0.D0                                                         MSK01190
      DO 20 I=1,IND2P1                                                  MSK01200
          ARRAY(R,1)=CDABS(X(R))                                        MSK01210
          ARRAY(R,2)=N/STEP                                             MSK01220
          IF(ARRAY(R,1).GT.MAXY) THEN                                   MSK01230
              MAXY=ARRAY(R,1)                                           MSK01240
              RMAX=R-1                                                  MSK01250
          END IF                                                        MSK01260
          R=R+1                                                         MSK01270
          N=N+1.D0                                                      MSK01280
20    CONTINUE                                                          MSK01290
C                                                                       MSK01300
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH SUBPROGRAM ***         MSK01310
C                                                                       MSK01320
      IF(REP.EQ.1)THEN                                                  MSK01330
C                                                                       MSK01340
29    WRITE(10,30)RMAX                                                  MSK01350
30    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,  MSK01360
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,   MSK01370
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,   MSK01380
     *' CONTINUE WITH THE PROGRAM.',//,' :')                            MSK01390
C                                                                       MSK01400
      READ(5,*)L                                                        MSK01410
C                                                                       MSK01420
      IF(L.NE.1)THEN                                                    MSK01430
C         CALL FRTCMS('CLRSCRN ')                                       MSK01440
          WRITE(10,40)                                                  MSK01450
40        FORMAT(' ERROR',/)                                            MSK01460
          GO TO 29                                                      MSK01470
      END IF                                                            MSK01480
C                                                                       MSK01490
      END IF                                                            MSK01500
C                                                                       MSK01510
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***   MSK01520
C                                                                       MSK01530
      IF(REP.EQ.1)THEN                                                  MSK01540
          MINY=0.D0                                                     MSK01550
          INT=1.D0/STEP                                                 MSK01560
C                                                                       MSK01570
          CALL PLOT(MAXY,MINY,INT,IND2P1)                               MSK01580
      END IF                                                            MSK01590
C                                                                       MSK01600
```

```
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***   MSK01610
C                                                                       MSK01620
      FLAG=0                                                            MSK01630
      CALL STATS(IN,REP,FLAG)                                           MSK01640
C                                                                       MSK01650
      RETURN                                                            MSK01660
      END                                                               MSK01670
```

```
      SUBROUTINE MFSK(TYPE2,BAUD,BITS,FREQ,IPHAS,AMP,ANS2,
     *DSEED,IN,REP)
C
C     *** PURPOSE ***
C
C     THIS SUBROUTINE MODULATES THE CARRIER USING M-ARY FREQUENCY SHIFT
C     KEYING AS THE MODULATION TECHNIQUE.
C
C     *** PARAMETER DEFINITIONS ***
C
C     TYPE2=      INDICATES LOGIC TYPE TO BE EMPLOYED
C     BAUD=       SYMBOL RATE OR BAUD RATE
C     BITS=       NUMBER OF BITS IN EACH BINARY CODE WORD
C     FREQ=       CARRIER FREQUENCY
C     IPHAS=      INITIAL PHASE ANGLE IN DEGREES
C     AMP=        AMPLITUDE
C     ANS2=       INTEGER VARIABLE TO BE PASSED TO STREAM
C     DSEED=      DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR
C     IN=         NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED
C     REP=        AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF
C                 THE CALL THE THIS SUBROUTINE
C
C     *** VARIABLE DEFINITIONS ***
C
C     ARRAY=      A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY
C                 DIGITS AND STORING THE VALUE OF THE TIME FUNCTION
C                 AND THE FFT
C     R=          AN INTEGER USED TO REPRESENT THE ROW OF ARRAY
C     TIME=       TIME VARIABLE
C     MT=         VALUE OF THE BINARY DIGIT
C     STEP=       INTERVAL AT WHICH THE SIGNAL IS REPRODUCED
C     PI=         NUMERICAL CONSTANT
C     OMEGA=      CARRIER ANGULAR FREQUENCY
C     DELTA=      INITIAL PHASE OFFSET IN RADIANS
C     NBAUD=      A COUNT OF THE NUMBER OF BAUDS MODULATED
C     BAUDD=      BAUD DURATION
C     X=          COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES
C     IWK=        INTEGER WORKING ARRAY USED BY FUNCTION FFTRC
C     MAXY=       MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     MINY=       MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE
C     INT=        INTERVAL BETWEEN POINTS ON THE ORDINATE
C     RMAX=       VALUE OF THE PRINCIPLE HARMONIC
C     K=          INTEGER VALUE OF THE NUMBER OF BITS IN A BINARY WORD
C     KM1=        INTEGER VALUE OF K MINUS 1
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K
C     ND2=        N DIVIDED BY 2
C     SUM1=       VARIABLE USED TO HOLD THE DECIMAL EQUIVALENT TO A
C                 BINARY CODE WORD OF LENGTH K
C     SUM2=       VARIABLE USED TO HOLD THE DECIMAL CONVERSION OF SUM1
C     J=          INTEGER USED TO INDEX A LOOP
```

```
C     FLAG=       AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM          MFS00610
C                 SUBPROGRAM STATS                                         MFS00620
C     DELF=       DELTA FREQUENCY BETWEEN SUCCESSIVE CODE WORDS            MFS00630
C     FRNG=       FREQUENCY RANGE AROUND THE CENTRAL CARRIER FREQUENCY     MFS00640
C     FRNGD2=     FREQUENCY RANGE DIVIDED BY 2.                            MFS00650
C     MFREQ=      FREQUENCY OF THE CODE WORD TO BE MODULATED ONTO THE      MFS00660
C                 CARRIER                                                  MFS00670
C     IND2P1=     LENGTH OF ARRAY DIVIDED BY 2 + 1                         MFS00680
C                                                                          MFS00690
C     *** VARIABLE DECLARATIONS ***                                        MFS00700
C                                                                          MFS00710
      INTEGER R,ANS2,TYPE2,IN,RMAX,K,KM1,J,REP,FLAG,IND2P1                 MFS00720
C                                                                          MFS00730
      DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT,                   MFS00740
     *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,                                     MFS00750
     *DSEED,MAXY,MINY,INT,N,ND2,SUM1,SUM2,DELF,FRNG,FRNGD2,MFREQ           MFS00760
C                                                                          MFS00770
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),     MFS00780
     *SUMX4(513)                                                           MFS00790
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                                 MFS00800
C                                                                          MFS00810
      COMPLEX*16 X(513)                                                    MFS00820
C                                                                          MFS00830
      INTEGER IWK(10)                                                      MFS00840
C                                                                          MFS00850
C     *** VARIABLE INITIALIZATION ***                                      MFS00860
C                                                                          MFS00870
      R=1                                                                  MFS00880
      TIME=0.D0                                                            MFS00890
      BAUDD=1.D0/BAUD                                                      MFS00900
      DELF=1.D0/BAUDD                                                      MFS00910
      K=BITS                                                               MFS00920
      N=2.D0**K                                                            MFS00930
      FRNG=(N-1.D0)*DELF                                                   MFS00940
      FRNGD2=FRNG/2.D0                                                     MFS00950
      STEP=1.D0/(2.D0*(FREQ+FRNGD2+BAUD))                                  MFS00960
      PI=3.141592653589793D0                                               MFS00970
      OMEGA=2.D0*PI*FREQ                                                   MFS00980
      DELTA=IPHAS*PI/180.D0                                                MFS00990
      NBAUD=1.D0                                                           MFS01000
      MAXY=0.D0                                                            MFS01010
      IND2P1=IN/2+1                                                        MFS01020
C                                                                          MFS01030
9     IF(R.LE.IN) THEN                                                     MFS01040
C                                                                          MFS01050
C     *** CONVERT A STREAM OF K BITS TO A SINGLE REPRESENTATIVE BINARY     MFS01060
C     VARIABLE IN DECIMAL FORM ***                                         MFS01070
C                                                                          MFS01080
         SUM1=0.D0                                                         MFS01090
         KM1=K-1                                                           MFS01100
```

```
      DO 10 I=1,K
         CALL STREAM(DSEED,ANS2,TYPE2,MT)
         IF(TYPE2.EQ.1.AND.MT.EQ.-1.D0) THEN
            MT=0.D0
         ELSE IF(TYPE2.EQ.3.AND.MT.EQ.-1.D0) THEN
            MT=1.D0
         END IF
         SUM1=SUM1+(MT*(10.D0**KM1))
         KM1=KM1-1
10    CONTINUE
C
C   *** CONVERT THE REPRESENTATIVE BINARY VARIABLE TO ITS DECIMAL
C   EQUIVALENT ***
C
      SUM2=0.D0
      KM1=K-1
      ND2=N/2.D0
      DO 20 I=1,K
         IF(SUM1/10.D0**KM1.GE.1.D0) THEN
            SUM2=SUM2+ND2
            SUM1=SUM1-10.D0**KM1
            ND2=ND2/2.D0
            KM1=KM1-1
         ELSE
            ND2=ND2/2.D0
            KM1=KM1-1
         END IF
20    CONTINUE
C
C   *** DO THE MODULATION AND ASSIGN TO ARRAY ***
C
      J=R
      MFREQ=-FRNGD2+(SUM2*DELF)
      DO 30 I=J,IN
         ARRAY(R,1)=AMP*DCOS(((OMEGA+(2.D0*PI*MFREQ))*TIME)+
     *            DELTA)
         ARRAY(R,2)=TIME
         IF(ARRAY(R,1).GT.MAXY) THEN
            MAXY=ARRAY(R,1)
         END IF
         R=R+1
         TIME=TIME+STEP
         IF(TIME.GT.NBAUD*BAUDD) THEN
            NBAUD=NBAUD+1.D0
            GO TO 9
         END IF
30    CONTINUE
    END IF
C
C   *** PLOT THE TIME SERIES IF DESIRED ***
```

```
C
      IF(REP.EQ.1)THEN
         MINY=-MAXY
C
         CALL PLOT(MAXY,MINY,STEP,IN)
      END IF
C
C     *** GENERATE THE FFT ***
C
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)
C
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***
C
      N=0.D0
      R=1
      MAXY=0.D0
      DO 40  I=1,IND2P1
         ARRAY(R,1)=CDABS(X(R))
         ARRAY(R,2)=N/STEP
         IF(ARRAY(R,1).GT.MAXY)THEN
            MAXY=ARRAY(R,1)
            RMAX=R-1
         END IF
         R=R+1
         N=N+1.D0
40    CONTINUE
C
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***
C
      IF(REP.EQ.1)THEN
C
49    WRITE(10,50)RMAX
50    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,
     *' CONTINUE WITH THE PROGRAM.',//,' :')
C
      READ(5,*)L
C
      IF(L.NE.1)THEN
C        CALL FRTCMS('CLRSCRN ')
         WRITE(10,60)
60       FORMAT(' ERROR',/)
         GO TO 49
      END IF
C
      END IF
C
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***
```

```
C                                                                       MFS02110
      IF(REP.EQ.1)THEN                                                  MFS02120
          MINY=0.D0                                                     MFS02130
          INT=1.D0/STEP                                                 MFS02140
C                                                                       MFS02150
          CALL PLOT(MAXY,MINY,INT,IND2P1)                               MFS02160
      END IF                                                            MFS02170
C                                                                       MFS02180
      FLAG=0                                                            MFS02190
      CALL STATS(IN,REP,FLAG)                                           MFS02200
C                                                                       MFS02210
      RETURN                                                            MFS02220
      END                                                               MFS02230
```

```
      SUBROUTINE QPRS(TYPE2,TYPE3,BAUD,BITS,FREQ,IPHAS,AMP,             QPR00110
     *ANS2,DSEED,IN,REP)                                                QPR00120
C                                                                       QPR00130
C     *** PURPOSE ***                                                   QPR00140
C                                                                       QPR00150
C     THIS SUBROUTINE MODULATES THE CARRIER USING QUADRATURE PHASE SHIFTQPR00160
C     KEYING AS THE MODULATION TECHNIQUE.                               QPR00170
C                                                                       QPR00180
C     *** PARAMETER DEFINITIONS ***                                     QPR00190
C                                                                       QPR00200
C     TYPE2=        INDICATES LOGIC TYPE TO BE EMPLOYED                 QPR00210
C     TYPE3=        INDICATES THE CLASS OF QPRS                         QPR00220
C     BAUD=         SYMBOL RATE OR BAUD RATE                            QPR00230
C     BITS=         NUMBER OF BITS IN EACH BINARY CODE WORD             QPR00240
C     FREQ=         CARRIER FREQUENCY                                   QPR00250
C     IPHAS=        INITIAL PHASE ANGLE IN DEGREES                      QPR00260
C     AMP=          AMPLITUDE                                           QPR00270
C     ANS2=         INTEGER VARIABLE TO BE PASSED TO STREAM             QPR00280
C     DSEED=        DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR   QPR00290
C     IN=           NUMBER OF POSITIONS IN ARRAY TO BE UTILIZED         QPR00300
C     REP=          AN INTEGER EQUAL TO THE NUMBER OF THE REPETITION OF QPR00310
C                   THE CALL THE THIS SUBROUTINE                        QPR00320
C                                                                       QPR00330
C     *** VARIABLE DEFINITIONS ***                                      QPR00340
C                                                                       QPR00350
C     ARRAY=        A DOUBLE PRECISION ARRAY FOR PASSING THE BINARY     QPR00360
C                   DIGITS AND STORING THE VALUE OF THE TIME FUNCTION   QPR00370
C                   AND THE FFT                                         QPR00380
C     ASUBN=        A DOUBLE PRECISION ARRAY CONTAINING THE VALUES OF   QPR00390
C                   THE IN PHASE BINARY DIGIT TO BE MODULATED           QPR00400
C     BSUBN=        A DOUBLE PRECISION ARRAY CONTAINING THE VALUES OF THE QPR00410
C                   QUADRATURE BINARY DIGIT TO BE MODULATED             QPR00420
C     HOFT=         THE IMPULSE RESPONSE FOR THE SPECIFIED CLASS FILTER QPR00430
C     T=            VARIABLE WHICH DETERMINES THE MAGNITUDE OF THE IMPULSEQPR00440
C                   RESPONSE AT A GIVEN TIME FOR A SPECIFIED BINARY DIGIT QPR00450
C     NDP=          VARIABLE USED IN THE COMPUTATION OF T               QPR00460
C     R=            AN INTEGER USED TO REPRESENT THE ROW OF ARRAY       QPR00470
C     TIME=         TIME VARIABLE                                       QPR00480
C     MT=           VALUE OF BINARY DIGIT PASSED FROM SUBPROGRAM STREAM QPR00490
C     STEP=         INTERVAL AT WHICH THE SIGNAL IS REPRODUCED          QPR00500
C     PI=           NUMERICAL CONSTANT                                  QPR00510
C     OMEGA=        CARRIER ANGULAR FREQUENCY                           QPR00520
C     DELTA=        INITIAL PHASE OFFSET IN RADIANS                     QPR00530
C     BAUDD=        BAUD DURATION AND QPRS BIT DURATION                 QPR00540
C     X=            COMPLEX ARRAY TO RECEIVE THE FFT OF THE TIME SERIES QPR00550
C     IWK=          INTEGER WORKING ARRAY USED BY FUNCTION FFTRC        QPR00560
C     MAXY=         MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE         QPR00570
C     MINY=         MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE         QPR00580
C     INT=          INTERVAL BETWEEN POINTS ON THE ORDINATE             QPR00590
C     RMAX=         VALUE OF THE PRINCIPLE HARMONIC                     QPR00600
```

```
C      FLAG=         AN INTEGER WHICH CONTROL ENTRANCE AND EXIT FROM             QPR00610
C                    SUBPROGRAM STATS                                            QPR00620
C      IND2P1=       LENGTH OF ARRAY DIVIDED BY 2 + 1                            QPR00630
C      MAX=          MAX NUMBER OF INCREMENTS IN 6 BAUD DURATIONS                QPR00640
C      INDEX=        INDEX OF A LOOP                                             QPR00650
C                                                                                QPR00660
C      *** VARIABLE DECLARATIONS ***                                             QPR00670
C                                                                                QPR00680
       INTEGER R,ANS2,TYPE2,TYPE3,IN,RMAX,REP,FLAG,IND2P1,MAX,INDEX              QPR00690
C                                                                                QPR00700
       DOUBLE PRECISION BAUD,BITS,FREQ,IPHAS,AMP,TIME,MT1,MT2,                   QPR00710
      *STEP,PI,OMEGA,DELTA,NBAUD,BAUDD,HOFT,T,NDP,                               QPR00720
      *DSEED,MAXY, MINY,INT,MT                                                   QPR00730
C                                                                                QPR00740
       DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),          QPR00750
      *SUMX4(513),ASUBN(2000),BSUBN(2000)                                        QPR00760
       COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                                      QPR00770
C                                                                                QPR00780
       COMPLEX*16 X(513)                                                         QPR00790
C                                                                                QPR00800
       INTEGER IWK(10)                                                           QPR00810
C                                                                                QPR00820
C      *** VARIABLE INITIALIZATION ***                                           QPR00830
C                                                                                QPR00840
       R=1                                                                       QPR00850
       PI=3.141592653589793D0                                                    QPR00860
       BAUDD=1.D0/BAUD                                                           QPR00870
       TIME=6.D0/BAUD                                                            QPR00880
       STEP=1.D0/(2.D0*(FREQ+((PI+1.D0)*BAUD)))                                  QPR00890
       MAX=TIME/STEP+1.D0                                                        QPR00900
       INDEX=IN+MAX                                                              QPR00910
       OMEGA=2.D0*PI*FREQ                                                        QPR00920
       DELTA=IPHAS*PI/180.D0                                                     QPR00930
       MAXY=0.D0                                                                 QPR00940
       IND2P1=IN/2+1                                                             QPR00950
C                                                                                QPR00960
       DO 10 I=1,INDEX                                                           QPR00970
           CALL STREAM(DSEED,ANS2,TYPE2,MT)                                      QPR00980
           ASUBN(I)=MT                                                           QPR00990
           CALL STREAM(DSEED,ANS2,TYPE2,MT)                                      QPR01000
           BSUBN(I)=MT                                                           QPR01010
10     CONTINUE                                                                  QPR01020
C                                                                                QPR01030
       DO 20 I=1,1024                                                            QPR01040
           ARRAY(I,1)=0.D0                                                       QPR01050
20     CONTINUE                                                                  QPR01060
C                                                                                QPR01070
C      *** DO THE MODULATION AND ASSIGN THE VALUES TO ARRAY***                   QPR01080
C                                                                                QPR01090
       DO 30 I=1,IN                                                              QPR01100
```

```
C
      DO 40 J=1,INDEX
          NDP=J-1
          T=TIME-(NDP/BAUD)
          IF(TYPE3.EQ.1)THEN
              IF(T.EQ.-BAUDD/2.D0.OR.T.EQ.BAUDD/2.D0)THEN
                  HOFT= 1.D0
              ELSE
                  HOFT= (4.D0/(BAUD**2*PI))*(DCOS(PI*T*BAUD)/
     *                  ((1.D0/BAUD**2)-(4.D0*T**2)))
              END IF
          ELSE IF(TYPE3.EQ.2)THEN
              IF(T.EQ.0.D0) THEN
                  HOFT=2.D0
              ELSE IF(T.EQ.-BAUDD.OR.T.EQ.BAUDD)THEN
                  HOFT= 1.D0
              ELSE
                  HOFT= (2.D0/(BAUD**3*PI*T))*(DSIN(PI*T*BAUD)/
     *                  ((1.D0/BAUD**2)-T**2))
              END IF
          ELSE IF(TYPE3.EQ.3)THEN
              IF(T.EQ.0.D0) THEN
                  HOFT= 1.D0
              ELSE IF(T.EQ.-BAUDD)THEN
                  HOFT=2.D0
              ELSE IF(T.EQ.BAUDD)THEN
                  HOFT=-1.D0
              ELSE
                  HOFT= (1.D0/(BAUD**2*PI*T))*(DSIN(PI*T*BAUD))*
     *                  ((3.D0*T-BAUDD)/(T**2-(1.D0/BAUD**2)))
              END IF
          ELSE IF(TYPE3.EQ.4)THEN
              IF(T.EQ.-BAUDD)THEN
                  HOFT= 1.D0
              ELSE IF(T.EQ.BAUDD)THEN
                  HOFT=-1.D0
              ELSE
                  HOFT= (2.D0/(BAUD**2*PI))*(DSIN(PI*T*BAUD)/
     *                  (T**2-(1.D0/BAUD**2)))
              END IF
          ELSE IF(TYPE3.EQ.5)THEN
              IF(T.EQ.0.D0) THEN
                  HOFT=-2.D0
              ELSE IF(T.EQ.-2.D0*BAUDD.OR.T.EQ.2.D0*BAUDD)THEN
                  HOFT= 1.D0
              ELSE
                  HOFT= (8.D0/(BAUD**3*PI*T))*(DSIN(PI*T*BAUD)/
     *                  (T**2-(4.D0/BAUD**2)))
              END IF
C
```

```
              END IF                                                    QPR01610
C                                                                       QPR01620
              ARRAY(I,1)=ARRAY(I,1)+((ASUBN(J)*HOFT*AMP*DCOS((OMEGA*    QPR01630
     *                   TIME)+DELTA))+(BSUBN(J)*HOFT*AMP*DSIN((OMEGA*  QPR01640
     *                   TIME)+DELTA)))                                 QPR01650
C                                                                       QPR01660
              IF(DABS(ARRAY(I,1)).GT.MAXY)THEN                          QPR01670
                  MAXY=DABS(ARRAY(I,1))                                 QPR01680
              END IF                                                    QPR01690
C                                                                       QPR01700
40        CONTINUE                                                      QPR01710
C                                                                       QPR01720
          ARRAY(I,2)=TIME                                               QPR01730
          TIME=TIME+STEP                                                QPR01740
C                                                                       QPR01750
30    CONTINUE                                                          QPR01760
C                                                                       QPR01770
C     *** PLOT THE TIME SERIES IF DESIRED ***                           QPR01780
C                                                                       QPR01790
      IF(REP.EQ.1)THEN                                                  QPR01800
          MINY=-MAXY                                                    QPR01810
C                                                                       QPR01820
          CALL PLOT(MAXY,MINY,STEP,IN)                                  QPR01830
      END IF                                                            QPR01840
C                                                                       QPR01850
C     *** GENERATE THE FFT ***                                          QPR01860
C                                                                       QPR01870
      CALL FFTRC(ARRAY(1,1),IN,X,IWK)                                   QPR01880
C                                                                       QPR01890
C     *** CALCULATE THE AMPLITUDE SPECTRUM OF THE FUNCTION ***          QPR01900
C     *** FIND THE NUMBER AND VALUE OF THE PRINCIPLE HARMONIC ***       QPR01910
C                                                                       QPR01920
      N=0.D0                                                            QPR01930
      R=1                                                               QPR01940
      MAXY=0.D0                                                         QPR01950
      DO 50 I=1,IND2P1                                                  QPR01960
          ARRAY(R,1)=CDABS(X(R))                                        QPR01970
          ARRAY(R,2)=N/STEP                                             QPR01980
          IF(ARRAY(R,1).GT.MAXY)THEN                                    QPR01990
              MAXY=ARRAY(R,1)                                           QPR02000
              RMAX=R-1                                                  QPR02010
          END IF                                                        QPR02020
          R=R+1                                                         QPR02030
          N=N+1.D0                                                      QPR02040
50    CONTINUE                                                          QPR02050
C                                                                       QPR02060
C     *** DISPLAY INFO IF THE FIRST TIME THROUGH THE SUBPROGRAM ***     QPR02070
C                                                                       QPR02080
      IF(REP.EQ.1)THEN                                                  QPR02090
C                                                                       QPR02100
```

```
59    WRITE(10,60)RMAX                                                       QPR02110
60    FORMAT(' THE FFT HAS BEEN GENERATED!  THE PRINCIPLE HARMONIC',/,       QPR02120
     *' IS THE',I5,' HARMONIC.  THE NEXT PLOT TO BE PRODUCED WILL',/,        QPR02130
     *' BE THE AMPLITUDE SPECTRUM.  ENTER A 1 IF YOU ARE READY TO',/,        QPR02140
     *' CONTINUE WITH THE PROGRAM.',//,' :')                                 QPR02150
C                                                                            QPR02160
      READ(5,*)L                                                             QPR02170
C                                                                            QPR02180
      IF(L.NE. 1)THEN                                                        QPR02190
C        CALL FRTCMS('CLRSCRN ')                                             QPR02200
         WRITE(10,70)                                                        QPR02210
70       FORMAT(' ERROR',/)                                                  QPR02220
         GO TO 59                                                            QPR02230
      END IF                                                                 QPR02240
C                                                                            QPR02250
      END IF                                                                 QPR02260
C                                                                            QPR02270
C     *** ALLOW FOR THE PLOT OF THE AMPLITUDE SPECTRUM OF THE FFT ***        QPR02280
C                                                                            QPR02290
      IF(REP.EQ.1)THEN                                                       QPR02300
         MINY=0.D0                                                           QPR02310
         INT=1.D0/STEP                                                       QPR02320
C                                                                            QPR02330
         CALL PLOT(MAXY,MINY,INT,IND2P1)                                     QPR02340
      END IF                                                                 QPR02350
C                                                                            QPR02360
C     *** ADD THE VALUES OF THE FFT TO THE ACCUMULATED STATISTICS ***        QPR02370
C                                                                            QPR02380
      FLAG=0                                                                 QPR02390
      CALL STATS(IN,REP,FLAG)                                                QPR02400
C                                                                            QPR02410
      RETURN                                                                 QPR02420
      END                                                                    QPR02430
```

```
      SUBROUTINE STREAM(DSEED,ANS2,TYPE2,MT)
C
C     *** PURPOSE ***
C
C     THIS SUBPROGRAM ALLOWS THE INPUT OF SUCCESSIVE BITS DURING
C     MODULATION
C
C     *** PARAMETER DEFINITIONS ***
C
C     DSEED=         DOUBLE PRECISION SEED FOR RANDOM NUMBER GENERATOR
C     ANS2=          WHETHER OR NOT THE BIT STREAM IS TO BE GENERATED
C                    BY THE RANDOM NUMBER GENERATOR
C     TYPE2=         THE TYPE OF BINARY LOGIC TO BE EMPLOYED
C     MT=            VALUE OF THE BINARY DIGIT TO BE PASSED
C
C     *** VARIABLE DEFINITIONS ***
C
C     GGUBFS=        RANDOM NUMBER GENERATOR
C     IMT=           INTEGER VALUE OF BINARY DIGIT TO BE MODULATED
C
C     *** VARIABLE DECLARATIONS ***
C
      INTEGER ANS2,TYPE2,IMT
C
      DOUBLE PRECISION DSEED,MT
C
      IF(ANS2.EQ.1) THEN
          IF(TYPE2.EQ.1) THEN
              IF(GGUBFS(DSEED).LE..5D0) THEN
                  MT=1.D0
              ELSE
                  MT=-1.D0
              END IF
          ELSE IF(TYPE2.EQ.2) THEN
              IF(GGUBFS(DSEED).LE..5D0) THEN
                  MT=1.D0
              ELSE
                  MT=0.D0
              END IF
          ELSE IF(TYPE2.EQ.3) THEN
              IF(GGUBFS(DSEED).LE..5D0) THEN
                  MT=-1.D0
              ELSE
                  MT=0.D0
              END IF
          END IF
      ELSE IF(ANS2.EQ.2) THEN
          WRITE(10,10)
10        FORMAT(' ENTER THE NEXT BIT IN THE DESIRED BIT STREAM.',/)
          READ(5,*)IMT
```

```
         MT=IMT                                                         STR00610
      END IF                                                            STR00620
      RETURN                                                            STR00630
      END                                                               STR00640
```

```
      SUBROUTINE ORTHO(K,MT,SUM2,C,FLAG)                                ORT00110
C                                                                       ORT00120
C     *** PURPOSE ***                                                   ORT00130
C                                                                       ORT00140
C     THIS SUBROUTINE GENERATES AN ORTHOGONAL SET OF N VECTORS OF LENGTHORT00150
C     N, WHERE N IS 2**K, WHERE K IS THE LENGTH OF THE BINARY CODE WORD.ORT00160
C     AND DETERMINES THE VALUE, MT, OF A BINARY DIGIT TO BE RETURNED    ORT00170
C                                                                       ORT00180
C     *** PARAMETER DEFINITIONS ***                                     ORT00190
C                                                                       ORT00200
C     K=          NUMBER OF BITS IN THE BINARY CODE WORD                ORT00210
C     MT=         THE VALUE OF THE BINARY DIGIT TO BE MODULATED         ORT00220
C     SUM2=       THE DECIMAL EQUIVALENT OF A SET OF RANDOMLY DRAWN     ORT00230
C                 BINARY DIGITS                                         ORT00240
C     C=          THE COLUMN OF THE VECTOR WHERE THE BINARY DIGIT TO    ORT00250
C                 BE MODULATED IS LOCATED                               ORT00260
C     FLAG=       INTEGER WHICH CONTROLS POINT OF ENTRY TO SUBROUTINE   ORT00270
C                 CRTHO                                                 ORT00280
C                                                                       ORT00290
C     *** VARIABLE DEFINITICNS ***                                      ORT00300
C                                                                       ORT00310
C     ROW=        RCW OF ARRAY H2N WHICH MATCHES A BINARY CODE WORD     ORT00320
C     KM1=        INTEGER VALUE OF K MINUS 1                            ORT00330
C     N=          NUMBER OF POSSIBLE BINARY CODE WORDS = 2**K           ORT00340
C     H2N=        MATRIX OF N ORTHOGONAL VECTORS OF LENGTH N            ORT00350
C     RH2N=       ROW OF MATRIX H2N                                     ORT00360
C     CH2N=       COLUMN OF MATRIX H2N                                  ORT00370
C     H2NR=       RANK OF MATRIX H2N                                    ORT00380
C     RH2NP1=     ROW OF MATRIX H2N EQUAL TO HALF THE RANK PLUS 1       ORT00390
C     CH2NP1=     COLUMN OF MATRIX H2N EQUAL TO HALF THE RANK PLUS 1    ORT00400
C     X=          DOUBLE PRECISION EQUIVALENT ROW REPRESENTATION OF H2N ORT00410
C                                                                       ORT00420
C     *** VARIABLE DECLARATIONS ***                                     ORT00430
C                                                                       ORT00440
      INTEGER K,RH2N,CH2N,RH2NP1,CH2NP1,H2NR,N,KM1,H2N(65,65),          ORT00450
     *FLAG,ROW,C                                                        ORT00460
C                                                                       ORT00470
      DOUBLE PRECISION X,MT,SUM2                                        ORT00480
C                                                                       ORT00490
C     *** VARIABLE INITIALIZATION ***                                   ORT00500
C                                                                       ORT00510
      KM1=K-1                                                           ORT00520
      N=2**K                                                            ORT00530
      RH2N=1                                                            ORT00540
      CH2N=1                                                            ORT00550
      H2NR=2                                                            ORT00560
      RH2NP1=H2NR+1                                                     ORT00570
      CH2NP1=H2NR+1                                                     ORT00580
      H2N(1,1)=1                                                        ORT00590
      H2N(1,2)=1                                                        ORT00600
```

```
      H2N(2,1)=1                                                        ORT00610
      H2N(2,2)=-1                                                       ORT00620
C                                                                       ORT00630
C     *** GENERATE A MATRIX OF N ORTHOGONAL VECTORS OF LENGTH N ***     ORT00640
C                                                                       ORT00650
      IF(FLAG.EQ.0)THEN                                                 ORT00660
      DO 10 I=1,KM1                                                     ORT00670
          DO 20 L=1,H2NR                                                ORT00680
              DO 30 M=1,H2NR                                            ORT00690
                  H2N(RH2N,CH2N)=H2N(RH2N,CH2N)                         ORT00700
                  H2N(RH2N,CH2NP1)=H2N(RH2N,CH2N)                       ORT00710
                  H2N(RH2NP1,CH2N)=H2N(RH2N,CH2N)                       ORT00720
                  H2N(RH2NP1,CH2NP1)=-H2N(RH2N,CH2N)                    ORT00730
                  CH2N=CH2N+1                                           ORT00740
                  CH2NP1=CH2NP1+1                                       ORT00750
30            CONTINUE                                                  ORT00760
              RH2N=RH2N+1                                               ORT00770
              RH2NP1=RH2NP1+1                                           ORT00780
              CH2N=1                                                    ORT00790
              CH2NP1=H2NR+1                                             ORT00800
20        CONTINUE                                                      ORT00810
          H2NR=2*H2NR                                                   ORT00820
          RH2N=1                                                        ORT00830
          CH2N=1                                                        ORT00840
          RH2NP1=H2NR+1                                                 ORT00850
          CH2NP1=H2NR+1                                                 ORT00860
10    CONTINUE                                                          ORT00870
C                                                                       ORT00880
C     *** ASSIGN EACH ROW OF H2N A REPRESENTATIVE DECIMAL NUMBER ***    ORT00890
C                                                                       ORT00900
      DO 40 I=1,N                                                       ORT00910
          H2N(I,65)=I-1                                                 ORT00920
40    CONTINUE                                                          ORT00930
C                                                                       ORT00940
C     *** DETERMINE WHICH RCW OR H2N MATCHES THE VALUE OF THE           ORT00950
C     REPRESENTATIVE DECIMAL EQUIVALENT TO THE BINARY CODE WORD ***     ORT00960
C                                                                       ORT00970
      DO 50 I=1,N                                                       ORT00980
          X=H2N(I,65)                                                   ORT00990
          IF(SUM2.EQ.X)THEN                                             ORT01000
              ROW=I                                                     ORT01010
          END IF                                                        ORT01020
50    CONTINUE                                                          ORT01030
C                                                                       ORT01040
      END IF                                                            ORT01050
C                                                                       ORT01060
C     *** DETERMINE THE NEW ROW OF H2N ***                              ORT01070
C                                                                       ORT01080
      IF(FLAG.EQ.1)THEN                                                 ORT01090
          DO 60 I=1,N                                                   ORT01100
```

```
              X=H2N(I,65)                                              ORT01110
              IF(SUM2.EQ.X) THEN                                       ORT01120
                 ROW=I                                                 ORT01130
              END IF                                                   ORT01140
60        CONTINUE                                                     ORT01150
      END IF                                                           ORT01160
C                                                                      ORT01170
C     *** DETERMINE THE VALUE OF MT TO BE RETURNED ***                 ORT01180
C                                                                      ORT01190
      MT=H2N(ROW,C)                                                    ORT01200
      C=C+1                                                            ORT01210
C                                                                      ORT01220
      RETURN                                                           ORT01230
      END                                                              ORT01240
```

```
      SUBROUTINE PLOT(MAXY,MINY,INT,IN)                                 PLO00110
C                                                                       PLO00120
C     *** PURPOSE ***                                                   PLO00130
C                                                                       PLO00140
C     THIS SUBPROGRAM CONTROL THE USERS ABILITY TO MAKE A PLOT OF THE   PLO00150
C     TIME FUNCTION OR THE FFT                                          PLO00160
C                                                                       PLO00170
C     *** PARAMETER DEFINITIONS ***                                     PLO00180
C                                                                       PLO00190
C     MAXY=        MAXIMUM VALUE TO BE PLOTTED ON THE ABCISSAE          PLO00200
C     MINY=        MINIMUM VALUE TO BE PLOTTED ON THE ABCISSAE          PLO00210
C     INT=         DELTA TIME AT WHICH THE FUNCTION IS REPRODUCED       PLO00220
C     IN=          MAX LENGTH OF VECTOR TO BE PLOTTED                   PLO00230
C                                                                       PLO00240
C     *** VARIABLE DEFINITIONS ***                                      PLO00250
C                                                                       PLO00260
C     ANS=         RESPONSE TO INQUIRY                                  PLO00270
C     ARRAY=       ARRAY CONTAINING VALUES TO BE PLOTTED                PLO00280
C     RANGE=       ARRAY TO SPECIFY MIN AND MAX VALUES FOR THE ORDINATE PLO00290
C                  AND ABCISSA OF THE PLOT                              PLO00300
C     NI=          INTEGER NUMBER OF X,Y PAIRS TO BE PLOTTED            PLO00310
C     ND=          DOUBLE PRECISION OF NI                               PLO00320
C     R=           INTEGER VALUE FOR ROW OF ARRAY                       PLO00330
C                                                                       PLO00340
C     *** VARIABLE DECLARATIONS ***                                     PLO00350
C                                                                       PLO00360
      DOUBLE PRECISION MAXY,MINY,INT,ND                                 PLO00370
C                                                                       PLO00380
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  PLO00390
     *SUMX4(513)                                                        PLO00400
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              PLO00410
C                                                                       PLO00420
      REAL RANGE(4)                                                     PLO00430
C                                                                       PLO00440
      INTEGER ANS,NI,R,IN                                               PLO00450
C                                                                       PLO00460
C     CALL FRTCMS('CLRSCRN ')                                           PLO00470
C                                                                       PLO00480
      WRITE(10,10)                                                      PLO00490
10    FORMAT(' ENTER A 1 IF YOU DESIRE TO GENERATE A PLOT.',/,          PLO00500
     *' ENTER ANY OTHER INTEGER TO CONTINUE THE PROGRAM.',//,' :')      PLO00510
C                                                                       PLO00520
      READ(5,*)ANS                                                      PLO00530
C                                                                       PLO00540
      IF(ANS.EQ.1)THEN                                                  PLO00550
C        CALL FRTCMS('CLRSCRN ')                                        PLO00560
19       WRITE(10,20)IN,IN                                              PLO00570
20       FORMAT(' YOU MAY PLOT A MAXIMUM OF',I5,' X,Y PAIRS ON YOUR'    PLO00580
     *   ,/,' GRAPH.  IT IS RECOMMENDED THAT YOU PLOT NO MORE THAN'     PLO00590
     *   ,/,' 129 CONSECUTIVE PAIRS OF COORDINATE POINTS SO YOU',/,     PLO00600
```

```
     *' WILL HAVE THE OPPORTUNITY TO PLOT MORE THAN ONE SECTION',/,
     *' OF THE TOTAL RECORD OF',I5,' POINTS.  ENTER THE NUMBER',/,
     *' OF POINTS TO BE PLOTTED.',//,' :')
C
      READ(5,*)NI
C
      IF(NI.LE.IN)THEN
         CONTINUE
      ELSE
C        CALL FRTCMS('CLRSCRN ')
         WRITE(10,30)
30       FORMAT(' ERROR',/)
         GO TO 19
      END IF
C
C     CALL FRTCMS('CLRSCRN ')
39    WRITE(10,40)IN
40    FORMAT(' AT WHICH NUMBER OF THE',I5,' X,Y PAIRS DO YOU WISH',/
     *' TO START THE PLOT.',//,
     *' CAUTION!  THE POINT YOU SPECIFY TO START THE PLOT MUST BE',
     */,' SMALL ENOUGH TO ALLOW THE ENTIRE RANGE OF POINTS YOU',/,
     *' DESIRED TO HAVE PLOTTED AS SPECIFIED BY YOUR PREVIOUS INPUT'
     *)
C
      READ(5,*)R
C
      IF(R.GT.((IN+1)-NI))THEN
C        CALL FRTCMS('CLRSCRN ')
         WRITE(10,50)
50       FORMAT(' ERROR',/)
         GO TO 39
      END IF
C
      ND=NI
      RANGE(1)=(ARRAY(R,2)+(ND*INT))
      RANGE(2)=ARRAY(R,2)
      RANGE(3)=1.5D0*MAXY
      RANGE(4)=1.5D0*MINY
C
      WRITE(10,60)
60    FORMAT('1')
      CALL UTPLOT(ARRAY(R,2),ARRAY(R,1),NI,RANGE,2,0)
C
      WRITE(10,70)
70    FORMAT(' IF YOU WOULD LIKE ANOTHER PLOT OF THE SAME GRAPH OR',
     */,' A PLOT OVER A DIFFERENT RANGE OR FROM ANOTHER STARTING',/,
     *' POINT, ENTER A 1.  ENTER ANY OTHER INTEGER TO CONTINUE WITH'
     *,/,' THE PROGRAM.',//,' :')
C
      READ(5,*)ANS
```

```
C
         IF(ANS.EQ.1)THEN
            GO TO 19
         END IF
      END IF
C
      RETURN
      END
```

```
      SUBROUTINE STATS(IN,REP,FLAG)
C
C     *** PURPOSE ***
C
C     THIS SUBPROGRAM COMPILES THE ACCUMULATED STATISTICS OF THE
C     ELEMENTS OF THE AMPLITUDE SPECTRUM OF THE FFTS.
C
C     *** PARAMETER DEFINITIONS ***
C
C     IN=         INTEGER OF THE NUMBER OF POSITIONS USED IN ARRAY
C     REP=        INTEGER OF THE NUMBER OF THE REPETITION OF THE
C                 GENERATION OF THE AMPLITUDE SPECTRUM OF THE FFT
C     FLAG=       AN INTEGER THAT CONTROLS THE POINT OF ENTRANCE OR
C                 EXIT FROM THE SUBROUTINE
C
C     *** VARIABLE DEFINITIONS ***
C
C     IND2P1=     POSITIONS USED IN ARRAYS SUMX AND SUMXSQ
C     ARRAY=      AN ARRAY CONTAINING THE VALUES OF THE AMPLITUDE
C                 SPECTRUM OF THE FFT
C     SUMX=       AN ARRAY CONTAINING THE SUM OF THE VALUES OF THE
C                 AMPLITUDE SPECTRUM OF THE FFT
C     SUMXSQ=     AN ARRAY CONTAINING THE SUM OF THE SQUARES OF THE
C                 VALUES OF THE AMPLITUDE SPECTRUM OF THE FFT
C     SUMX3=      AN ARRAY CONTAINING THE SUM OF THE SQUARES OF THE
C                 VALUES OF THE AMPLITUDE SPECTRUM OF THE FFT
C     SUMX4=      AN ARRAY CONTAINING THE SUM OF THE QUARTICS OF THE
C                 VALUES OF THE AMPLITUDE SPECTRUM OF THE FFT
C     XBAR=       AN ARRAY CONTAINING THE AVERAGE VALUE OF THE
C                 ELEMENTS OF THE AMPLITUDE SPECTRUM
C     VAR=        AN ARRAY CONTAINING THE VARIANCE OF THE VALUES OF
C                 THE ELEMENTS OF THE AMPLITUDE SPECTRUM
C     SKEW=       AN ARRAY CONTAINING THE SKEWNESS OF THE DISTRIBUTION
C                 OF THE ELEMENTS OF THE AMPLITUDE SPECTRUM
C     KUR=        AN ARRAY CONTAINING THE KURTOSIS OF THE DISTRIBUTION
C                 OF THE ELEMENTS OF THE AMPLITUDE SPECTRUM
C     SUMVAR=     SUM OF THE VARIANCES OF AN ELEMENT OF THE AMPLITUDE
C                 SPECTRUM
C     AVAR=       AVERAGE VARIANCE OF AN ELEMENT OF THE AMPLITUDE
C                 SPECTRUM
C     VARVAR=     VARIANCE OF THE VARIANCES OF AN ELEMENT OF THE
C                 AMPLITUDE SPECTRUM
C     SUMVSQ=     SUM OF THE SQUARE OF THE VARIANCES OF AN ELEMENT OF
C                 AMPLITUDE SPECTRUM
C     SUMSKW=     SUM OF THE SKEWNESS OF THE ELEMENT OF THE AMPLITUDE
C                 SPECTRUM
C     ASKEW=      AVERAGE SKEWNESS OF THE ELEMENTS OF THE AMPLITUDE
C                 SPECTRUM
C     VARSKW=     VARIANCE OF THE SKEWNESS OF THE ELEMENTS OF THE
C                 AMPLITUDE SPECTRUM
```

```
C     SUMSSQ=     SUM OF THE SQUARE OF THE SKEWNESS OF THE ELEMENTS OF  STA00610
C                 THE AMPLITUDE SPECTRUM                                STA00620
C     SUMKUR=     SUM OF THE KURTOSIS OF THE ELEMENTS OF THE AMPLITUDE  STA00630
C                 SPECTRUM                                              STA00640
C     AKUR=       AVERAGE KURTOSIS OF AN ELEMENT OF THE AMPLITUDE       STA00650
C                 SPECTRUM                                              STA00660
C     VARKUR=     VARIANCE OF THE KURTOSIS OF AN ELEMENT OF THE         STA00670
C                 AMPLITUDE SPECTRUM                                    STA00680
C     SUMKSQ=     SUM OF THE SQUARE OF THE KURTOSIS OF THE ELEMENTS OF  STA00690
C                 THE AMPLITUDE SPECTRUM                                STA00700
C                                                                       STA00710
C     REPDP=      DOUBLE PRECISION VALUE OF REP                         STA00720
C                                                                       STA00730
C     *** VARIABLE DECLARATIONS ***                                     STA00740
C                                                                       STA00750
      INTEGER IN,REP,FLAG,IND2P1                                        STA00760
C                                                                       STA00770
      DOUBLE PRECISION REPDP,SUMVAR,SUMVSQ,AVAR,VARVAR,SUMSKW,SUMSSQ,   STA00780
     *ASKEW,VARSKW,SUMKUR,SUMKSQ,AKUR,VARKUR,NDP                        STA00790
C                                                                       STA00800
      DOUBLE PRECISION ARRAY(1024,2),SUMX(513),SUMXSQ(513),SUMX3(513),  STA00810
     *SUMX4(513),XBAR(513),VAR(513),SKEW(513),KUR(513)                  STA00820
      COMMON ARRAY,SUMX,SUMXSQ,SUMX3,SUMX4                              STA00830
C                                                                       STA00840
C     *** VARIABLE INITIALIZATION ***                                   STA00850
C                                                                       STA00860
      IND2P1=IN/2+1                                                     STA00870
      IF(REP.EQ.1)THEN                                                  STA00880
          DO 10 I=1,IND2P1                                              STA00890
              SUMX(I)=0.D0                                              STA00900
              SUMXSQ(I)=0.D0                                            STA00910
              SUMX3(I)=0.D0                                             STA00920
              SUMX4(I)=0.D0                                             STA00930
10        CONTINUE                                                      STA00940
      END IF                                                            STA00950
C                                                                       STA00960
C     *** IF FINAL TIME THROUGH STATS, COMPUTE THE OUTPUT STATISTICS ***STA00970
C                                                                       STA00980
      IF(FLAG.EQ.1)THEN                                                 STA00990
          GO TO 30                                                      STA01000
      END IF                                                            STA01010
C                                                                       STA01020
C     *** ADD THE ELEMENTS OF ARRAY TO THE ELEMENTS OF SUMX, SUMXSQ,    STA01030
C     SUMX3, AND SUMX4 ***                                              STA01040
C                                                                       STA01050
      DO 20 I=1,IND2P1                                                  STA01060
          SUMX(I)=SUMX(I)+ARRAY(I,1)                                    STA01070
          SUMXSQ(I)=SUMXSQ(I)+ARRAY(I,1)**2                             STA01080
          SUMX3(I)=SUMX3(I)+ARRAY(I,1)**3                               STA01090
          SUMX4(I)=SUMX4(I)+ARRAY(I,1)**4                               STA01100
```

```
20    CONTINUE                                                          STA01110
C                                                                       STA01120
C     *** COMPUTE THE FINAL STATISTICS IF FLAG EQUALS 1 ***             STA01130
C                                                                       STA01140
30    IF(FLAG.EQ.1)THEN                                                 STA01150
C                                                                       STA01160
C     *** COMPUTE STATISTICS ASSOCIATED WITH EACH ELEMENT OF FFT ***    STA01170
C                                                                       STA01180
          REP=REP-1                                                     STA01190
          REPDP=REP                                                     STA01200
          DO 40 I=1,IND2P1                                              STA01210
              XBAR(I)=SUMX(I)/REP                                       STA01220
              IF(REP.EQ.1)THEN                                          STA01230
              VAR (I)=((REPDP*SUMXSQ(I))-SUMX (I)**2)/REPDP**2          STA01240
              ELSE                                                      STA01250
              VAR (I)=((REPDP*SUMXSQ(I))-SUMX (I)**2)/(REPDP*(REPDP-1.D0)) STA01260
              END IF                                                    STA01270
              SKEW(I)=(SUMX3(I)/REPDP)-(3.D0*(SUMXSQ(I)/REPDP)*         STA01280
     *                (SUMX(I)/REPDP))+(2.D0*(SUMX(I)/REPDP)**2)        STA01290
              KUR (I)=(SUMX4(I)/REPDP)-(4.D0*(SUMX3(I)/REPDP)*          STA01300
     *               (SUMX(I)/REPDP))+(6.D0*(SUMX(I)/REPDP)**2*         STA01310
     *               (SUMXSQ(I)/REPDP))-(3.D0*(SUMX(I)/REPDP)**4)       STA01320
40        CONTINUE                                                      STA01330
C                                                                       STA01340
C     *** OUTPUT SOME DATA ***                                          STA01350
C                                                                       STA01360
          WRITE(6,50)                                                   STA01370
50        FORMAT('1',2X,' N',11X,' MEAN',17X,' VARIANCE',17X,' SKEWNESS'STA01380
     *    ,16X,' KURTOSIS')                                             STA01390
C                                                                       STA01400
          DO 60 I=1,IND2P1                                              STA01410
              WRITE(6,70)I,XBAR(I),VAR(I),SKEW(I),KUR(I)                STA01420
70            FORMAT(1X,I5,2X,E23.16,2X,E23.16,2X,E23.16,2X,E23.16)     STA01430
60        CONTINUE                                                      STA01440
C                                                                       STA01450
          WRITE(6,61)                                                   STA01460
61        FORMAT('1',2X,' N',10X,' SUM X',18X,' SUM X**2',16X,          STA01470
     *    ' SUM X**3',16X,' SUM X**4')                                  STA01480
C                                                                       STA01490
          DO 62 I=1,IND2P1                                              STA01500
              WRITE(6,63)I,SUMX(I),SUMXSQ(I),SUMX3(I),SUMX4(I)          STA01510
63            FORMAT(1X,I5,2X,E23.16,2X,E23.16,2X,E23.16,2X,E23.16)     STA01520
62        CONTINUE                                                      STA01530
C                                                                       STA01540
C     *** COMPUTE STATISTICS ASSOCIATED WITH ALL ELEMENTS OF FFT ***    STA01550
C                                                                       STA01560
          SUMVAR=0.D0                                                   STA01570
          SUMVSQ=0.D0                                                   STA01580
          VARVAR=0.D0                                                   STA01590
          SUMSKW=0.D0                                                   STA01600
```

```
      SUMSSQ=0.D0                                                       STA01610
      VARSKW=0.D0                                                       STA01620
      SUMKUR=0.D0                                                       STA01630
      SUMKSQ=0.D0                                                       STA01640
      VARKUR=0.D0                                                       STA01650
      NDP=IND2P1                                                        STA01660
C                                                                       STA01670
      DO 80 I=1,IND2P1                                                  STA01680
         SUMVAR=SUMVAR+VAR(I)                                           STA01690
         SUMVSQ=SUMVSQ+(VAR(I)**2)                                      STA01700
         SUMSKW=SUMSKW+SKEW(I)                                          STA01710
         SUMSSQ=SUMSSQ+(SKEW(I)**2)                                     STA01720
         SUMKUR=SUMKUR+KUR(I)                                           STA01730
         SUMKSQ=SUMKSQ+(KUR(I)**2)                                      STA01740
80    CONTINUE                                                          STA01750
C                                                                       STA01760
      AVAR=SUMVAR/NDP                                                   STA01770
      ASKEW=SUMSKW/NDP                                                  STA01780
      AKUR=SUMKUR/NDP                                                   STA01790
C                                                                       STA01800
      DO 90 I=1,IND2P1                                                  STA01810
         VARVAR=VARVAR+(VAR(I)-AVAR)**2                                 STA01820
         VARSKW=VARSKW+(SKEW(I)-ASKEW)**2                               STA01830
         VARKUR=VARKUR+(KUR(I)-AKUR)**2                                 STA01840
90    CONTINUE                                                          STA01850
C                                                                       STA01860
      VARVAR=VARVAR/(NDP-1.D0)                                          STA01870
      VARSKW=VARSKW/(NDP-1.D0)                                          STA01880
      VARKUR=VARKUR/(NDP-1.D0)                                          STA01890
C                                                                       STA01900
      WRITE(6,91)                                                       STA01910
91    FORMAT('1',2X,' SUM OF VARIANCES',7X,' SUM OF VARIANCES**2')      STA01920
C                                                                       STA01930
      WRITE(6,92) SUMVAR,SUMVSQ                                         STA01940
92    FORMAT(1X,E23.16,2X,E23.16)                                       STA01950
C                                                                       STA01960
      WRITE(6,93)                                                       STA01970
93    FORMAT('0',2X,' SUM OF SKEWNESS',9X,' SUM OF SKEWNESS**2')        STA01980
C                                                                       STA01990
      WRITE(6,94) SUMSKW,SUMSSQ                                         STA02000
94    FORMAT(1X,E23.16,2X,E23.16)                                       STA02010
C                                                                       STA02020
      WRITE(6,95)                                                       STA02030
95    FORMAT('0',2X,' SUM OF KURTOSIS',9X,' SUM OF KURTOSIS**2')        STA02040
C                                                                       STA02050
      WRITE(6,96) SUMKUR,SUMKSQ                                         STA02060
96    FORMAT(1X,E23.16,2X,E23.16)                                       STA02070
C                                                                       STA02080
      WRITE(6,100)                                                      STA02090
100   FORMAT('0',3X,' MEAN VARIANCE',7X,' VARIANCE OF THE VARIANCES'STA02100
```

```
     *    )                                                             STA02110
C                                                                       STA02120
          WRITE(6,101)AVAR,VARVAR                                       STA02130
101       FORMAT(1X,E23.16,2X,E23.16)                                   STA02140
C                                                                       STA02150
          WRITE(6,102)                                                  STA02160
102       FORMAT('0',3X,' MEAN SKEWNESS',7X,' VARIANCE OF THE SKEWNESS')STA02170
C                                                                       STA02180
          WRITE(6,103)ASKEW,VARSKW                                      STA02190
103       FORMAT(1X,E23.16,2X,E23.16)                                   STA02200
C                                                                       STA02210
          WRITE(6,104)                                                  STA02220
104       FORMAT('0',3X,' MEAN KURTOSIS',7X,' VARIANCE OF THE KURTOSIS')STA02230
C                                                                       STA02240
          WRITE(6,105)AKUR,VARKUR                                       STA02250
105       FORMAT(1X,E23.16,2X,E23.16)                                   STA02260
C                                                                       STA02270
          WRITE(6,106)                                                  STA02280
106       FORMAT('1')                                                   STA02290
C                                                                       STA02300
      END IF                                                            STA02310
C                                                                       STA02320
      RETURN                                                            STA02330
      END                                                               STA02340
```

APPENDIX B

IMSL/NON-IMSL ROUTINES UTILIZED

IMSL ROUTINES

```
C   IMSL ROUTINE NAME   - GGUBFS                                       GGU00110
C                                                                      GGU00120
C----------------------------------------------------------------------GGU00130
C                                                                      GGU00140
C   COMPUTER            - IBM/SINGLE                                   GGU00150
C                                                                      GGU00160
C   LATEST REVISION     - JUNE 1, 1980                                 GGU00170
C                                                                      GGU00180
C   PURPOSE             - BASIC UNIFORM (0,1) RANDOM NUMBER GENERATOR - GGU00190
C                           FUNCTION FORM OF GGUBS                     GGU00200
C                                                                      GGU00210
C   USAGE               - FUNCTION GGUBFS (DSEED)                      GGU00220
C                                                                      GGU00230
C   ARGUMENTS    GGUBFS - RESULTANT DEVIATE.                           GGU00240
C                DSEED  - INPUT/OUTPUT DOUBLE PRECISION VARIABLE       GGU00250
C                           ASSIGNED AN INTEGER VALUE IN THE           GGU00260
C                           EXCLUSIVE RANGE (1.D0, 2147483647.D0).     GGU00270
C                           DSEED IS REPLACED BY A NEW VALUE TO BE     GGU00280
C                           USED IN A SUBSEQUENT CALL.                 GGU00290
C                                                                      GGU00300
C   PRECISION/HARDWARE  - SINGLE/ALL                                   GGU00310
C                                                                      GGU00320
C   REQD. IMSL ROUTINES - NONE REQUIRED                                GGU00330
C                                                                      GGU00340
C   NOTATION            - INFORMATION ON SPECIAL NOTATION AND          GGU00350
C                           CONVENTIONS IS AVAILABLE IN THE MANUAL     GGU00360
C                           INTRODUCTION OR THROUGH IMSL ROUTINE UHELP GGU00370
C                                                                      GGU00380
C   COPYRIGHT           - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.      GGU00390
C                                                                      GGU00400
C   WARRANTY            - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN GGU00410
C                           APPLIED TO THIS CODE. NO OTHER WARRANTY,   GGU00420
C                           EXPRESSED OR IMPLIED, IS APPLICABLE.       GGU00430
C                                                                      GGU00440
C----------------------------------------------------------------------GGU00450
C                                                                      GGU00460
      REAL FUNCTION GGUBFS (DSEED)                                     GGU00470
C                                  SPECIFICATIONS FOR ARGUMENTS        GGU00480
      DOUBLE PRECISION   DSEED                                         GGU00490
C                                  SPECIFICATIONS FOR LOCAL VARIABLES  GGU00500
```

```
      DOUBLE PRECISION   D2P31M,D2P31                                   GGU00510
C                                  D2P31M=(2**31) - 1                   GGU00520
C                                  D2P31 =(2**31) (OR AN ADJUSTED VALUE) GGU00530
      DATA               D2P31M/2147483647.D0/                          GGU00540
      DATA               D2P31 /2147483648.D0/                          GGU00550
C                                  FIRST EXECUTABLE STATEMENT           GGU00560
      DSEED = DMOD(16807.D0*DSEED,D2P31M)                               GGU00570
      GGUBFS = DSEED / D2P31                                            GGU00580
      RETURN                                                            GGU00590
      END                                                               GGU00600
```

```
C   IMSL ROUTINE NAME   - FFTRC                                         FFT00110
C                                                                       FFT00120
C-----------------------------------------------------------------------FFT00130
C                                                                       FFT00140
C   COMPUTER            - IBM/DOUBLE                                    FFT00150
C                                                                       FFT00160
C   LATEST REVISION     - JANUARY 1, 1978                               FFT00170
C                                                                       FFT00180
C   PURPOSE             - COMPUTE THE FAST FOURIER TRANSFORM OF A       FFT00190
C                           REAL VALUED SEQUENCE                        FFT00200
C                                                                       FFT00210
C   USAGE               - CALL FFTRC (A,N,X,IWK,WK)                     FFT00220
C                                                                       FFT00230
C   ARGUMENTS    A      - INPUT REAL VECTOR OF LENGTH N WHICH           FFT00240
C                           CONTAINS THE DATA TO BE TRANSFORMED.        FFT00250
C                N      - INPUT NUMBER OF DATA POINTS TO BE TRANSFORMED.FFT00260
C                            N MUST BE A POSITIVE EVEN INTEGER.         FFT00270
C                X      - OUTPUT COMPLEX VECTOR OF LENGTH N/2+1         FFT00280
C                           CONTAINING THE FIRST N/2+1 COEFFICIENTS OF  FFT00290
C                           THE FOURIER TRANSFORM. THE REMAINING        FFT00300
C                           COEFFICIENTS MAY BE DETERMINED BY           FFT00310
C                             X(N+2-I) = CONJG(X(I)), FOR I=2,...,N/2.  FFT00320
C                IWK    - INTEGER WORK VECTOR.                          FFT00330
C                           IF N IS A POWER OF 2, THEN IWK SHOULD BE OF FFT00340
C                           LENGTH M WHERE N=2**M.                      FFT00350
C   PRECISION/HARDWARE  - SINGLE AND DOUBLE/H32                         FFT00430
C                       - SINGLE/H36,H48,H60                            FFT00440
C                                                                       FFT00450
C   REQD. IMSL ROUTINES - FFTCC,FFT2C                                   FFT00460
C                                                                       FFT00470
C   NOTATION            - INFORMATION ON SPECIAL NOTATION AND           FFT00480
C                           CONVENTIONS IS AVAILABLE IN THE MANUAL      FFT00490
C                           INTRODUCTION OR THROUGH IMSL ROUTINE UHELP  FFT00500
C                                                                       FFT00510
C   REMARKS  1.  FFTRC COMPUTES THE FOURIER TRANSFORM, X, ACCORDING     FFT00520
C                TC THE FOLLOWING FORMULA;                              FFT00530
C                                                                       FFT00540
C                  X(K+1) = SUM FROM J = 0 TO N-1 OF                    FFT00550
C                           A(J+1)*CEXP((0.0,(2.0*PI*J*K)/N))           FFT00560
C                  FOR K=0,1,...,N/2 AND PI=3.1415...                   FFT00570
C                                                                       FFT00580
C                THE USER CAN COMPUTE THE REMAINING X VALUES BY         FFT00590
C                PERFORMING THE FOLLOWING STEPS;                        FFT00600
C                                                                       FFT00610
C                     ND2 = N/2                                         FFT00620
C                     DO 10 I=2,ND2                                     FFT00630
C                        X(N+2-I) = CONJG(X(I))                         FFT00640
C                  10 CONTINUE                                          FFT00650
C            2.  FFTRC CAN BE USED TO COMPUTE                           FFT00660
C                                                                       FFT00670
```

```
C                  X(K+1) = (1/N)*SUM FROM J = 0 TO N-1 OF              FFT00680
C                           A(J+1)*CEXP((0.0,(-2.0*PI*J*K)/N))          FFT00690
C                  FOR K=0,1,...,N/2 AND PI=3.1415...                   FFT00700
C                                                                       FFT00710
C                BY PERFORMING THE FOLLOWING STEPS;                     FFT00720
C                                                                       FFT00730
C                     CALL FFTRC (A,N,X,IWK,WK)                         FFT00740
C                     ND2P1 = N/2+1                                     FFT00750
C                     DO  10 I=1,ND2P1                                  FFT00760
C                        X(I) = CONJG(X(I))/N                           FFT00770
C                  10 CONTINUE                                          FFT00780
C                                                                       FFT00790
C   COPYRIGHT           - 1978 BY IMSL, INC.  ALL RIGHTS RESERVED.      FFT00800
C                                                                       FFT00810
C   WARRANTY            - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN FFT00820
C                           APPLIED TO THIS CODE.  NO OTHER WARRANTY,   FFT00830
C                           EXPRESSED OR IMPLIED, IS APPLICABLE.        FFT00840
C                                                                       FFT00850
C   MODIFIED 5 AUGUST 1985 TO ALLOW THE GENERATION ONLY OF FFT CF VECTORFFT00860
C   OF LENGTH EQUAL TO AN EVEN POWER OF 2 AND THE ENTIRE FFT.           FFT00870
C-----------------------------------------------------------------------FFT00880
C                                                                       FFT00890
      SUBROUTINE FFTRC  (A,N,X,IWK)                                     FFT00900
C                                  SPECIFICATIONS FOR ARGUMENTS         FFT00910
      INTEGER            N,IWK(1)                                       FFT00920
      DOUBLE PRECISION   A(N)                                           FFT00930
      COMPLEX*16         X(1)                                           FFT00940
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   FFT00950
      INTEGER            ND2P1,ND2,I,MTWO,M,IMAX,ND4,NP2,K,NMK,J        FFT00960
      DOUBLE PRECISION   RPI,ZERO,ONE,HALF,THETA,TP,G(2),B(2),Z(2),AI,  FFT00970
     1                   AR                                             FFT00980
      COMPLEX*16         XIMAG,ALPH,BETA,GAM,S1,ZD                      FFT00990
      EQUIVALENCE        (GAM,G(1)),(ALPH,B(1)),(Z(1),AR),(Z(2),AI),    FFT01000
     1                   (ZD,Z(1))                                      FFT01010
      DATA               ZERO/0.0D0/,HALF/0.5D0/,ONE/1.0D0/,IMAX/24/    FFT01020
      DATA               RPI/3.141592653589793D0/                       FFT01030
C                                  FIRST EXECUTABLE STATEMENT           FFT01040
      IF (N .NE. 2) GO TO 5                                             FFT01050
C                                  N EQUAL TO 2                         FFT01060
      ZD = DCMPLX(A(1),A(2))                                            FFT01070
      THETA = AR                                                        FFT01080
      TP = AI                                                           FFT01090
      X(2) = DCMPLX(THETA-TP,ZERO)                                      FFT01100
      X(1) = DCMPLX(THETA+TP,ZERO)                                      FFT01110
      GO TO 9005                                                        FFT01120
    5 CONTINUE                                                          FFT01130
C                                  N GREATER THAN 2                     FFT01140
      ND2 = N/2                                                         FFT01150
      ND2P1 = ND2+1                                                     FFT01160
C                                  MOVE A TO X                          FFT01170
```

```
      J = 1                                                             FFT01180
      DO 6 I=1,ND2                                                      FFT01190
         X(I) = DCMPLX(A(J),A(J+1))                                     FFT01200
         J = J+2                                                        FFT01210
    6 CONTINUE                                                          FFT01220
C                                  COMPUTE THE CENTER COEFFICIENT       FFT01230
      GAM = DCMPLX(ZERO,ZERO)                                           FFT01240
      DO 10 I=1,ND2                                                     FFT01250
         GAM = GAM + X(I)                                               FFT01260
   10 CONTINUE                                                          FFT01270
      TP = G(1)-G(2)                                                    FFT01280
      GAM = DCMPLX(TP,ZERO)                                             FFT01290
C                                  DETERMINE THE SMALLEST M SUCH THAT   FFT01300
C                                  N IS LESS THAN OR EQUAL TO 2**M      FFT01310
      MTWO = 2                                                          FFT01320
      M = 1                                                             FFT01330
      DO 15 I=1,IMAX                                                    FFT01340
         IF (ND2 .LE. MTWO) GO TO 20                                    FFT01350
         MTWO = MTWO+MTWO                                               FFT01360
         M = M+1                                                        FFT01370
   15 CONTINUE                                                          FFT01380
   20 IF (ND2 .EQ. MTWO) GO TO 25                                       FFT01390
C                                  N IS NOT A POWER OF TWO, CALL FFTCC  FFT01400
C                                  N IS A POWER OF TWO, CALL FFT2C      FFT01410
   25 CALL FFT2C (X,M,IWK)                                              FFT01420
   30 ALPH = X(1)                                                       FFT01430
      X(1) = B(1) + B(2)                                                FFT01440
      ND4 = (ND2+1)/2                                                   FFT01450
      IF (ND4 .LT. 2) GO TO 40                                          FFT01460
      NP2 = ND2 + 2                                                     FFT01470
      THETA = RPI/ND2                                                   FFT01480
      TP = THETA                                                        FFT01490
      XIMAG = DCMPLX(ZERO,ONE)                                          FFT01500
C                                  DECOMPOSE THE COMPLEX VECTOR X       FFT01510
C                                  INTO THE COMPONENTS OF THE TRANSFORM FFT01520
C                                  OF THE INPUT DATA.                   FFT01530
      DO 35 K = 2,ND4                                                   FFT01540
         NMK = NP2 - K                                                  FFT01550
         S1 = DCONJG(X(NMK))                                            FFT01560
         ALPH = X(K) + S1                                               FFT01570
         BETA = XIMAG*(S1-X(K))                                         FFT01580
         S1 = DCMPLX(DCOS(THETA),DSIN(THETA))                           FFT01590
         X(K) = (ALPH+BETA*S1)*HALF                                     FFT01600
         X(NMK) = DCONJG(ALPH-BETA*S1)*HALF                             FFT01610
         THETA = THETA + TP                                             FFT01620
   35 CONTINUE                                                          FFT01630
   40 CONTINUE                                                          FFT01640
      X(ND2P1) = GAM                                                    FFT01650
C     ND2=N/2                                                           FFT01660
C     DO 90 I=2,ND2                                                     FFT01670
```

```
C            X(N+2-I)=DCONJG(X(I))                                              FFT01680
C90     CONTINUE                                                                FFT01690
  9005 RETURN                                                                   FFT01700
       END                                                                      FFT01710
```

```
C   IMSL ROUTINE NAME   - FFT2C                                         FFT00110
C                                                                       FFT00120
C-----------------------------------------------------------------------FFT00130
C                                                                       FFT00140
C   COMPUTER            - IBM/DOUBLE                                    FFT00150
C                                                                       FFT00160
C   LATEST REVISION     - NCVEMBER 1, 1984                              FFT00170
C                                                                       FFT00180
C   PURPOSE             - COMPUTE THE FAST FOURIER TRANSFORM OF A       FFT00190
C                           COMPLEX VALUED SEQUENCE OF LENGTH EQUAL TO  FFT00200
C                           A POWER OF TWO                              FFT00210
C                                                                       FFT00220
C   USAGE               - CALL FFT2C (A,M,IWK)                          FFT00230
C                                                                       FFT00240
C   ARGUMENTS    A      - COMPLEX VECTOR OF LENGTH N, WHERE N=2**M.     FFT00250
C                           ON INPUT A CONTAINS THE COMPLEX VALUEC      FFT00260
C                           SEQUENCE TO BE TRANSFORMED.                 FFT00270
C                           ON OUTPUT A IS REPLACED BY THE              FFT00280
C                           FOURIER TRANSFORM.                          FFT00290
C                M      - INPUT EXPONENT TO WHICH 2 IS RAISED TO        FFT00300
C                           PRODUCE THE NUMBER OF DATA POINTS, N        FFT00310
C                           (I.E. N = 2**M).                            FFT00320
C                IWK    - WORK VECTOR OF LENGTH M+1.                    FFT00330
C                                                                       FFT00340
C   PRECISION/HARCWARE  - SINGLE AND DOUBLE/H32                         FFT00350
C                       - SINGLE/H36,H48,H60                            FFT00360
C                                                                       FFT00370
C   REQD. IMSL ROUTINES - NCNE REQUIRED                                 FFT00380
C                                                                       FFT00390
C   NOTATION            - INFORMATION ON SPECIAL NOTATION AND           FFT00400
C                           CONVENTIONS IS AVAILABLE IN THE MANUAL      FFT00410
C                           INTRODUCTION OR THROUGH IMSL ROUTINE UHEIP  FFT00420
C                                                                       FFT00430
C   REMARKS  1.  FFT2C COMPUTES THE FOURIER TRANSFORM, X, ACCORDING     FFT00440
C                TC THE FOLLOWING FORMULA;                              FFT00450
C                                                                       FFT00460
C                  X(K+1) = SUM FROM J = 0 TO N-1 OF                    FFT00470
C                           A(J+1)*CEXP((0.0,(2.0*PI*J*K)/N))           FFT00480
C                  FOR K=0,1,...,N-1 AND PI=3.1415...                   FFT00490
C                                                                       FFT00500
C                NOTE THAT X OVERWRITES A ON OUTPUT.                    FFT00510
C            2.  FFT2C CAN BE USED TO COMPUTE THE INVERSE FOURIER       FFT00520
C                TRANSFORM, X, ACCORDING TO THE FOLLOWING FORMULA;      FFT00530
C                                                                       FFT00540
C                  X(K+1) = (1/N)*SUM FROM J = 0 TO N-1 OF              FFT00550
C                           A(J+1)*CEXP((0.0,(-2.0*PI*J*K)/N))          FFT00560
C                  FOR K=0,1,...,N-1 AND PI=3.1415...                   FFT00570
C                                                                       FFT00580
C                BY PERFORMING THE FOLLOWING STEPS;                     FFT00590
C                                                                       FFT00600
```

```
C                     DO 10 I=1,N                                       FFT00610
C                        A(I) = CONJG(A(I))                             FFT00620
C                  10 CONTINUE                                          FFT00630
C                     CALL FFT2C (A,M,IWK)                              FFT00640
C                     DO 20 I=1,N                                       FFT00650
C                        A(I) = CONJG(A(I))/N                           FFT00660
C                  20 CONTINUE                                          FFT00670
C                                                                       FFT00680
C   COPYRIGHT           - 1978 BY IMSL, INC.  ALL RIGHTS RESERVED.      FFT00690
C                                                                       FFT00700
C   WARRANTY            - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN FFT00710
C                           APPLIED TO THIS CODE.  NO OTHER WARRANTY,   FFT00720
C                           EXPRESSED OR IMPLIED, IS APPLICABLE.        FFT00730
C                                                                       FFT00740
C-----------------------------------------------------------------------FFT00750
C                                                                       FFT00760
      SUBROUTINE  FFT2C (A,M,IWK)                                       FFT00770
C                                  SPECIFICATIONS FOR ARGUMENTS         FFT00780
      INTEGER            M,IWK(1)                                       FFT00790
      COMPLEX*16         A(1)                                           FFT00800
C                                  SPECIFICATIONS FOR LOCAL VARIABLES   FFT00810
      INTEGER            I,ISP,J,JJ,JSP,K,K0,K1,K2,K3,KB,KN,MK,MM,MP,N, FFT00820
     1                   N4,N8,N2,LM,NN,JK                              FFT00830
      DOUBLE PRECISION   RAD,C1,C2,C3,S1,S2,S3,CK,SK,SQ,A0,A1,A2,A3,    FFT00840
     1                   B0,B1,B2,B3,TWOPI,TEMP,                        FFT00850
     2                   ZERO,ONE,Z0(2),Z1(2),Z2(2),Z3(2)               FFT00860
      COMPLEX*16         ZA0,ZA1,ZA2,ZA3,AK2                            FFT00870
      EQUIVALENCE        (ZA0,Z0(1)),(ZA1,Z1(1)),(ZA2,Z2(1)),           FFT00880
     1                   (ZA3,Z3(1)),(A0,Z0(1)),(B0,Z0(2)),(A1,Z1(1)),  FFT00890
     2                   (B1,Z1(2)),(A2,Z2(1)),(B2,Z2(2)),(A3,Z3(1)),   FFT00900
     3                   (B3,Z3(2))                                     FFT00910
      DATA               SQ/.7071067811865475D0/,                       FFT00920
     1                   SK/.3826834323650898D0/,                       FFT00930
     2                   CK/.9238795325112868D0/,                       FFT00940
     3                   TWOPI/6.283185307179586D0/                     FFT00950
      DATA               ZERO/0.0D0/,ONE/1.0D0/                         FFT00960
C                                  SQ=SQRT2/2,SK=SIN(PI/8),CK=COS(PI/8) FFT00970
C                                  TWOPI=2*PI                           FFT00980
C                                  FIRST EXECUTABLE STATEMENT           FFT00990
      MP = M+1                                                          FFT01000
      N = 2**M                                                          FFT01010
      IWK(1) = 1                                                        FFT01020
      MM = (M/2)*2                                                      FFT01030
      KN = N+1                                                          FFT01040
C                                  INITIALIZE WORK VECTOR               FFT01050
      DO 5  I=2,MP                                                      FFT01060
         IWK(I) = IWK(I-1)+IWK(I-1)                                     FFT01070
    5 CONTINUE                                                          FFT01080
      RAD = TWOPI/N                                                     FFT01090
      MK = M - 4                                                        FFT01100
```

```
      KB = 1                                                            FFT01110
      IF (MM .EQ. M) GO TO 15                                           FFT01120
      K2 = KN                                                           FFT01130
      K0 = IWK(MM+1) + KB                                               FFT01140
   10 K2 = K2 - 1                                                       FFT01150
      K0 = K0 - 1                                                       FFT01160
      AK2 = A(K2)                                                       FFT01170
      A(K2) = A(K0) - AK2                                               FFT01180
      A(K0) = A(K0) + AK2                                               FFT01190
      IF (K0 .GT. KB) GO TO 10                                          FFT01200
   15 C1 = ONE                                                          FFT01210
      S1 = ZERO                                                         FFT01220
      JJ = 0                                                            FFT01230
      K = MM - 1                                                        FFT01240
      J = 4                                                             FFT01250
      IF (K .GE. 1) GO TO 30                                            FFT01260
      GO TO 70                                                          FFT01270
   20 IF (IWK(J) .GT. JJ) GO TO 25                                      FFT01280
      JJ = JJ - IWK(J)                                                  FFT01290
      J = J-1                                                           FFT01300
      IF (IWK(J) .GT. JJ) GO TO 25                                      FFT01310
      JJ = JJ - IWK(J)                                                  FFT01320
      J = J - 1                                                         FFT01330
      K = K + 2                                                         FFT01340
      GO TO 20                                                          FFT01350
   25 JJ = IWK(J) + JJ                                                  FFT01360
      J = 4                                                             FFT01370
   30 ISP = IWK(K)                                                      FFT01380
      IF (JJ .EQ. 0) GO TO 40                                           FFT01390
C                                  RESET TRIGONOMETRIC PARAMETERS       FFT01400
      C2 = JJ * ISP * RAD                                               FFT01410
      C1 = DCOS(C2)                                                     FFT01420
      S1 = DSIN(C2)                                                     FFT01430
   35 C2 = C1 * C1 - S1 * S1                                            FFT01440
      S2 = C1 * (S1 + S1)                                               FFT01450
      C3 = C2 * C1 - S2 * S1                                            FFT01460
      S3 = C2 * S1 + S2 * C1                                            FFT01470
   40 JSP = ISP + KB                                                    FFT01480
C                                  DETERMINE FOURIER COEFFICIENTS       FFT01490
C                                    IN GROUPS OF 4                     FFT01500
      DO 50 I=1,ISP                                                     FFT01510
         K0 = JSP - I                                                   FFT01520
         K1 = K0 + ISP                                                  FFT01530
         K2 = K1 + ISP                                                  FFT01540
         K3 = K2 + ISP                                                  FFT01550
         ZA0 = A(K0)                                                    FFT01560
         ZA1 = A(K1)                                                    FFT01570
         ZA2 = A(K2)                                                    FFT01580
         ZA3 = A(K3)                                                    FFT01590
         IF (S1 .EQ. ZERO) GO TO 45                                     FFT01600
```

```
           TEMP = A1                                                            FFT01610
           A1 = A1 * C1 - B1 * S1                                               FFT01620
           B1 = TEMP * S1 + B1 * C1                                             FFT01630
           TEMP = A2                                                            FFT01640
           A2 = A2 * C2 - B2 * S2                                               FFT01650
           B2 = TEMP * S2 + B2 * C2                                             FFT01660
           TEMP = A3                                                            FFT01670
           A3 = A3 * C3 - B3 * S3                                               FFT01680
           B3 = TEMP * S3 + B3 * C3                                             FFT01690
   45      TEMP = A0 + A2                                                       FFT01700
           A2 = A0 - A2                                                         FFT01710
           A0 = TEMP                                                            FFT01720
           TEMP = A1 + A3                                                       FFT01730
           A3 = A1 - A3                                                         FFT01740
           A1 = TEMP                                                            FFT01750
           TEMP = B0 + B2                                                       FFT01760
           B2 = B0 - B2                                                         FFT01770
           B0 = TEMP                                                            FFT01780
           TEMP = B1 + B3                                                       FFT01790
           B3 = B1 - B3                                                         FFT01800
           B1 = TEMP                                                            FFT01810
           A(K0) = DCMPLX(A0+A1,B0+B1)                                          FFT01820
           A(K1) = DCMPLX(A0-A1,B0-B1)                                          FFT01830
           A(K2) = DCMPLX(A2-B3,B2+A3)                                          FFT01840
           A(K3) = DCMPLX(A2+B3,B2-A3)                                          FFT01850
   50 CONTINUE                                                                  FFT01860
      IF (K .LE. 1) GO TO 55                                                    FFT01870
      K = K - 2                                                                 FFT01880
      GO TO 30                                                                  FFT01890
   55 KB = K3 + ISP                                                             FFT01900
C                                      CHECK FOR COMPLETION OF FINAL            FFT01910
C                                        ITERATION                              FFT01920
      IF (KN .LE. KB) GO TO 70                                                  FFT01930
      IF (J .NE. 1) GO TO 60                                                    FFT01940
      K = 3                                                                     FFT01950
      J = MK                                                                    FFT01960
      GO TO 20                                                                  FFT01970
   60 J = J - 1                                                                 FFT01980
      C2 = C1                                                                   FFT01990
      IF (J .NE. 2) GO TO 65                                                    FFT02000
      C1 = C1 * CK + S1 * SK                                                    FFT02010
      S1 = S1 * CK - C2 * SK                                                    FFT02020
      GO TO 35                                                                  FFT02030
   65 C1 = (C1 - S1) * SQ                                                       FFT02040
      S1 = (C2 + S1) * SQ                                                       FFT02050
      GO TO 35                                                                  FFT02060
   70 CONTINUE                                                                  FFT02070
C                                      PERMUTE THE COMPLEX VECTOR IN            FFT02080
C                                        REVERSE BINARY ORDER TO NORMAL         FFT02090
C                                        ORDER                                  FFT02100
```

```
      IF(M .LE. 1) GO TO 9005                                           FFT02110
      MP = M+1                                                          FFT02120
      JJ = 1                                                            FFT02130
C                                  INITIALIZE WORK VECTOR               FFT02140
      IWK(1) = 1                                                        FFT02150
      DO 75  I = 2,MP                                                   FFT02160
         IWK(I) = IWK(I-1) * 2                                          FFT02170
   75 CONTINUE                                                          FFT02180
      N4 = IWK(MP-2)                                                    FFT02190
      IF (M .GT. 2) N8 = IWK(MP-3)                                      FFT02200
      N2 = IWK(MP-1)                                                    FFT02210
      LM = N2                                                           FFT02220
      NN = IWK(MP)+1                                                    FFT02230
      MP = MP-4                                                         FFT02240
C                                  DETERMINE INDICES AND SWITCH A       FFT02250
      J = 2                                                             FFT02260
   80 JK = JJ + N2                                                      FFT02270
      AK2 = A(J)                                                        FFT02280
      A(J) = A(JK)                                                      FFT02290
      A(JK) = AK2                                                       FFT02300
      J = J+1                                                           FFT02310
      IF (JJ .GT. N4) GO TO 85                                          FFT02320
      JJ = JJ + N4                                                      FFT02330
      GO TO 105                                                         FFT02340
   85 JJ = JJ - N4                                                      FFT02350
      IF (JJ .GT. N8) GO TO 90                                          FFT02360
      JJ = JJ + N8                                                      FFT02370
      GO TO 105                                                         FFT02380
   90 JJ = JJ - N8                                                      FFT02390
      K = MP                                                            FFT02400
   95 IF (IWK(K) .GE. JJ) GO TO 100                                     FFT02410
      JJ = JJ - IWK(K)                                                  FFT02420
      K = K - 1                                                         FFT02430
      GO TO 95                                                          FFT02440
  100 JJ = IWK(K) + JJ                                                  FFT02450
  105 IF (JJ .LE. J) GO TO 110                                          FFT02460
      K = NN - J                                                        FFT02470
      JK = NN - JJ                                                      FFT02480
      AK2 = A(J)                                                        FFT02490
      A(J) = A(JJ)                                                      FFT02500
      A(JJ) = AK2                                                       FFT02510
      AK2 = A(K)                                                        FFT02520
      A(K) = A(JK)                                                      FFT02530
      A(JK) = AK2                                                       FFT02540
  110 J = J + 1                                                         FFT02550
C                                  CYCLE REPEATED UNTIL LIMITING NUMBER FFT02560
C                                    OF CHANGES IS ACHIEVED             FFT02570
      IF (J .LE. LM) GO TO 80                                           FFT02580
C                                                                       FFT02590
 9005 RETURN                                                            FFT02600
```

```
END                                                          FFT02610
```

NON-IMSL ROUTINE

```
C.......................................................................UTP00110
C                                                                       UTP00120
C     SUBROUTINE UTPLOT                                                 UTP00130
C                                                                       UTP00140
C     PURPOSE                                                           UTP00150
C                                                                       UTP00160
C         PRINTS GRAPHS ON THE STANDARD OUTPUT PRINTER                  UTP00170
C                                                                       UTP00180
C     FEATURES                                                          UTP00190
C                                                                       UTP00200
C     1) FULL CONTROL OVER SCALING                                      UTP00210
C     2) ABILITY TO PLOT SINGLE OR DOUBLE PRECISION VECTORS             UTP00220
C                                                                       UTP00230
C     CALLING SEQUENCE                                                  UTP00240
C                                                                       UTP00250
C     CALL UTPLOT(X,Y,N,RANGE,K,MODCUR)                                 UTP00260
C                                                                       UTP00270
C     DESCRIPTION CF ARGUMENTS                                          UTP00280
C                                                                       UTP00290
C     X      VECTOR OF ABSCISSAE                                        UTP00300
C                                                                       UTP00310
C     Y      VECTOR OF ASSOCIATED ORDINATES                             UTP00320
C                                                                       UTP00330
C     N      NUMBER OF (X,Y) PAIRS                                      UTP00340
C                                                                       UTP00350
C     RANGE  4 WORD SCALING VECTOR WHERE                                UTP00360
C            RANGE(1)= MAXIMUM X TO BE PLOTTED                          UTP00370
C            RANGE(2)= MINIMUM X TO BE PLOTTED                          UTP00380
C            RANGE(3)= MAXIMUM Y TO BE PLOTTED                          UTP00390
C            RANGE(4)= MINIMUM Y TO BE PLOTTED                          UTP00400
C                                                                       UTP00410
C            ALL (X,Y) POINTS OUTSIDE THE ABOVE RANGE WILL BE PLOTTED  UTP00420
C            IN THE BORDER OF THE GRAPH.                                UTP00430
C                                                                       UTP00440
C     K      EVERY KTH ELEMENT OF X & Y WILL BE PLOTTED, E.G.,          UTP00450
C            FOR REAL*4 DATA (SINGLE PRECISION) K=1                     UTP00460
C            FOR REAL*8 DATA (DOUBLE PRECISION) K=2.                    UTP00470
C                                                                       UTP00480
C     MODCUR CONTROLS THE NUMBER OF CURVES ON ONE GRAPH                 UTP00490
C            =0 THERE IS ONLY 1 CURVE ON THIS GRAPH                     UTP00500
C            =1 THIS IS THE FIRST OF TWO OR MORE CURVES ON THIS GRAPH  UTP00510
C            =2 THIS IS AN INTERMEDIATE CURVE ON THIS GRAPH             UTP00520
C            =3 THIS IS THE LAST CURVE ON THIS GRAPH                    UTP00530
C                                                                       UTP00540
C     SCALING                                                           UTP00550
C                                                                       UTP00560
C            SCALING IS PERFORMED ONLY ON THE FIRST SET OF POINTS (WHEN UTP00570
```

```
C        MODCUR = 0 OR 1.) ARRAY RANGE IS USED TO SET UP THE SCALE FAC- UTP00580
C        TORS AND NEED ONLY BE DEFINED FOR THE FIRST CALL TO UTPLOT.    UTP00590
C                                                                       UTP00600
C     GRID LABELLING                                                    UTP00610
C                                                                       UTP00620
C            THE DATA TO BE GRAPHED WILL BE FIT INTO AN 80 COLUMN BY    UTP00630
C        BY 60 ROW GRID. THE GRID WILL BE LABELLED THUSLY:              UTP00640
C                                                                       UTP00650
C        IN THE X DIRECTION (COLUMN-WISE), THERE WILL BE 5 VALUES:      UTP00660
C        THE MAXIMUM, THE MINIMUM, AND 3 INTERMEDIATE AT INCREMENTS OF  UTP00670
C        (RANGE(2)-RANGE(1))/4. FROM THE MINIMUM.                       UTP00680
C                                                                       UTP00690
C        IN THE Y DIRECTION (ROW-WISE) THERE WILL BE 7 VALUES: THE MAXI-UTP00700
C        MUM, THE MINIMUM, AND 5 INTERMEDIATE AT INCREMENTS OF          UTP00710
C        (RANGE(4)-RANGE(3))/6. FROM THE MINIMUM.                       UTP00720
C                                                                       UTP00730
C        IF THE LABELS HAVE A VALUE BETWEEN 1. AND 10**8, THEY WILL BE  UTP00740
C        PRINTED IN AN F11.2 FORMAT, OTHERWISE THEY WILL BE PRINTED IN AUTP00750
C        1PE10.3 FORMAT.                                                UTP00760
C                                                                       UTP00770
C     PLOTTING                                                          UTP00780
C                                                                       UTP00790
C            FOUR CHARACTERS ARE USED FOR PLOTTING CURVES, ".","+","*", UTP00800
C        AND "X".  WHEN MORE THAN 4 CURVES ARE PLOTTED THE CHARACTERS   UTP00810
C        ARE USED REPEATEDLY.  IF A NEW CURVE IS TO BE PLACED IN THE    UTP00820
C        PLOTTING GRID WHERE AN OLD CURVE EXISTS, THE NEW CURVE REPLACESUTP00830
C        THE OLD ONE. THUS, IF 3 IDENTICAL CURVES ARE PLOTTED, THEY WILLUTP00840
C        APPEAR AS ONE CURVE COMPOSED OF "*"'S.                         UTP00850
C                                                                       UTP00860
C     MESSAGES                                                          UTP00870
C                                                                       UTP00880
C            UNDER CERTAIN CIRCUMSTANCES, A PLOT WILL NOT BE OUTPUT AND UTP00890
C        ONE OF THE FOLLOWING MESSAGES WILL BE PRINTED ON THE STANDARD  UTP00900
C        OUTPUT IN PLACE OF THE PLOT.                                   UTP00910
C                                                                       UTP00920
C        "ALL Y-VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN Y     UTP00930
C         WHEN MODCUR=0 OR 1."                                          UTP00940
C                                                                       UTP00950
C        "ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX AND MIN X   UTP00960
C         WHEN MODCUR=0 OR 1."                                          UTP00970
C                                                                       UTP00980
C        "GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO PLOT UNTIL GRID    UTP00990
C         PROPERLY SETUP."                                              UTP01000
C                                                                       UTP01010
C     NOTE                                                              UTP01020
C                                                                       UTP01030
C            THE USER IS EXPECTED TO PROVIDE THE NECESSARY CARRIAGE     UTP01040
C        CONTROLS TO PLACE THE GRAPH PROPERLY ON THE PAGE.  BEFORE      UTP01050
C        CALLING UTPLOT THE USER SHOULD ISSUE A PRINT STATEMENT WHICH   UTP01060
C        EJECTS A PAGE SO THAT THE GRAPH WILL BE PLOTTED AT THE TOP     UTP01070
```

```
C         OF THE NEXT PAGE. A TITLE CAN BE PRINTED AT THE BOTTOM OF
C         THE GRAPH BY ISSUING A PRINT STATEMENT RIGHT AFTER CALLING
C         THE SUBROUTINE.
C
C      MAINTENANCE
C         ALTERED FOR WATFIV COMPILATION BY J. FOUST 5/81
C
C.......................................................................
C
       SUBROUTINE UIPLOT (X   ,Y   ,NDATA,RANGE,KKZ,MODCUR)
       DIMENSION GRID(61,81),XSCALE(5),YSCALE(7)
       DIMENSION X   (1),Y   (1),RANGE(4)
       INTEGER*2 GRID,BLANK,DOT,XCHAR(4)/1H.,1H+,1H*,1HX/
       DATA DOT,BLANK/Z4B40,Z4040/
       KDATA=NDATA*KKZ
       IF(MODCUR.GT.1) GO TO 444
C
C      GRID IS THE MATRIX USED TO PLOT THE POINTS
C
       IERR=0
       XMAX=RANGE(1)
       XMIN=RANGE(2)
       YMAX=RANGE(3)
       YMIN=RANGE(4)
C
C      CHECKING X AND Y POINTS AND PLOTTING THOSE OUT OF RANGE
C      AT THE MARGIN
C
       DO 30 I=1,KDATA,KKZ
       IF(X(I).GT.XMAX.OR.X(I).LT.XMIN.OR.Y(I).GT.YMAX.OR.Y(I).LT.YMIN)
      1  IERR=IERR+1
       IF(X(I).LE.XMAX) GO TO 205
       X   (I)=XMAX
       GOTO 210
  205  IF(X(I).GE.XMIN) GO TO 210
       X   (I)=XMIN
  210  IF(Y(I).LE.YMAX) GO TO 215
       Y   (I)=YMAX
       GOTO 30
  215  IF(Y(I).GE.YMIN) GO TO 30
       Y   (I)=YMIN
C
   30  CONTINUE
C
C      PLOTTING X AND Y AXIS , IF NECESSARY
C
       JERR=0
       XRANGE=XMAX-XMIN
       YRANGE=YMAX-YMIN
       IF (YRANGE.NE.0.)  GO TO 298
```

```
      IF(YMIN.EQ.0.) GO TO 889                                          UTP01580
      YMIN=0.                                                           UTP01590
      YRANGE=YMAX                                                       UTP01600
      GO TO 299                                                         UTP01610
  298 IF (XRANGE.NE.0.)  GO TO 299                                      UTP01620
      IF(XMIN.EQ.0.) GO TO 887                                          UTP01630
      XMIN=0.                                                           UTP01640
      XRANGE=XMAX                                                       UTP01650
C                                                                       UTP01660
C     BLANKING OUT MATRIX-(GRID)                                        UTP01670
C                                                                       UTP01680
  299 DO 300 I=1,61                                                     UTP01690
      DO 301 JJ=1,81                                                    UTP01700
301   GRID(I,JJ)=BLANK                                                  UTP01710
  300 CONTINUE                                                          UTP01720
      IF(XMAX*XMIN.GE.0.) GO TO 222                                     UTP01730
      IYAXIS=80.*(-XMIN)/XRANGE+1.5                                     UTP01740
      DO 40 I=1,61                                                      UTP01750
   40 GRID(I,IYAXIS)=DOT                                                UTP01760
  222 IF(YMAX*YMIN.GE.0.) GO TO 333                                     UTP01770
      IXAXIS=60.*YMAX/YRANGE+1.5                                        UTP01780
      DO 60 I=1,81                                                      UTP01790
   60 GRID(IXAXIS,I)=DOT                                                UTP01800
C                                                                       UTP01810
C     COMPUTE PROPER SCALE NUMBERS                                      UTP01820
C                                                                       UTP01830
  333 XINCR=XRANGE/4.                                                   UTP01840
      YINCR=YRANGE/6.                                                   UTP01850
      XSCALE(1)=XMAX                                                    UTP01860
      XSCALE(5)=XMIN                                                    UTP01870
      DO 80 I=2,4                                                       UTP01880
      XSCALE(I)=XSCALE(I-1)-XINCR                                       UTP01890
      IF(ABS(XSCALE(I)).LT.1.E-4)  XSCALE(I)=0.                         UTP01900
   80 CONTINUE                                                          UTP01910
      YSCALE(1)=YMAX                                                    UTP01920
      YSCALE(7)=YMIN                                                    UTP01930
      DO 81 I=2,6                                                       UTP01940
      YSCALE(I)=YSCALE(I-1)-YINCR                                       UTP01950
      IF(ABS(YSCALE(I)).LT.1.E-4)  YSCALE(I)=0.                         UTP01960
   81 CONTINUE                                                          UTP01970
      DO 85 II=1,2                                                      UTP01980
      JJ=6-II                                                           UTP01990
      XT=XSCALE(JJ)                                                     UTP02000
      XSCALE(JJ)=XSCALE(II)                                             UTP02010
   85 XSCALE(II)=XT                                                     UTP02020
C                                                                       UTP02030
C                                                                       UTP02040
C     PLACING POINTS IN THEIR PROPER GRID POSITIONS                     UTP02050
C                                                                       UTP02060
  444 IF(MODCUR.LT.2) JSET=0                                            UTP02070
```

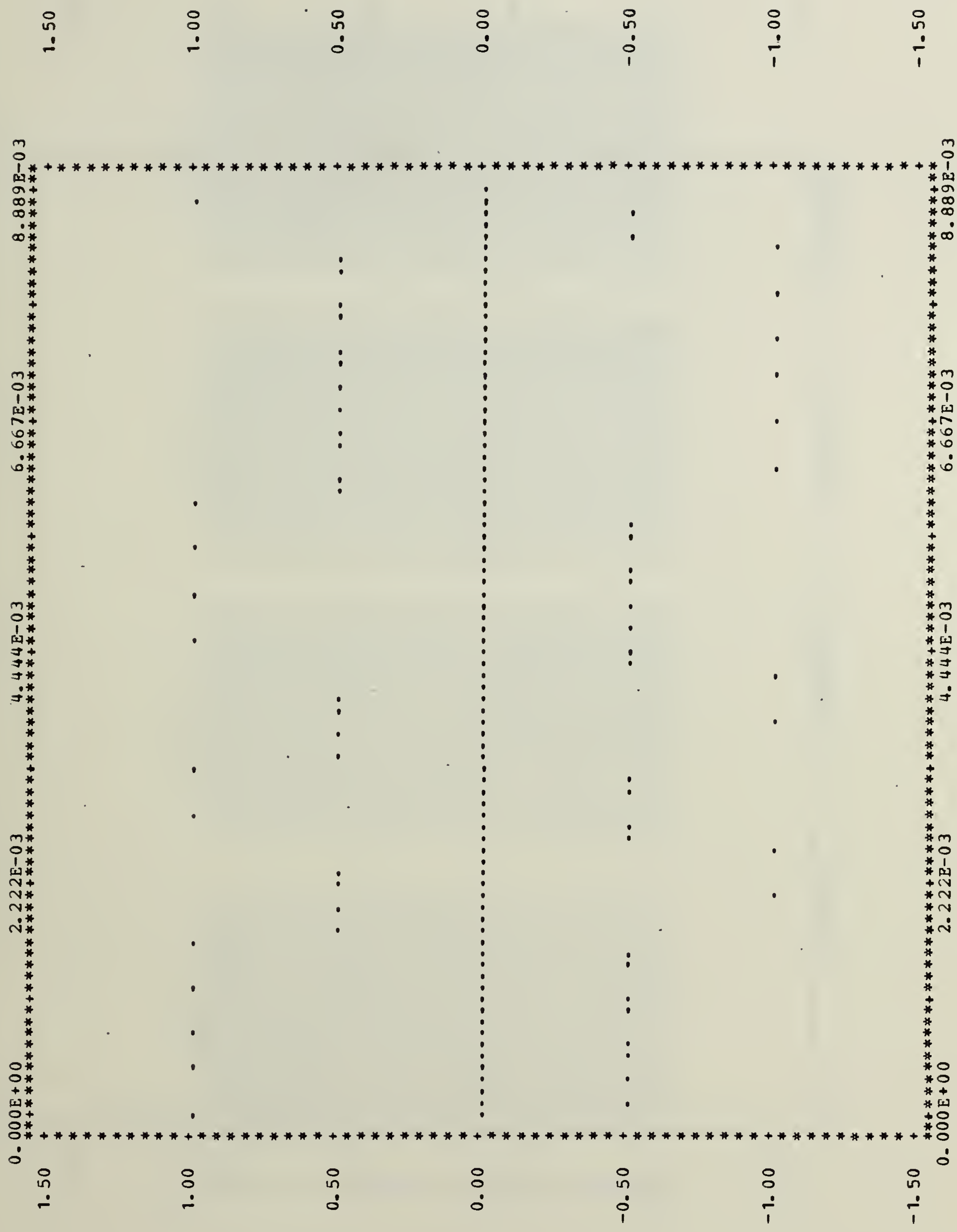
```
      IF(JERR.GT.0) GO TO 885                                           UTP02080
      JSET=JSET+1                                                       UTP02090
      IF(JSET.GT.4) JSET=1                                              UTP02100
      DO 700 I=1,KDATA,KKZ                                              UTP02110
      IPTX=60.*(YMAX-Y(I))/YRANGE+1.5                                   UTP02120
      IPTY=80.*(X (I)-XMIN)/XRANGE+1.5                                  UTP02130
      IF(IPTX.GT.61.OR.IPTY.GT.81) GO TO 70                             UTP02140
      IF(IPTX.LE.0.OR.IPTY.LE.0) GO TO 70                               UTP02150
      GRID(IPTX,IPTY) = XCHAR(JSET)                                     UTP02160
      GO TO 700                                                         UTP02170
   70 IERR=IERR+1                                                       UTP02180
  700 CONTINUE                                                          UTP02190
C     OUTPUT SECTION WITH GRAPH                                         UTP02200
C                                                                       UTP02210
      IF(MODCUR.EQ.1.OR.MODCUR.EQ.2) RETURN                             UTP02220
      AXR=ABS(XRANGE)                                                   UTP02230
      AYR=ABS(YRANGE)                                                   UTP02240
      IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 400                         UTP02250
      WRITE(6,17) XSCALE                                                UTP02260
   17 FORMAT(12X,1PE10.3,4(10X,E10.3)/15X,'**',8('+*********'),'+**')  UTP02270
      GO TO 401                                                         UTP02280
  400 WRITE(6,117) XSCALE                                               UTP02290
  117 FORMAT( 8X,F11.2,4( 9X,F11.2)/15X,'**',8('+*********'),'+**')    UTP02300
  401 II=1                                                              UTP02310
      DO 101 IK=1,61                                                    UTP02320
      IF(MOD(IK-1,10).NE.0) GO TO 92                                    UTP02330
      IF(AYR.LT.1.E+8.AND.AYR.GE..95) GO TO 404                         UTP02340
      WRITE(6,18) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)           UTP02350
   18 FORMAT(3X,1PE10.3,2X,1H+,1X,81A1,1X,1H+,2X,E10.3)                 UTP02360
      GO TO 405                                                         UTP02370
  404 WRITE(6,118) YSCALE(II),(GRID(IK,IX),IX=1,81),YSCALE(II)          UTP02380
  118 FORMAT(2X,F11.2,'  + ',81A1,' +  ',F11.2)                         UTP02390
  405 II=II+1                                                           UTP02400
      GO TO 101                                                         UTP02410
   92 WRITE(6,19) (GRID(IK,IX),IX=1,81)                                 UTP02420
   19 FORMAT(15X,'* ',81A1,' *')                                        UTP02430
  101 CONTINUE                                                          UTP02440
      IF(AXR.LT.1.E+8.AND.AXR.GE..95) GO TO 402                         UTP02450
      WRITE(6,22) XSCALE                                                UTP02460
   22 FORMAT(15X,'**',8('+*********'),'+**'/12X,1PE10.3,4(10X,E10.3),//)UTP02470
      GO TO 403                                                         UTP02480
  402 WRITE(6,217) XSCALE                                               UTP02490
  217 FORMAT(15X,'**',8('+*********'),'+**'/ 8X,F11.2,4( 9X,F11.2),//)  UTP02500
  403 IF(IERR.GT.0) WRITE(6,20) IERR                                    UTP02510
   20 FORMAT(10X,'NUMBER OF POINTS OUT OF RANGE =', I4)                 UTP02520
 1000 RETURN                                                            UTP02530
C                                                                       UTP02540
  889 WRITE(6,888)                                                      UTP02550
  888 FORMAT(' ALL Y VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN YUTP02560
     1 WHEN MODCUR=0 OR 1.')                                            UTP02570
```

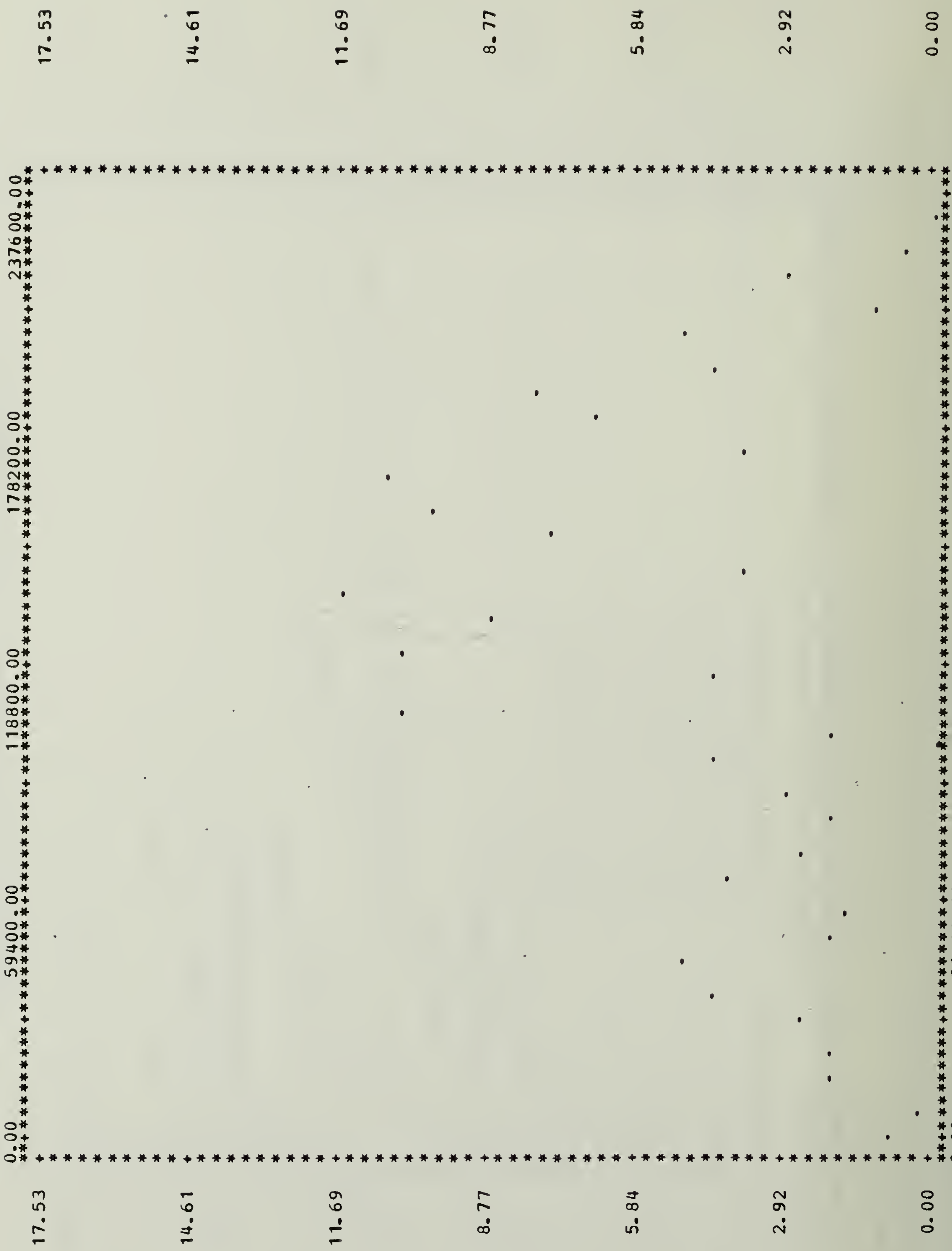
```
      JERR=10                                                           UTP02580
      RETURN                                                            UTP02590
  887 WRITE(6,886)                                                      UTP02600
  886 FORMAT(' ALL X VALUES=0. CANNOT SETUP PLOT GRID. CHECK MAX & MIN XUTP02610
     1 WHEN MODCUR=0 OR 1.')                                            UTP02620
      JERR=10                                                           UTP02630
      RETURN                                                            UTP02640
  885 WRITE(6,884)                                                      UTP02650
  884 FORMAT(' GRID NOT SETUP WHEN MODCUR LAST 0 OR 1. NO PLOT UNTIL GRIUTP02660
     1D PROPERLY SETUP')                                                UTP02670
      RETURN                                                            UTP02680
      END                                                               UTP02690
```

APPENDIX C

REPRESENTATIVE RESULTS OF TRIAL SIMULATIONS

```
MODULATION TECHNIQUE = BPSK
BIPOLAR LOGIC
BAUD OR SYMBOL RATE =          1200 HZ
BITS PER BINARY CODE WORD =              1
BIT RATE =  0.120000000000000E+04
CARRIER FREQUENCY =         2400 HZ
MAXIMUM CARRIER AMPLITUDE =              1 VOLT(S)
INITIAL PHASE ANGLE =             0 DEGREES
TIME BETWEEN SAMPLES =  0.138888888888889E-03 SEC
NUMBER OF SAMPLES GENERATED =            64
SEED FOR RANDOM NUMBER GENERATOR =              1
NUMBER OF TIMES SIMULATION REPEATS =          100
   SUM OF VARIANCES          SUM OF VARIANCES**2
 0.201573472326531 2E+03   0.278328162263990 8E+04
   SUM OF SKEWNESS            SUM OF SKEWNESS**2
-0.103929526472373 9E+05   0.105466506583276 5E+08
   SUM OF KURTOSIS            SUM OF KURTOSIS**2
 0.709790182652583 0E+04   0.564546616177089 8E+07
     MEAN VARIANCE          VARIANCE OF THE VARIANCES
 0.610828704019791 4E+01   0.485004060618770 2E+02
     MEAN SKEWNESS          VARIANCE OF THE SKEWNESS
-0.314937959007193 5E+03   0.227297355110884 4E+06
     MEAN KURTOSIS          VARIANCE OF THE KURTOSIS
 0.215087934137146 4E+03   0.128712285037349 3E+06
```


1.50
1.00
0.50
0.00
-0.50
-1.00
-1.50
0.000E+00
2.222E-03
4.444E-03
6.667E-03
8.889E-03



0.00
59400.00
118800.00
178200.00
237600.00
17.53
14.61
11.69
8.77
5.84
2.92
0.00

```
 N           MEAN                        VARIANCE                     SKEWNESS                      KURTOSIS
 1    0.1000000000000006E+01    0.1561758578801998E-14    -0.1465494392505207E-13    0.2220446049250313E-14
 2    0.1047493608738669E+01    0.2709840268498855E+00    -0.4986164958259542E-01    0.1859590336938843E+00
 3    0.1781990149502563E+01    0.6052571991271320E+00    -0.4851377411586108E+01    0.9402801672503074E+00
 4    0.2374133319422179E+01    0.1061217311525198E+01    -0.1559158728654502E+02    0.2555698305934559E+01
 5    0.2641583690207520E+01    0.1327139362401261E+01    -0.2238636080694528E+02    0.4659815636965693E+01
 6    0.2634626472178204E+01    0.1802009151563938E+01    -0.2105244372349955E+02    0.1043729257485951E+02
 7    0.2930178593409705E+01    0.1790464995452298E+01    -0.3180766187327060E+02    0.9230331781179999E+01
 8    0.2742584859974633E+01    0.1444992379222851E+01    -0.2556107345444832E+02    0.5407086307096591E+01
 9    0.2852400569556203E+01    0.1931984417605075E+01    -0.2933416809306337E+02    0.8404639812274688E+01
10    0.2056852875467849E+01    0.9460987670881228E+00    -0.8572991054816528E+01    0.2193728030163435E+01
11    0.1456809184009350E+01    0.1098943847046864E+01    -0.1522616927873501E+01    0.2001109408989501E+01
12    0.1445688920057778E+01    0.5573480287919284E+00    -0.1701780327864210E+01    0.5079578481182498E+00
13    0.1920945625822921E+01    0.8927281915799500E+00    -0.6589427533799427E+01    0.2348172349608227E+01
14    0.3224566286363947E+01    0.2099606310260772E+01    -0.4608799772325335E+02    0.9535238158770767E+01
15    0.4083755764208747E+01    0.3945243048148941E+01    -0.1014772695897762E+03    0.3145535439259885E+02
16    0.5391087995993649E+01    0.5520139340157494E+01    -0.2478708803627854E+03    0.9424422092077816E+02
17    0.5177315729058215E+01    0.1136909276933618E+02    -0.1938682694723599E+03    0.3347284221347290E+03
18    0.7437747541830537E+01    0.1296676217270220E+02    -0.6963060930667482E+03    0.4650218840509096E+03
19    0.8281071475316468E+01    0.1466781733568776E+02    -0.9929510812163269E+03    0.4278082717480065E+03
20    0.9168033672456426E+01    0.2027197304238261E+02    -0.1367270735397245E+04    0.9377448702396778E+03
21    0.8770044710833503E+01    0.1938346454362091E+02    -0.1168636475312538E+04    0.9921291201235363E+03
22    0.9524106864593513E+01    0.1961533586049662E+02    -0.1510992880029381E+04    0.1378692671328936E+04
23    0.8962219620941568E+01    0.1842175759183958E+02    -0.1262048684336893E+04    0.7640763959078340E+03
24    0.7991136976586805E+01    0.1591304091880872E+02    -0.8697872809031544E+03    0.5831743233597981E+03
25    0.8132813049012353E+01    0.1673585689614668E+02    -0.9191274726176290E+03    0.6136877164277339E+03
26    0.6361858526867442E+01    0.8566761867573708E+01    -0.4268921770206431E+03    0.1903785080820935E+03
27    0.5294298817640966E+01    0.7006192523842890E+01    -0.2299556005105339E+03    0.1330192136653815E+03
28    0.4057930055889589E+01    0.4930941126913854E+01    -0.9519419493004550E+02    0.6781882261712292E+02
29    0.3416828880886142E+01    0.2501314042785288E+01    -0.5501999913351484E+02    0.1726642370562735E+02
30    0.2867533428301556E+01    0.1412648850252024E+01    -0.3077393481179399E+02    0.4150646443966473E+01
31    0.2020303908837564E+01    0.1060744882742050E+01    -0.8050905470433777E+01    0.2614532403606947E+01
32    0.1365571743759467E+01    0.4519751609420714E+00    -0.1273765189038258E+01    0.4704424385912696E+00
33    0.1080000000000754E+01    0.1003636363636323E+01    -0.3456000000020134E+00    0.1012677119999934E+01
```

```
 N          SUM  X                   SUM  X**2                SUM  X**3                SUM  X**4
 1   0.1000000000000007E+03   0.1000000000000015E+03   0.1000000000000022E+03   0.1000000000000030E+03
 2   0.1047493608738669E+03   0.1365517046929747E+03   0.2046763767568517E+03   0.3383849595387993E+03
 3   0.1781990149502563E+03   0.3774693520060027E+03   0.8977044812979923E+03   0.2326050692513711E+04
 4   0.2374133319422179E+03   0.6687114156800523E+03   0.2076369626799344E+04   0.6889765711506957E+04
 5   0.2641583690207520E+03   0.8291832361147630E+03   0.2936841778974143E+04   0.1138916448013025E+05
 6   0.2634626472178204E+03   0.8725245707950468E+03   0.3402833293597278E+04   0.1502031925104808E+05
 7   0.2930178593409705E+03   0.1035850693477425E+04   0.4207727078806093E+04   0.1899359170922933E+05
 8   0.2742584859974633E+03   0.8952314169592701E+03   0.3305282702701148E+04   0.1337153864187625E+05
 9   0.2852400569556203E+03   0.1004885358263358E+04   0.4038352093600026E+04   0.1772010346221309E+05
10   0.2056852875467849E+03   0.5167281530737599E+03   0.1485073506709137E+04   0.4690631226818507E+04
11   0.1456809184009350E+03   0.3210247407190382E+03   0.8262950792109978E+03   0.2278514895214681E+04
12   0.1445688920057778E+03   0.2641791002081834E+03   0.5575810707434266E+03   0.1272769524951599E+04
13   0.1920945625822921E+03   0.4573833007032363E+03   0.1238876179577409E+04   0.3712419048853903E+04
14   0.3224566286363947E+03   0.1247643798231314E+04   0.5380965068146941E+04   0.2495637275319738E+05
15   0.4083755764208747E+03   0.2058285175937562E+04   0.1173346266754204E+05   0.7229234279025983E+05
16   0.5391087995993649E+03   0.3452876772730274E+04   0.2524443357094650E+05   0.2050931970507939E+06
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21   0.8770044710833503E+03   0.9610331412820340E+04   0.1206027241518287E+06   0.1669696517013331E+07
22   0.9524106864593513E+03   0.1101277940700889E+05   0.1454196535290649E+06   0.2152530635514160E+07
23   0.8962219620941568E+03   0.9855892054991122E+04   0.1227228629308833E+06   0.1661508753740510E+07
24   0.7991136976586806E+03   0.7961218068819355E+04   0.9110717013921001E+05   0.1143542851587153E+07
25   0.8132813049012353E+03   0.8271114641737083E+04   0.9666101038478942E+05   0.1235886896537965E+07
26   0.6361858526867442E+03   0.4895433816477395E+04   0.4264830561897630E+05   0.4069483181946355E+06
27   0.5294298817640966E+03   0.3496573056907900E+04   0.2693422775779996E+05   0.2313456000907510E+06
28   0.4057930055889589E+03   0.2134842805413680E+04   0.1317634959336049E+05   0.9107918677629661E+05
29   0.3416828880886142E+03   0.1415102050361508E+04   0.6668540831626178E+04   0.3463189945762253E+05
30   0.2867533428301556E+03   0.9621270324176382E+03   0.3554851209525683E+04   0.1400578999184000E+05
31   0.2020303908837565E+03   0.5131765317978972E+03   0.1488901535488743E+04   0.4723919613838425E+04
32   0.1365571743759467E+03   0.2312241596686921E+03   0.4469257803795999E+03   0.9444076554027791E+03
33   0.1080000000000754E+03   0.2160000000001588E+03   0.4320000000004758E+03   0.8640000000012697E+03
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   SUM OF SKEWNESS          SUM OF SKEWNESS**2
-0.971960390097499 7E+04   0.859810388330445 3E+07
   SUM OF KURTOSIS          SUM OF KURTOSIS**2
 0.866564342671265 6E+04   0.829341190073421 9E+07
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 0.651297801706672 1E+01   0.515363971913394 8E+02
    MEAN SKEWNESS        VARIANCE OF THE SKEWNESS
-0.294533451544696 8E+03   0.179229856209468 2E+06
    MEAN KURTOSIS        VARIANCE OF THE KURTOSIS
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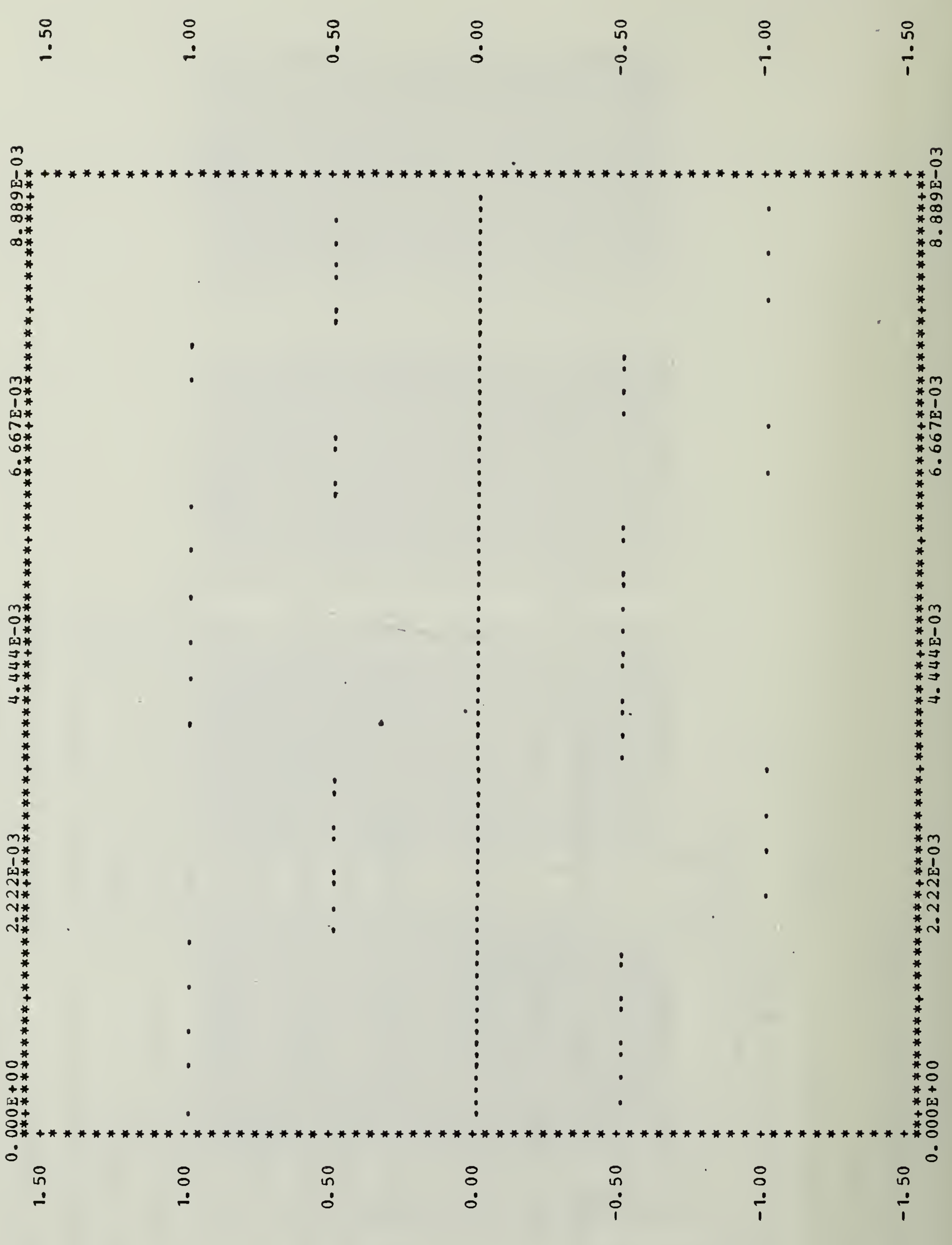
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 2   0.1206991215019278E+01   0.3394579115190850E+00   -0.5825378055947565E+00   0.2121849517747392E+00
 3   0.1614193814360449E+01   0.6594138922933482E+00   -0.3002537615750380E+01   0.1142743841392047E+01
 4   0.2227669986106446E+01   0.1028688761026641E+01   -0.1153444489528357E+02   0.3602977400661302E+01
 5   0.2606830384359121E+01   0.1860771962726079E+01   -0.2056467900078679E+02   0.8393233099009628E+01
 6   0.2869827559993243E+01   0.2773607056523804E+01   -0.2706458826036814E+02   0.2484078413586156E+02
 7   0.3193892922935319E+01   0.1919637658811091E+01   -0.4389937025518355E+02   0.1049069398838691E+02
 8   0.2887029562873031E+01   0.2188092253886460E+01   -0.2996273462075921E+02   0.1240623718927321E+02
 9   0.2645128655136111E+01   0.1564423519331396E+01   -0.2282782127376995E+02   0.4783908803836340E+01
10   0.2165532638363491E+01   0.1012907097513055E+01   -0.1023789451958566E+02   0.3065360931783477E+01
11   0.1691277358074538E+01   0.1004960153591563E+01   -0.3911484804814908E+01   0.1499184701566339E+01
12   0.1589018609218827E+01   0.6409517041368564E+00   -0.2957243584462853E+01   0.6008947870243588E+00
13   0.2022206621896048E+01   0.8674855068396650E+00   -0.8124920456579111E+01   0.1759584375414942E+01
14   0.2893180879486128E+01   0.2056527174777121E+01   -0.3029972471223451E+02   0.1099295459446458E+02
15   0.3800440008063125E+01   0.3850369283893350E+01   -0.7769874123112918E+02   0.3737869876870587E+02
16   0.5570047561752625E+01   0.7494036582454018E+01   -0.2769226081575563E+03   0.1304851489126716E+03
17   0.6309396047434741E+01   0.1987022375415137E+02   -0.3359332752853699E+03   0.1232319292891567E+04
18   0.7725994558988540E+01   0.1531549511531786E+02   -0.7877268097177533E+03   0.5389886730059789E+03
19   0.7809215803380767E+01   0.1544649313954077E+02   -0.8025080297305087E+03   0.7311368578778502E+03
20   0.8414654985868134E+01   0.1653486279572041E+02   -0.1010517011328395E+04   0.8342365979814513E+03
21   0.9176381706965888E+01   0.2299461744077966E+02   -0.1317751057163412E+04   0.1483070263595537E+04
22   0.8737450979982724E+01   0.2048224307443957E+02   -0.1127935351642733E+04   0.1450198162098086E+04
23   0.8709795816472441E+01   0.1666453081075322E+02   -0.1160347310188729E+04   0.6012382067100471E+03
24   0.8359446618565224E+01   0.1416732832613374E+02   -0.1023422594961601E+04   0.5124736984154824E+03
25   0.7365872951243031E+01   0.1262467755534349E+02   -0.6663865046499641E+03   0.4404715992828096E+03
26   0.6265420185247174E+01   0.1029341182529051E+02   -0.3942727760614418E+03   0.2735691108412666E+03
27   0.5661086207993509E+01   0.7478565244377920E+01   -0.2891508150107528E+03   0.1483181453821855E+03
28   0.4637040646258831E+01   0.6384887129770313E+01   -0.1450576153004111E+03   0.1243505589276638E+03
29   0.3580536036274782E+01   0.3579040429595400E+01   -0.6316134998462517E+02   0.3454042237282812E+02
30   0.2568303570148102E+01   0.1367376958163926E+01   -0.2008704187963902E+02   0.5364378040649946E+01
31   0.1791906790941165E+01   0.8411220788771688E+00   -0.4841294269761784E+01   0.1786012611331170E+01
32   0.1390475344573220E+01   0.6184320019866056E+00   -0.1208132606045036E+01   0.9141790760984658E+00
33   0.9200000000007791E+00   0.1003636363636374E+01    0.2943999999989106E+00   0.1012677120000026E+01
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 2   0.1206991215019278E+03   0.1792891125537607E+03   0.2995818122167570E+03   0.5371329498846672E+03
 3   0.1614193814360449E+03   0.3258441423689951E+03   0.7565487015339066E+03   0.1941759256884656E+04
 4   0.2227669986106446E+03   0.5980915440415869E+03   0.1851104541888258E+04   0.6434635717617218E+04
 5   0.2606830384359121E+03   0.8637728895916740E+03   0.3339547410677492E+04   0.1429682053630766E+05
 6   0.2869827559993244E+03   0.1098178121005534E+04   0.5101104641473661E+04   0.2712332783742979E+05
 7   0.3193892922935319E+03   0.1210139328539929E+04   0.5165038885414519E+04   0.2418578125586438E+05
 8   0.2887029562873032E+03   0.1050115102825044E+04   0.4431878637369578E+04   0.2074597188371301E+05
 9   0.2645128655136111E+03   0.8545484886360252E+03   0.3099048835661787E+04   0.1207994399427354E+05
10   0.2165532638363491E+03   0.5692309634355466E+03   0.1736368916738238E+04   0.5928142778063767E+04
11   0.1691277358074538E+03   0.3855329653991237E+03   0.9928972246440080E+03   0.2704860929592714E+04
12   0.1589018609218827E+03   0.3159522327539222E+03   0.7054415458756292E+03   0.1669947189847840E+04
13   0.2022206621896049E+03   0.4948130273411497E+03   0.1371486571483153E+04   0.4145744104203795E+04
14   0.2893180879486128E+03   0.1040645750445347E+04   0.4328257571012639E+04   0.1994425856680307E+05
15   0.3800440008063125E+03   0.1825520984594126E+04   0.1015480598214063E+05   0.6249208342092874E+05
16   0.5570047561752626E+03   0.3844452605681585E+04   0.3034400480385781E+05   0.2622371362589436E+06
17   0.6309396047434741E+03   0.5947999999999499E+04   0.7102983984520202E+05   0.9705829999998300E+06
18   0.7725994558988540E+03   0.7485333208968521E+04   0.8278405157724163E+05   0.1000317965825323E+07
19   0.7809215803380767E+03   0.7627587967191728E+04   0.8624886821940661E+05   0.1092008676776739E+07
20   0.8414654985868135E+03   0.8717593269895867E+04   0.1048536341808207E+06   0.1413147608028859E+07
21   0.9176381706965888E+03   0.1069706524983101E+05   0.1458647596675802E+06   0.2225002804163320E+07
22   0.8737450979982725E+03   0.9662047027129625E+04   0.1252028417077052E+06   0.1843532137866726E+07
23   0.8709795816472441E+03   0.9235842866728653E+04   0.1101200770348890E+06   0.1419247629793849E+07
24   0.8359446618565224E+03   0.8390600281151395E+04   0.9410399639412192E+05   0.1144827215115574E+07
25   0.7365872951243031E+03   0.6675451511364377E+04   0.7002171584291269E+05   0.8171450560058780E+06
26   0.6265420185247174E+03   0.4944596780474033E+04   0.4566155380318585E+05   0.4693948257621125E+06
27   0.5661086207993509E+03   0.3945167664626847E+04   0.3167714185138088E+05   0.2816542865255081E+06
28   0.4637040646258831E+03   0.2782318421352912E+04   0.1989898011089206E+05   0.1612723577315059E+06
29   0.3580536036274782E+03   0.1636348833236177E+04   0.8696835236079992E+04   0.5144863119613108E+05
30   0.2568303570148102E+03   0.7949886417017775E+03   0.2797375666478596E+04   0.1086402293290285E+05
31   0.1791906790941165E+03   0.4043640805509461E+03   0.1047432809395370E+04   0.2988922040732839E+04
32   0.1390475344573220E+03   0.2545669365832754E+03   0.5544095492100302E+03   0.1343313554680140E+04
33   0.9200000000007791E+02   0.1840000000001444E+03   0.3680000000004329E+03   0.7360000000011546E+03
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-0.5381895541377615E+04   0.3582631135045827E+07
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
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     MEAN SKEWNESS        VARIANCE OF THE SKEWNESS
-0.1630877436781095E+03   0.8452843545285224E+05
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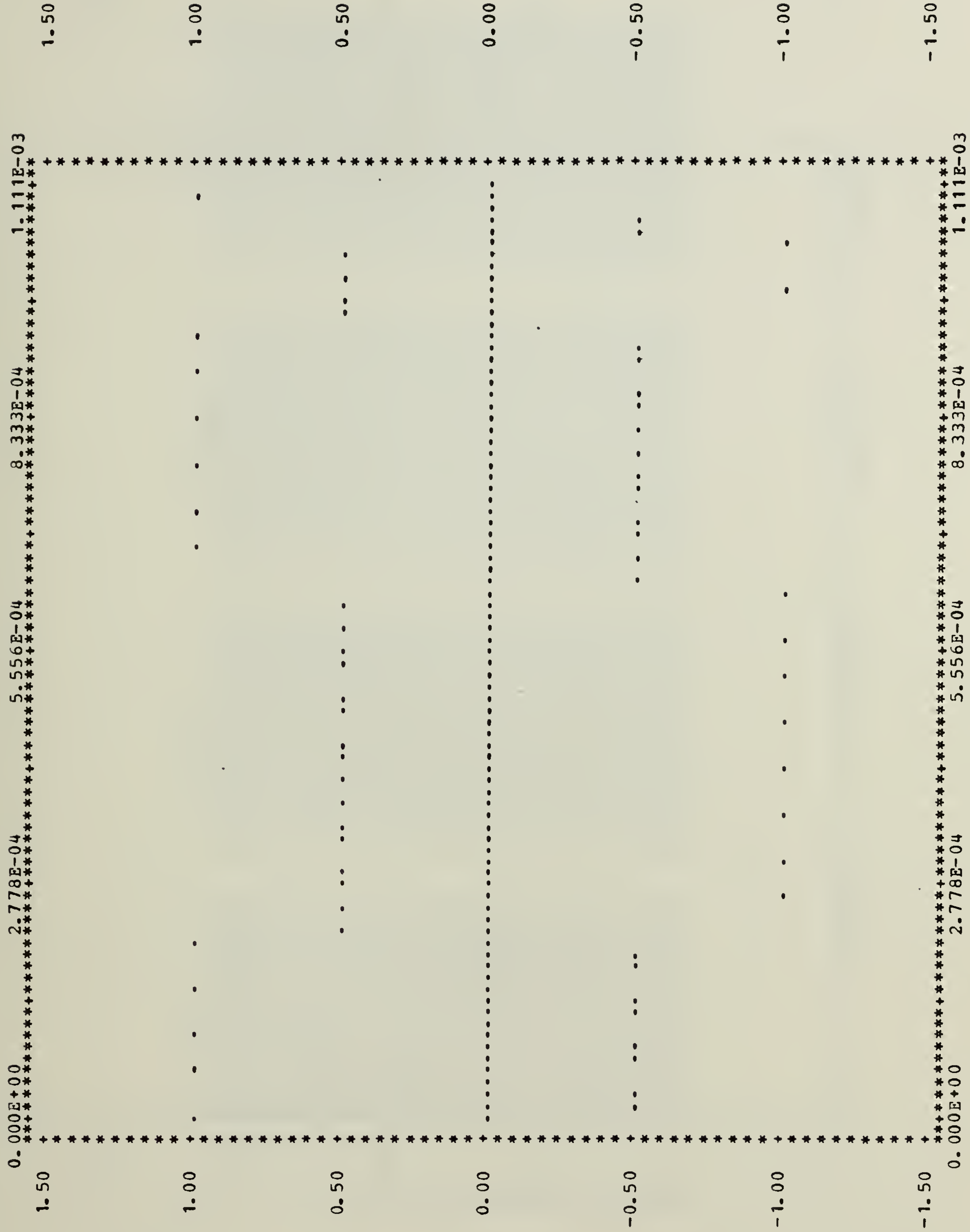
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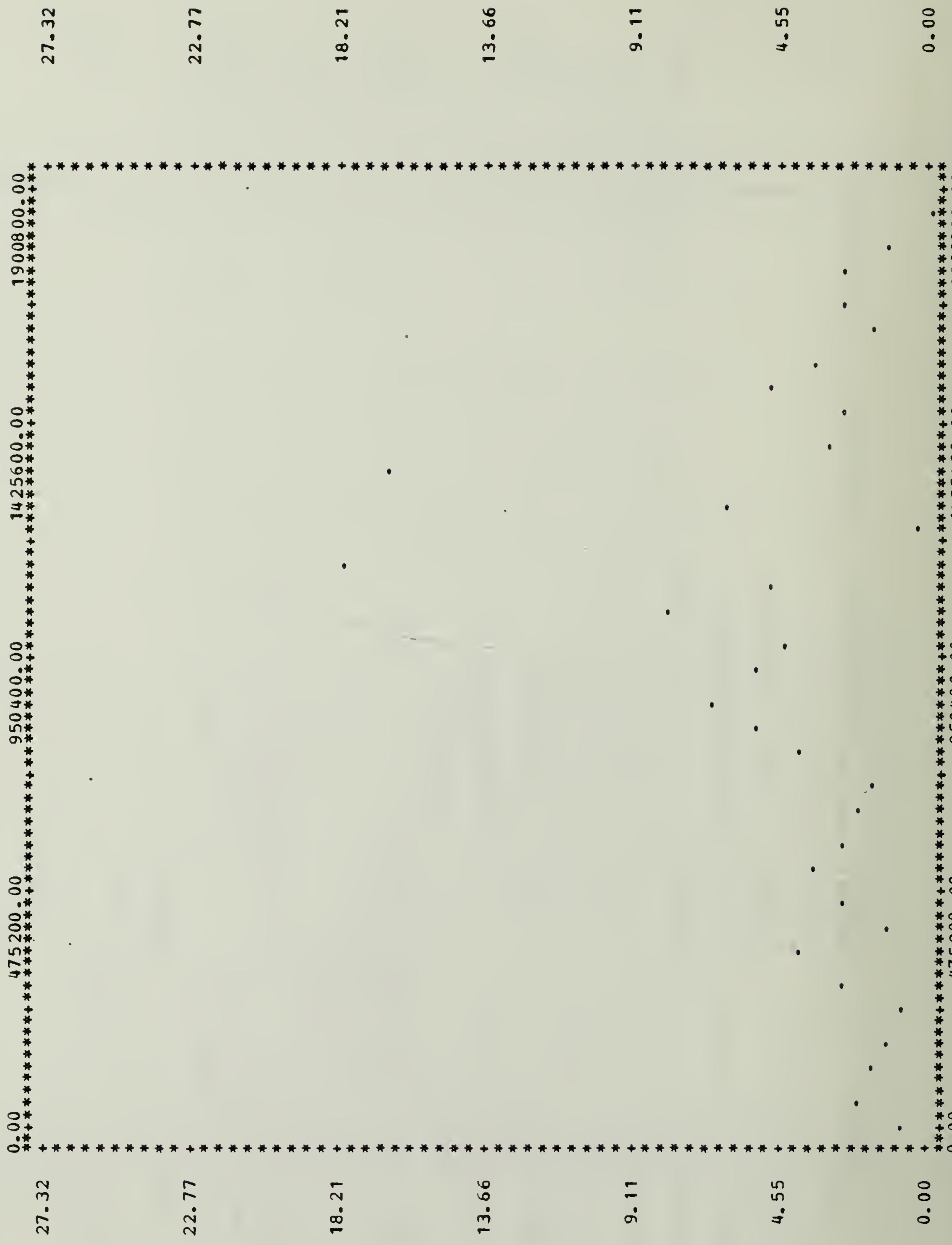
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 3   0.1581662562971217E+01   0.6913486002106669E+00   -0.2512033644738964E+01   0.1326654635257686E+01
 4   0.1746011668828425E+01   0.1660728937560371E+01   -0.2735720817539909E+01   0.7181153218390413E+01
 5   0.2487376832401961E+01   0.3187132562789080E+01   -0.1345866539145792E+02   0.2313107027830058E+02
 6   0.2392317133198317E+01   0.4403999674859614E+01   -0.1579140068729958E+00   0.9523892208727593E+02
 7   0.2873941993780831E+01   0.3317611212361697E+01   -0.2808951707223596E+02   0.2224684476840443E+02
 8   0.2936029392917652E+01   0.3699996587518791E+01   -0.2980126647160134E+02   0.2984697963609836E+02
 9   0.2478264041916265E+01   0.2971723315233370E+01   -0.1211008099582720E+02   0.2739050343838217E+02
10   0.1775820899350969E+01   0.1041075605053106E+01   -0.4595670096970628E+01   0.2408205984396261E+01
11   0.1518861217105241E+01   0.8301259957717636E+00   -0.2277490279198786E+01   0.1192379894500322E+01
12   0.1434317744204484E+01   0.5944479879864332E+00   -0.1796914098729745E+01   0.4293200636053687E+00
13   0.1945015183250301E+01   0.4916250157649399E+00   -0.6735034995725021E+01   0.1041129156195698E+01
14   0.2804658738339067E+01   0.2804358963681170E+01   -0.2443773332277449E+02   0.2289686391698299E+02
15   0.3923050852610531E+01   0.3074810213843398E+01   -0.8866410939161910E+02   0.2115406187017686E+02
16   0.5644012086255505E+01   0.1119968617493584E+02   -0.2816643707881831E+03   0.2276781264367641E+03
17   0.5090345713940015E+01   0.3243270758845300E+02    0.1803958842095260E+03   0.6547664096250286E+04
18   0.6979480897242355E+01   0.1989841039462072E+02   -0.5293083246138370E+03   0.8340250774034976E+03
19   0.7219639256545543E+01   0.1405894216350526E+02   -0.6450669112614341E+03   0.4415132116379600E+03
20   0.7426325641963908E+01   0.3143013343320532E+02   -0.5045975981675309E+03   0.2873504517215812E+04
21   0.9181074919421593E+01   0.3147559988244039E+02   -0.1221066034803840E+04   0.2645319575375468E+04
22   0.7811178351200367E+01   0.6501637985261742E+02   -0.3234257528646465E+02   0.1620957998609241E+05
23   0.7155173881115702E+01   0.2437036621446784E+02   -0.5677598575289374E+03   0.1100562606554644E+04
24   0.7296060888561213E+01   0.1728529342726921E+02   -0.6196321132882680E+03   0.8989413566346584E+03
25   C.6686881379771213E+01   0.2957759461549051E+02   -0.2835528998457502E+03   0.2878907433833486E+04
26   0.6639869155630594E+01   0.1817828764231562E+02   -0.4549285871737381E+03   0.6616207898589500E+03
27   0.4767489656454035E+01   0.1017033455698602E+02   -0.1467728258669405E+03   0.2739258324928540E+03
28   0.3442148531187325E+01   0.1107312574626655E+02    0.6609619933125398E+01   0.6323762627354242E+03
29   0.3339390175580569E+01   0.6407469821591361E+01   -0.4267851440326571E+02   0.8996253220473250E+02
30   0.2345263541776711E+01   0.2296921742748596E+01   -0.1178274900462600E+02   0.1416383521220494E+02
31   0.1936721497866493E+01   0.8419979276324613E+00   -0.6653324231077595E+01   0.2421363813672397E+01
32   0.1507494021765924E+01   0.8299757840624045E+00   -0.2320704558100585E+01   0.1189920939805388E+01
33   0.9600000000005325E+00   0.1008484848484935E+01    0.1535999999991078E+00   0.1003192320000180E+01
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  3   0.1581662562971217E+03   0.3186091577313239E+03   0.7602618739154471E+03   0.2037758005591990E+04
  4   0.1746011668828425E+03   0.4692678395869791E+03   0.1574757939883318E+04   0.5920869916394998E+04
  5   0.2487376832401961E+03   0.9342304743531201E+03   0.4388074473669741E+04   0.2277539083259013E+05
  6   0.2392317133198317E+03   0.1008314094390523E+04   0.6076193597121237E+04   0.4287047552684854E+05
  7   0.2873941993780832E+03   0.1154397768385502E+04   0.5492156448322934E+04   0.2861846863853825E+05
  8   0.2936029392917652E+03   0.1228326521772000E+04   0.6115027949693274E+04   0.3356198711125626E+05
  9   0.2478264041916265E+03   0.9083798743536179E+03   0.4314248905159208E+04   0.2334844211414864E+05
 10   0.1775820899350969E+03   0.4184204715574260E+03   0.1138844471312494E+04   0.3396766130248446E+04
 11   0.1518861217105241E+03   0.3128764132640459E+03   0.7365106422760920E+03   0.1859737061213269E+04
 12   0.1434317744204484E+03   0.2645770899446408E+03   0.5473179563118097E+03   0.1186913250208475E+04
 13   0.1945015183250301E+03   0.4269792828681493E+03   0.1061323252148284E+04   0.2962998661477288E+04
 14   0.2804658738339067E+03   0.1064242601258605E+04   0.4937516474012145E+04   0.2601588997665944E+05
 15   0.3923050852610531E+03   0.1843439010387318E+04   0.9751238406710893E+04   0.5596569546028266E+05
 16   0.5644012086255505E+03   0.4294256174298470E+04   0.3817308968287571E+05   0.3682273043798486E+06
 17   0.5090345713940015E+03   0.5801999999999595E+04   0.1014598220203008E+06   0.2020016999999756E+07
 18   0.6979480897242356E+03   0.6841257988564547E+04   0.8057182515250085E+05   0.1045136458643242E+07
 19   0.7219639256545543E+03   0.6604154373652368E+04   0.6810750719184861E+05   0.7606683646978952E+06
 20   0.7426325641963908E+03   0.8626614463936393E+04   0.1307023222657515E+06   0.2227806669826787E+07
 21   0.9181074919421593E+03   0.1154529805596482E+05   0.1790297084410059E+06   0.3131754862963641E+07
 22   0.7811178351200367E+03   0.1253807232883525E+05   0.2783741984468482E+06   0.6845485247415800E+07
 23   0.7155173881115703E+03   0.7532317582132351E+04   0.9466983767713212E+05   0.1292127369194078E+07
 24   0.7296060888561213E+03   0.7034494498258915E+04   0.8136258831189237E+05   0.1067727029668344E+07
 25   0.6686881379771213E+03   0.7399620125646657E+04   0.1111429796046996E+06   0.1875286557886083E+07
 26   0.6639869155630594E+03   0.6208436716978700E+04   0.6935919118710130E+05   0.8491275569515316E+06
 27   0.4767489656454035E+03   0.3279758883581237E+04   0.2768557554783706E+05   0.2630640137869949E+06
 28   0.3442148531187325E+03   0.2281078099955895E+04   0.2184671358502179E+05   0.2439888675208497E+06
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 30   0.2345263541776711E+03   0.7774213605708154E+03   0.3191446804095530E+04   0.1477525773195163E+05
 31   0.1936721497866493E+03   0.4584468108654369E+03   0.1248140927526872E+04   0.3814593155215503E+04
 32   0.1507494021765924E+03   0.3094214251881780E+03   0.7127747450903528E+03   0.1747303658994075E+04
 33   0.9600000000005325E+02   0.1920000000001109E+03   0.3840000000003322E+03   0.7680000000008864E+03
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MAXIMUM CARRIER AMPLITUDE =           1 VOLT(S)
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   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.2867982085342969E+05   0.7352270919634266E+08
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.3172130538617988E+05   0.9751577105721891E+08
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     MEAN SKEWNESS        VARIANCE OF THE SKEWNESS
-0.8690854804069604E+03   0.1518671665998567E+07
     MEAN KURTOSIS        VARIANCE OF THE KURTOSIS
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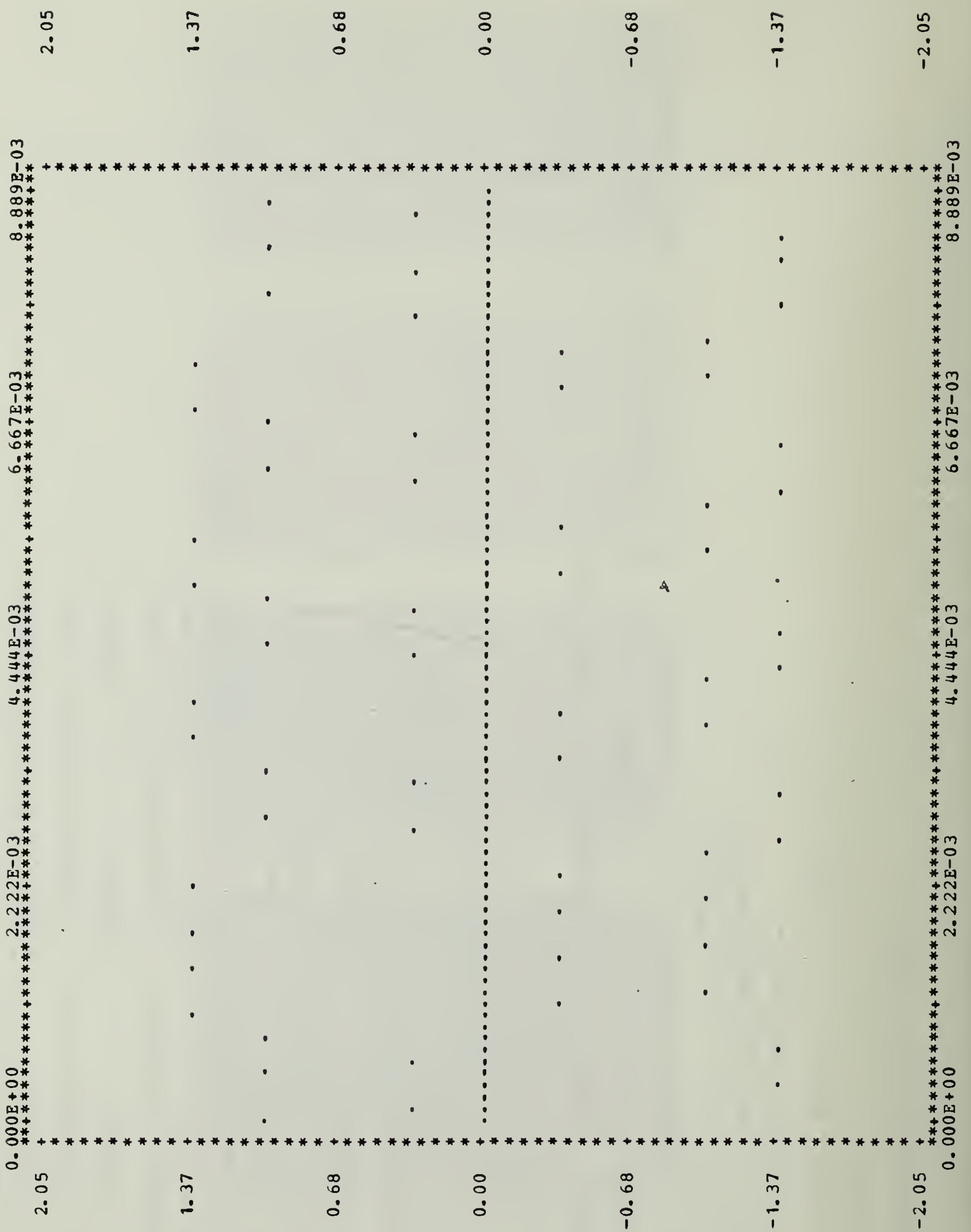
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  3   0.1904123124311341E+01   0.8284087495953819E+00   -0.6396824888399620E+01   0.1349318349217100E+01
  4   0.2553215788524060E+01   0.1879302963420428E+01   -0.1862544622019388E+02   0.1026923166295630E+02
  5   0.2895289168341145E+01   0.1912422014282412E+01   -0.3039376238603314E+02   0.1084570504651863E+02
  6   0.3593319677949141E+01   0.3184309731226340E+01   -0.6402691830945779E+02   0.3366925898761804E+02
  7   0.3930464341172416E+01   0.3283045787147481E+01   -0.8940037934545391E+02   0.2283247728193220E+02
  8   0.3176374883367992E+01   0.3145436453973428E+01   -0.4014507689068421E+02   0.2470809550339391E+02
  9   0.2909109395630561E+01   0.2151304999252531E+01   -0.3095463570067497E+02   0.1135174615476698E+02
 10   0.2310113664151272E+01   0.1448936237101654E+01   -0.1301985107944930E+02   0.5072264066794546E+01
 11   0.1929635110133316E+01   0.9744562139539873E+00   -0.6713188757562222E+01   0.1968696011013879E+01
 12   0.1736333797592857E+01   0.6802711602773372E+00   -0.4483354175680031E+01   0.9858941589486534E+00
 13   0.2636068859727789E+01   0.1794358124155069E+01   -0.2186458907425396E+02   0.7241698564094648E+01
 14   0.3803481344365238E+01   0.3696540555931117E+01   -0.7909443026761886E+02   0.3019946789259399E+02
 15   0.4986474438890647E+01   0.6643186706859601E+01   -0.1820813300838155E+03   0.1851316984165733E+03
 16   0.6662788401289627E+01   0.1197999263485765E+02   -0.4928116482116519E+03   0.3053780266286640E+03
 17   0.8502952468016774E+01   0.1828772628680051E+02   -0.1032192411932795E+04   0.1040229845620365E+04
 18   0.9607374541040577E+01   0.2259846110692997E+02   -0.1546130075896706E+04   0.1297725265881222E+04
 19   0.1050749780533153E+02   0.2760155075845678E+02   -0.2042263630476643E+04   0.1867716540639482E+04
 20   0.1067695777034067E+02   0.3148395414952713E+02   -0.2138268986234739E+04   0.2745005135857946E+04
 21   0.1159998938933332E+02   0.3440383797833590E+02   -0.2779251553193542E+04   0.3052109644195352E+04
 22   0.1201730038463690E+02   0.3898194048489874E+02   -0.3036760670813972E+04   0.4157543844077150E+04
 23   0.1150469025968273E+02   0.3514321583344966E+02   -0.2656279130419467E+04   0.3887224992526328E+04
 24   0.1386757705581011E+02   0.3291282390260102E+02   -0.4804532068481680E+04   0.4373177603554912E+04
 25   0.1182345337753549E+02   0.3194035977905371E+02   -0.2865392295692525E+04   0.3980226271969517E+04
 26   0.9898643164008999E+01   0.2786565305382517E+02   -0.1649460373455986E+04   0.2143450499397009E+04
 27   0.9338236097052430E+01   0.2066092774702154E+02   -0.1412504135019007E+04   0.1136753422781173E+04
 28   0.8039149828926604E+01   0.1918135866367653E+02   -0.8679192107121875E+03   0.9798561334811420E+03
 29   0.6484303130127103E+01   0.1011833637638492E+02   -0.4515507975554196E+03   0.2241552861347600E+03
 30   0.5229841853147019E+01   0.6718795090640344E+01   -0.2245224197961023E+03   0.1384975222799374E+03
 31   0.3689893691617248E+01   0.3326150665494782E+01   -0.7126153217631072E+02   0.2646677631971176E+02
 32   0.2445094403230528E+01   0.2453181599334463E+01   -0.1459789416489632E+02   0.1558568062797297E+02
 33   0.1849948452238745E+01   0.1351202751575251E+01   -0.5222799989371443E+01   0.4138653750210896E+01
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 3  0.19041231243113 41E+03   0.44458095346366 10E+03   0.11747911590082 25E+04   0.33549344962734 09E+04
 4  0.25532157885240 60E+03   0.83794207965547 63E+03   0.32520140483620 47E+04   0.14213338915810 56E+05
 5  0.28952891683411 45E+03   0.10275997162453 15E+04   0.42096788712404 56E+04   0.19234058713404 75E+05
 6  0.35933196779491 41E+03   0.16064412941850 59E+04   0.83322902490626 90E+04   0.48691060769618 08E+05
 7  0.39304643411724 16E+03   0.18698765266503 92E+04   0.10018701109193 12E+05   0.58071860704839 72E+05
 8  0.31763748833679 92E+03   0.13203339489124 72E+04   0.65492476099443 33E+04   0.36292885239549 59E+05
 9  0.29091093956305 61E+03   0.10592709425006 01E+04   0.44565580888241 18E+04   0.20692790884319 62E+05
10  0.23101136641512 72E+03   0.67710720160290 54E+03   0.23232736593496 92E+04   0.88383977878370 77E+04
11  0.19296351101333 16E+03   0.46882033100736 62E+03   0.12979393057603 45E+04   0.39004921103385 55E+04
12  0.17363337975928 57E+03   0.36883235053377 97E+03   0.86994179873160 32E+03   0.21955756456003 35E+04
13  0.26360688597277 89E+03   0.87252735761400 85E+03   0.33238958759298 71E+04   0.13879818397410 76E+05
14  0.38034813443652 38E+03   0.18126045487306 20E+04   0.98798856632766 86E+04   0.58783479590194 76E+05
15  0.49864744388906 47E+03   0.31441682169500 80E+04   0.23853824861858 35E+05   0.21070141958782 38E+06
16  0.66627884012896 27E+03   0.56252941988868 66E+04   0.54280720149318 59E+05   0.57006281976496 36E+06
17  0.85029524680167 74E+03   0.90405049697285 06E+04   0.11293367080546 27E+06   0.15915152883752 90E+07
18  0.96073745410405 77E+03   0.11467412206769 53E+05   0.15744183555676 92E+06   0.23852952868476 71E+07
19  0.10507497805331 53E+04   0.13773304537991 91E+05   0.20786103654186 46E+06   0.34560571213102 05E+07
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21  0.11599989389333 32E+04   0.16861955343119 83E+05   0.28195840310492 36E+06   0.52063237462285 11E+07
22  0.12017300384636 90E+04   0.18300762961464 39E+05   0.32721812853954 82E+06   0.65441363459275 88E+07
23  0.11504690259682 73E+04   0.16714968164635 38E+05   0.28480210166756 84E+06   0.54763980002663 83E+07
24  0.13867577055810 11E+04   0.22489338906240 60E+05   0.41670277512162 49E+06   0.86973473675682 03E+07
25  0.11823453377535 49E+04   0.17141500595201 87E+05   0.29351715980169 49E+06   0.57646026261708 82E+07
26  0.98986431640090 00E+03   0.12557013301166 90E+05   0.18834951697862 24E+06   0.31699189064613 29E+07
27  0.93382360970524 30E+03   0.10765697187384 43E+05   0.14290692207274 81E+06   0.21001763204541 31E+07
28  0.80391498289266 04E+03   0.83617475048970 42E+04   0.10194651600495 66E+06   0.13868550867520 77E+07
29  0.64843031301271 03E+03   0.52063340095997 22E+04   0.47714026572586 81E+05   0.47690996779388 31E+06
30  0.52298418531470 19E+03   0.34002852948662 19E+04   0.25426371901799 22E+05   0.21216832867874 19E+06
31  0.36898936916172 48E+03   0.16908204614276 59E+04   0.88676269541194 26E+04   0.51015801382700 73E+05
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   SUM OF SKEWNESS          SUM OF SKEWNESS**2
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   SUM OF KURTOSIS          SUM OF KURTOSIS**2
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    MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.8383233305479857E+03   0.1249052537633781E+07
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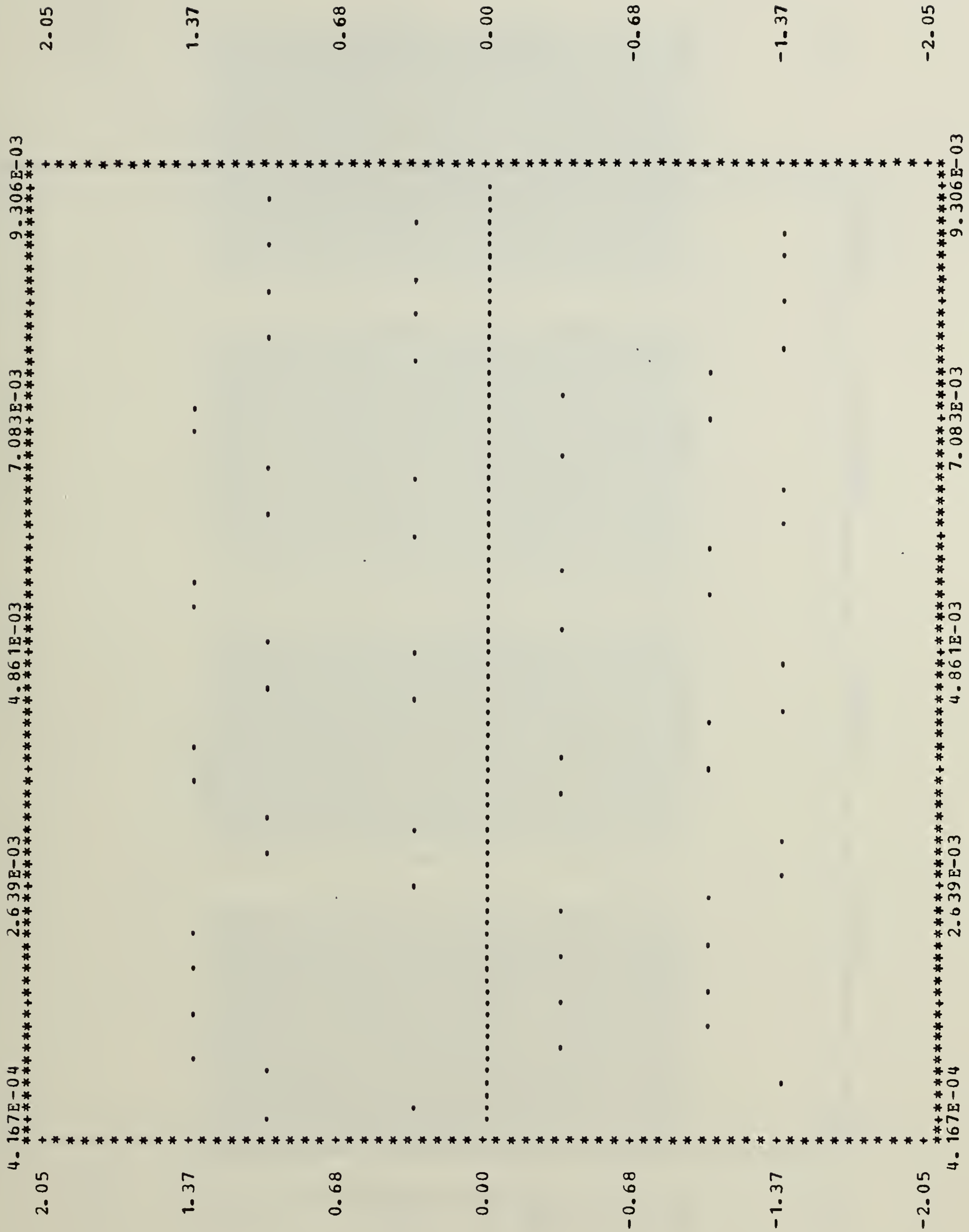
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 3   0.2001396615374287E+01   0.9269424591664253E+00   -0.7733658389670000E+01   0.1862322872670187E+01
 4   0.2772862445069488E+01   0.1678068152390965E+01   -0.2623023671424697E+02   0.8004509154649167E+01
 5   0.3251532646964970E+01   0.2932577358584998E+01   -0.4366853012949963E+02   0.2588931213699834E+02
 6   0.3777641084824826E+01   0.4020832039397192E+01   -0.7125587489602146E+02   0.7882832999429900E+02
 7   0.3829098409125102E+01   0.3882607022946678E+01   -0.7927245839330759E+02   0.3918838665086150E+02
 8   0.2961659942016187E+01   0.3191184577366257E+01   -0.3117942587408732E+02   0.2612505891404616E+02
 9   0.2968246427181287E+01   0.2173213541787000E+01   -0.3417545686971072E+02   0.1113594383145398E+02
10   0.2148359327285216E+01   0.1060831343738275E+01   -0.1029303883092354E+02   0.2522974975096634E+01
11   0.1345271169743835E+01   0.4197276401107519E+00   -0.1125305770333078E+01   0.4717607434503110E+00
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13   0.2439525645946195E+01   0.1781420668748019E+01   -0.1588289360955499E+02   0.9490600068457177E+01
14   0.3624460779686187E+01   0.2958165706320683E+01   -0.6557803973417343E+02   0.2992394022408189E+02
15   0.5344290929937282E+01   0.8707443216668699E+01   -0.2327526112313629E+03   0.2336896609052334E+03
16   0.6817466947394810E+01   0.8177726358497095E+01   -0.5351265563927940E+03   0.1713281150266957E+03
17   0.7712888151201321E+01   0.2474902892394821E+02   -0.6993895599099603E+03   0.1906132600582511E+04
18   0.9428086215184937E+01   0.1931615055428528E+02   -0.1470236620891471E+04   0.8926570202434632E+03
19   0.1072214978861974E+02   0.2805072869446679E+02   -0.2185062282026585E+04   0.1838937522132344E+04
20   0.1081933826880679E+02   0.3440851415469506E+02   -0.2210060342212764E+04   0.2931776835225231E+04
21   0.1199506255571578E+02   0.3580001811338520E+02   -0.3041862605032027E+04   0.3576329272194000E+04
22   0.1128875410898178E+02   0.3443719159620903E+02   -0.2585353070858207E+04   0.2812818126869951E+04
23   0.1122041374376493E+02   0.3976866880087194E+02   -0.2372557155779416E+04   0.5281536943398933E+04
24   0.1239679867770296E+02   0.3228274309630087E+02   -0.3399416891619934E+04   0.3179717696454303E+04
25   0.1194093966023447E+02   0.3512070429981194E+02   -0.3060399165727626E+04   0.3009353203186677E+04
26   0.9561857571851002E+01   0.2543911177410117E+02   -0.1477814600152428E+04   0.1874123783999903E+04
27   0.1060742458462544E+02   0.3139753080593636E+02   -0.2076204826664873E+04   0.2806095691376629E+04
28   0.8728674900290654E+01   0.2466868494522429E+02   -0.1082343896000136E+04   0.2016793419812381E+04
29   0.6834317564181064E+01   0.1211209931277713E+02   -0.5263413260618458E+03   0.4487766787298260E+03
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31   0.3639693642400281E+01   0.2758452726478166E+01   -0.6782334107449190E+02   0.2464070669964832E+02
32   0.2386927083876014E+01   0.1399515226938646E+01   -0.1523753288228533E+02   0.4542469052879014E+01
33   0.1732050807568335E+01   0.0000000000000000E+00   -0.4392304845407262E+01   0.3552713678800501E-13
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  3  0.2001396615374287E+03  0.4923261446606412E+03  0.1381536117378906E+04  0.4227325282648300E+04
  4  0.2772862445069488E+03  0.9350053610143797E+03  0.3617146855206192E+04  0.1552076567236376E+05
  5  0.3251532646964970E+03  0.1347571613927817E+04  0.6663673366622948E+04  0.3730772050466114E+05
  6  0.3777641084824826E+03  0.1825119588475971E+04  0.1070423830368278E+05  0.7445167878094695E+05
  7  0.3829098409125102E+03  0.1850577557948160E+04  0.1039848598462211E+05  0.6487941989349113E+05
  8  0.2961659942016187E+03  0.1193070234373592E+04  0.5728176453630993E+04  0.3076395259880928E+05
  9  0.2968246427181287E+03  0.1096196825884361E+04  0.4581703878290195E+04  0.2085133629191266E+05
 10  0.2148359327285216E+03  0.5665670829434276E+03  0.1699175588603837E+04  0.5554999135160828E+04
 11  0.1345271169743835E+03  0.2225284883853590E+03  0.4236019985524009E+03  0.8928460993959043E+03
 12  0.1227933909092941E+03  0.2008212021965416E+03  0.3661456844087844E+03  0.7003073260736443E+03
 13  0.2439525645946195E+03  0.7714891839289738E+03  0.2867656512893159E+04  0.1200917193304039E+05
 14  0.3624460779686187E+03  0.1606529999274088E+04  0.8283267759160608E+04  0.4822673270831660E+05
 15  0.5344290929937282E+03  0.3718181432831191E+04  0.3062557969012455E+05  0.2856040295092663E+06
 16  0.6817466947394810E+03  0.5457380467373284E+04  0.4880830611198267E+05  0.4743021367639485E+06
 17  0.7712888151201321E+03  0.8399018226765046E+04  0.1125053797712358E+06  0.1725371305828622E+07
 18  0.9428086215184937E+03  0.1080117987297027E+05  0.1407019411789127E+06  0.2005207843938780E+07
 19  0.1072214978861974E+04  0.1427347174971205E+05  0.2176277788915563E+06  0.3637040011384774E+07
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 21  0.1199506255571578E+04  0.1793235436477862E+05  0.3123365714840376E+06  0.6073380779387869E+07
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 23  0.1122041374376493E+04  0.1652686666941321E+05  0.2938795932623678E+06  0.5988858815854951E+07
 24  0.1239679867770296E+04  0.1856405331208358E+05  0.3197266820030420E+06  0.6140029605956307E+07
 25  0.1194093966023447E+04  0.1773555372261744E+05  0.3007804059612307E+06  0.5593517440986197E+07
 26  0.9561857571851002E+03  0.1166138408807245E+05  0.1684461971622795E+06  0.2740691242417772E+07
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 31  0.3639693642400281E+03  0.1597823800974241E+04  0.8014959320690399E+04  0.4479812197206906E+05
 32  0.2386927083876014E+03  0.7082940978410114E+03  0.2408701627482010E+04  0.8977311403841160E+04
 33  0.1732050807568335E+03  0.2999999999998121E+03  0.5196152422701748E+03  0.8999999999988742E+03
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   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.9600995280888690E+04   0.8204154937490084E+07
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.8272550682771584E+04   0.7152001918873632E+07
    MEAN VARIANCE         VARIANCE OF THE VARIANCES
 0.6363699791337385E+01   0.4884355155646109E+02
    MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.2909392509360209E+03   0.1690890175696266E+06
    MEAN KURTOSIS         VARIANCE OF THE KURTOSIS
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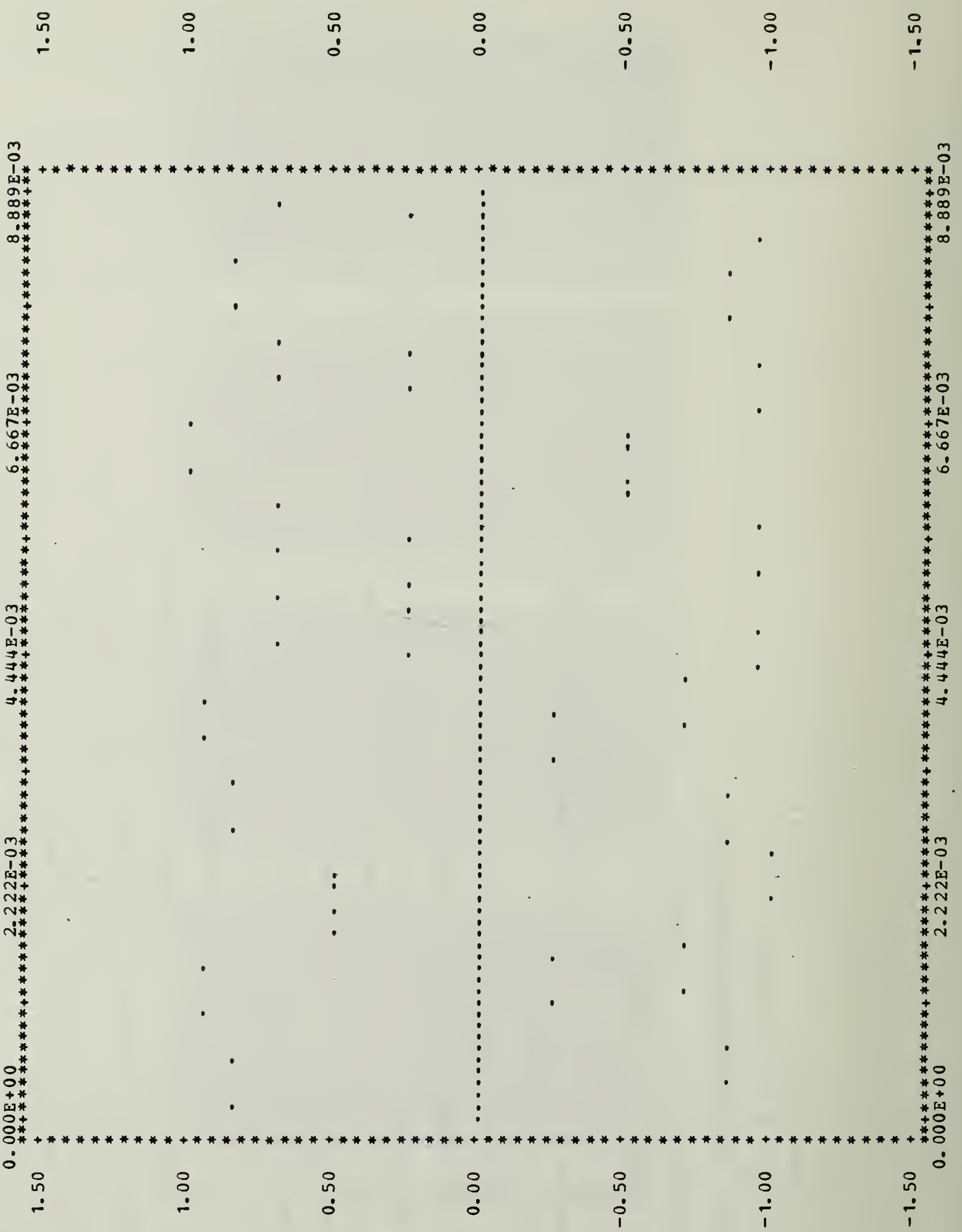
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  3   0.1279592076732864E+01   0.3929809053583419E+00   -0.7796903977805032E+00    0.5674271316067037E+00
  4   0.1737356302159723E+01   0.6936742970218630E+00   -0.4345593469482651E+01    0.1075933227133294E+01
  5   0.2121975123431636E+01   0.1523830949025344E+01   -0.8949356079797202E+01    0.6471426678194621E+01
  6   0.2424237800675234E+01   0.1477847946943727E+01   -0.1574379606014421E+02    0.6672349398345201E+01
  7   0.2493407977880165E+01   0.1246925063550747E+01   -0.1813201191600308E+02    0.4341297777074292E+01
  8   0.2478804546055675E+01   0.2098145396937312E+01   -0.1694930495176807E+02    0.9359754143637726E+01
  9   0.2071593329231943E+01   0.1038070914171632E+01   -0.8959518397406967E+01    0.2630686655844620E+01
 10   0.1792265854082727E+01   0.8172058974659458E+00   -0.4858409033532932E+01    0.1708412203826555E+01
 11   0.1338421965915424E+01   0.4602410319466023E+00   -0.1076573354148309E+01    0.4930109231783348E+00
 12   0.1206794109459943E+01   0.3465146025707462E+00   -0.5824924961494571E+00    0.2784383478326526E+00
 13   0.1701079214725041E+01   0.8240034102520097E+00   -0.3676238752314777E+01    0.1845216445410600E+01
 14   0.2834150610551414E+01   0.1823855047315213E+01   -0.2841376075861841E+02    0.1025688233426690E+02
 15   0.3743807553618862E+01   0.3367091128248024E+01   -0.7536218978763767E+02    0.2764443212163627E+02
 16   0.4695195021029540E+01   0.5878572281542108E+01   -0.1604268845957975E+03    0.7733863012447296E+02
 17   0.5610648269528947E+01   0.7832247511634661E+01   -0.2870389196847128E+03    0.1576959426040605E+03
 18   0.6706908951556747E+01   0.1336843509358619E+02   -0.4883380690179577E+03    0.4717187808135241E+03
 19   0.7233528197904389E+01   0.1179079685993331E+02   -0.6391723454185712E+03    0.3894371981662816E+03
 20   0.7838475981757254E+01   0.1550564901810932E+02   -0.8148308730885305E+03    0.8369144820736628E+03
 21   0.8345623481532100E+01   0.2143264337995021E+02   -0.9600418962579780E+03    0.1423931246664269E+04
 22   0.8944133416090430E+01   0.1849543486323111E+02   -0.1217075995286470E+04    0.1263290690873313E+04
 23   0.8814783978046604E+01   0.2037175020305552E+02   -0.1196920188977485E+04    0.9463713933138024E+03
 24   0.8749509753732253E+01   0.1838659826724127E+02   -0.1168060381440785E+04    0.8402328493104333E+03
 25   0.8285982175052635E+01   0.1666403923810872E+02   -0.9723427666802374E+03    0.6372386843278655E+03
 26   0.7248418801596032E+01   0.1376932655732141E+02   -0.6340385567820426E+03    0.5186332515460535E+03
 27   0.6082018000723616E+01   0.8179763542192111E+01   -0.3674332594430192E+03    0.1611004446780380E+03
 28   0.5574426942061457E+01   0.8531145086994827E+01   -0.2667689307470644E+03    0.3277737781942465E+03
 29   0.4540960061679976E+01   0.6292988896313568E+01   -0.1361945600435881E+03    0.1056182502126908E+03
 30   0.3600823367347476E+01   0.2838980150814418E+01   -0.6510362543227304E+02    0.2228552737517583E+02
 31   0.2979632931111714E+01   0.2494350499185918E+01   -0.3337309524735176E+02    0.1665843666245958E+02
 32   0.1788877268851379E+01   0.8979917766910076E+00   -0.4784211837438346E+01    0.1743915793219237E+01
 33   0.1438892582981557E+01   0.7161261323388549E+00   -0.1748123869941282E+01    0.9253962560184192E+00
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 2   0.8991336804147069E+02    0.1101399810746785E+03    0.1633003824800721E+03    0.2747253888189251E+03
 3   0.1279592076732864E+03    0.2026406979142283E+03    0.3724520780784378E+03    0.7766002785739216E+03
 4   0.1737356302159724E+03    0.3705144474705753E+03    0.8929060999836082E+03    0.2335831349797537E+04
 5   0.2121975123431636E+03    0.6011371063997799E+03    0.2031302663783766E+04    0.7730418455554565E+04
 6   0.2424237800675234E+03    0.7339998381696989E+03    0.2588405071282505E+04    0.1024637141588694E+05
 7   0.2493407977880165E+03    0.7451539157071692E+03    0.2517300294087098E+04    0.9340289925095110E+04
 8   0.2478804546055675E+03    0.8221635920514223E+03    0.3190123658049523E+04    0.1358254136951836E+05
 9   0.2071593329231943E+03    0.5319189126748201E+03    0.1551507389484043E+04    0.4948150356240742E+04
10   0.1792265854082727E+03    0.4021250730202174E+03    0.1033860830638506E+04    0.2927878573892384E+04
11   0.1338421965915424E+03    0.2247011980472043E+03    0.4363030505178581E+03    0.9326945526938799E+03
12   0.1206794109459943E+03    0.1799401479172257E+03    0.3019324775451872E+03    0.5492763501245419E+03
13   0.1701079214725041E+03    0.3709433870919051E+03    0.9466542826798441E+03    0.2697528412673160E+04
14   0.2834150610551415E+03    0.9838026180131017E+03    0.3916876358992104E+04    0.1737180587441166E+05
15   0.3743807553618863E+03    0.1734951521549920E+04    0.9146535856152885E+04    0.5276772696201834E+05
16   0.4695195021029540E+03    0.2786464284422727E+04    0.1879731998681482E+05    0.1379916742814523E+06
17   0.5610648269528947E+03    0.3923329904088649E+04    0.3103750564215353E+05    0.2685931834990769E+06
18   0.6706908951556748E+03    0.5821737842712236E+04    0.5930726451401991E+05    0.6740142140150419E+06
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23   0.8814783978046604E+03    0.9786844928065208E+04    0.1235746693889336E+06    0.1700328056148307E+07
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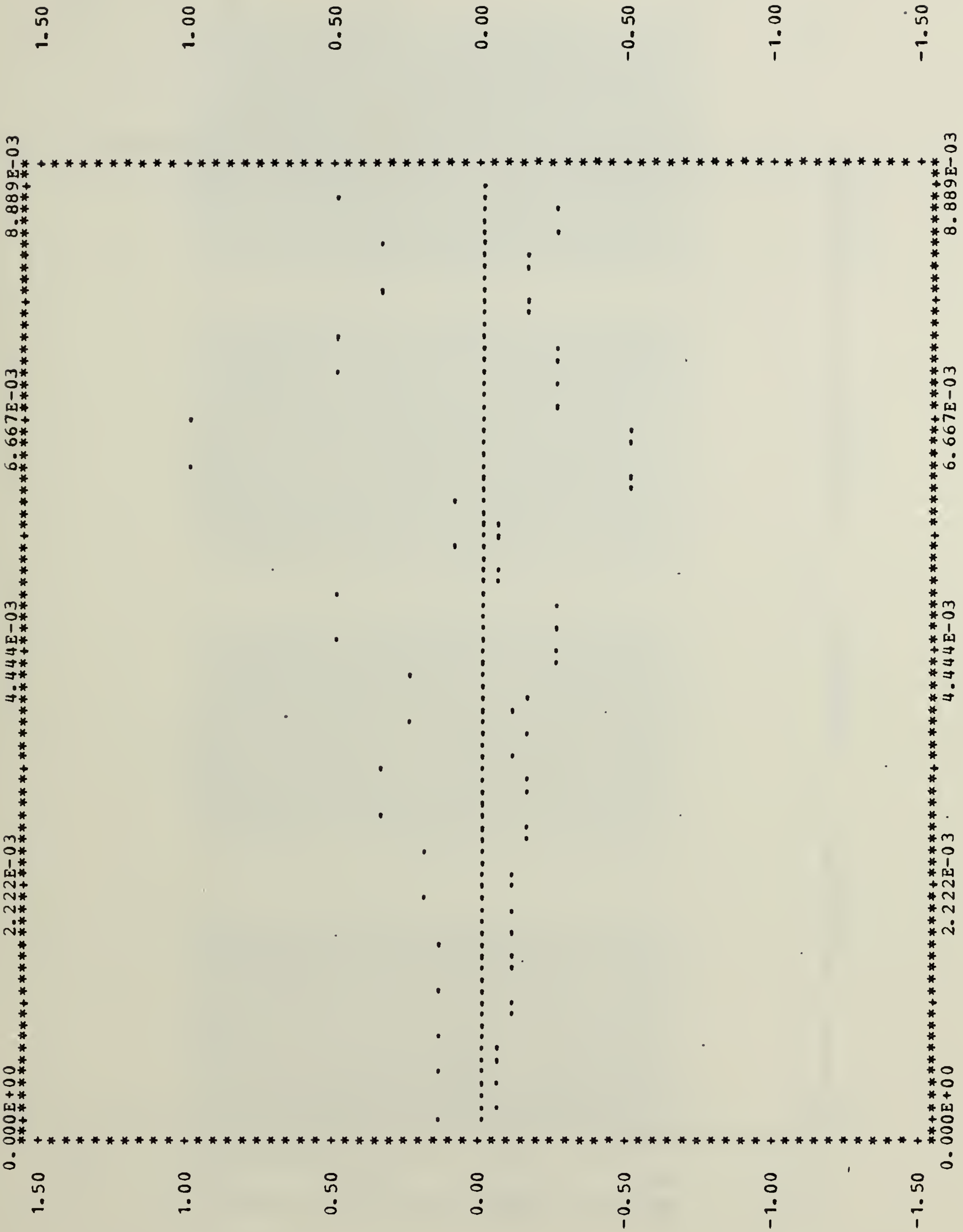
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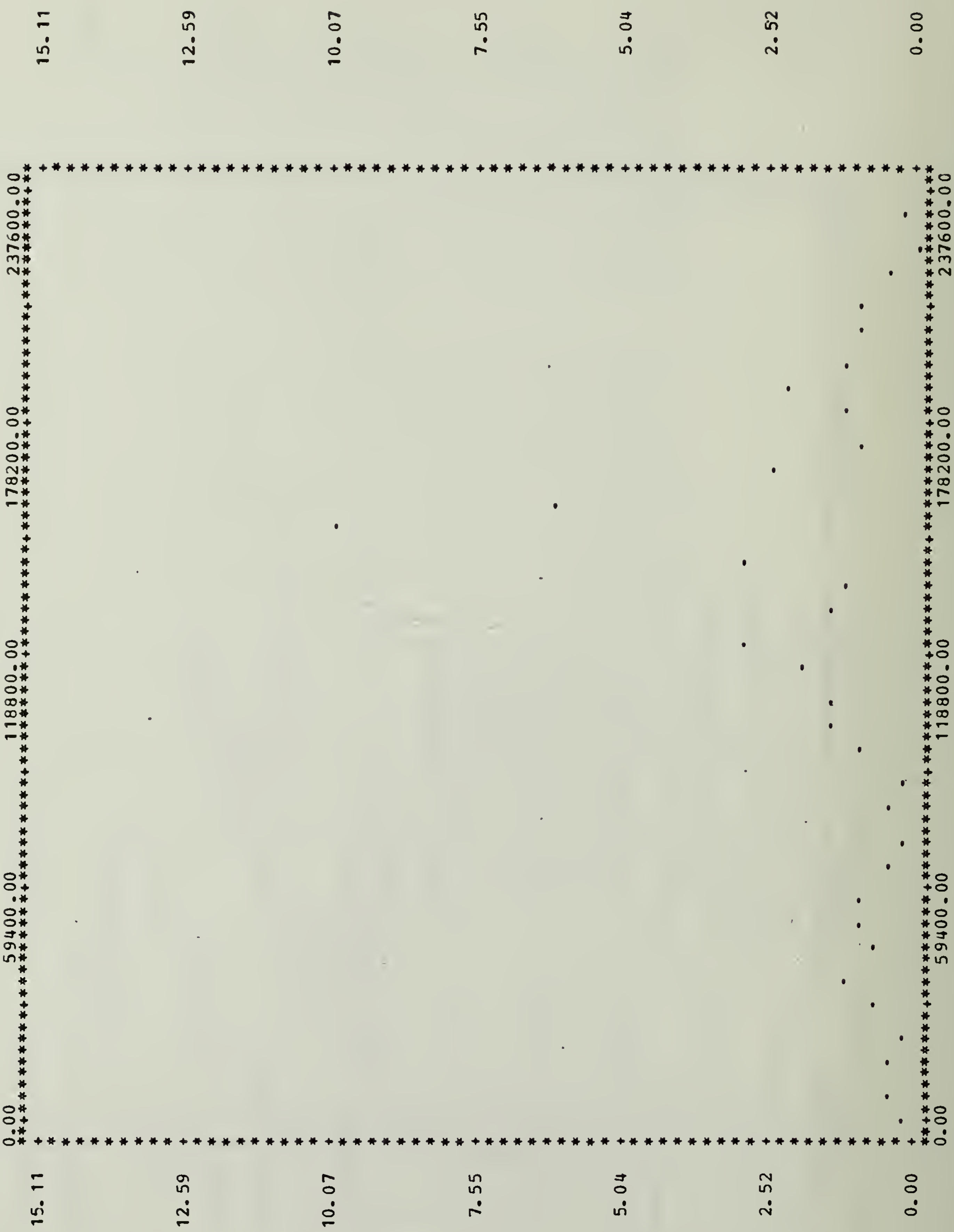
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 4   0.6569355772557277E+00   0.1457017233934383E+00    0.3309802432325256E+00   0.6104856817896656E-01
 5   0.7161005021434623E+00   0.1586238997580487E+00    0.3483330687474483E+00   0.1090588968757279E+00
 6   0.8413504533675261E+00   0.2506368816797936E+00    0.3341500081150626E+00   0.2119929827562888E+00
 7   0.8750519414575849E+00   0.1582141403087646E+00    0.2153114973989920E+00   0.8553177882653351E-01
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11   0.5096201315245369E+00   0.1626402382072894E+00    0.3366001013572022E+00   0.9761198503664166E-01
12   0.4682289421728521E+00   0.1574634369096420E+00    0.3172125727703493E+00   0.9859166537393366E-01
13   0.6648869535479373E+00   0.1580594153239595E+00    0.3627225421498026E+00   0.1048537336552618E+00
14   0.8376250912444208E+00   0.2646497831913186E+00    0.3375016241785487E+00   0.2258943155139170E+00
15   0.1210125608088872E+01   0.4229914530943488E+00   -0.5096043285692129E+00   0.4625565690160802E+00
16   0.1517580038320735E+01   0.7062878859778058E+00   -0.1866015564593158E+01   0.1681719571938255E+01
17   0.1809198427029523E+01   0.1114007724685303E+01   -0.4305283960734115E+01   0.4061604744465562E+01
18   0.2184365983429202E+01   0.1357504208894486E+01   -0.9744491483583519E+01   0.7477973881021072E+01
19   0.2187798064034754E+01   0.1242471878317058E+01   -0.1056072077463751E+02   0.4506869998249794E+01
20   0.2754817782881566E+01   0.2304339434717248E+01   -0.2331072874845357E+02   0.1840676577341128E+02
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23   0.4770282409732731E+01   0.2378616824097682E+01   -0.1692516756760991E+03   0.1754223705726594E+02
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25   0.2264338741105986E+01   0.1317600360027486E+01   -0.1196687807153250E+02   0.5562161697791915E+01
26   0.1730042306558164E+01   0.8497906580179376E+00   -0.3919560952908456E+01   0.1879382110769463E+01
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  3   0.5679613369866736E+02   0.3996492192118776E+02   0.3241400271345726E+02   0.2906212284536081E+02
  4   0.6569355772557277E+02   0.5758090588238202E+02   0.6026599072464039E+02   0.7124348934965693E+02
  5   0.7161005021434623E+02   0.6698375899305872E+02   0.7617463139187906E+02   0.1018941858527745E+03
  6   0.8413504533675261E+02   0.9560010982447375E+02   0.1331404709635767E+03   0.2135596761732665E+03
  7   0.8750519414575849E+02   0.9223478991543655E+02   0.1105186656464672E+03   0.1475338504496394E+03
  8   0.8810672568079662E+02   0.1021358804589603E+03   0.1443806707757001E+03   0.2375967453151129E+03
  9   0.7193220063807960E+02   0.6614802470810837E+02   0.7106619344194451E+02   0.8497279404873148E+02
 10   0.6400695740593127E+02   0.5935725261733565E+02   0.7229491320574764E+02   0.1080651844225191E+03
 11   0.5096201315245369E+02   0.4207265142803029E+02   0.4604068490771932E+02   0.5828863474887966E+02
 12   0.4682289421728521E+02   0.3751271448288537E+02   0.4056720468043424E+02   0.5091240706613379E+02
 13   0.6648869535479373E+02   0.5985534821689769E+02   0.6724844240378106E+02   0.8920162650581295E+02
 14   0.8376250912444208E+02   0.9636190788416297E+02   0.1355724593732854E+03   0.2188502038919660E+03
 15   0.1210125608088872E+03   0.1883165525915868E+03   0.3398188178268685E+03   0.6798641196073320E+03
 16   0.1517580038320735E+03   0.3002274179827592E+03   0.7196460184604044E+03   0.1979233294199776E+04
 17   0.1809198427029523E+03   0.4376066595804551E+03   0.1289983654765179E+04   0.4361413529881382E+04
 18   0.2184365983429202E+03   0.6115383916368165E+03   0.2078730882486524E+04   0.8233101049976278E+04
 19   0.2187798064034754E+03   0.6016507528528105E+03   0.1935506905686699E+04   0.6983075996726611E+04
 20   0.2754817782881566E+03   0.9870317057250584E+03   0.4308400407376489E+04   0.2165045465334777E+05
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 22   0.9147694673424342E+03   0.8856246087975177E+04   0.9035106102323497E+05   0.9666813766485890E+06
 23   0.4770282409732731E+03   0.2511042492446221E+04   0.1445885907409191E+05   0.9014912438871981E+05
 24   0.2682785373968661E+03   0.9453874859656329E+03   0.3944430526314505E+04   0.1856332225736484E+05
 25   0.2264338741105986E+03   0.6431654290900655E+03   0.2146899400038132E+04   0.8102049904027280E+04
 26   0.1730042306558164E+03   0.3834339133918852E+03   0.9995053040242969E+03   0.2906369127358244E+04
 27   0.1520548002468391E+03   0.3070911570882289E+03   0.7450754300789790E+03   0.2072581731545704E+04
 28   0.1268184557381321E+03   0.2118326797108026E+03   0.4182206545817384E+03   0.9320695629873251E+03
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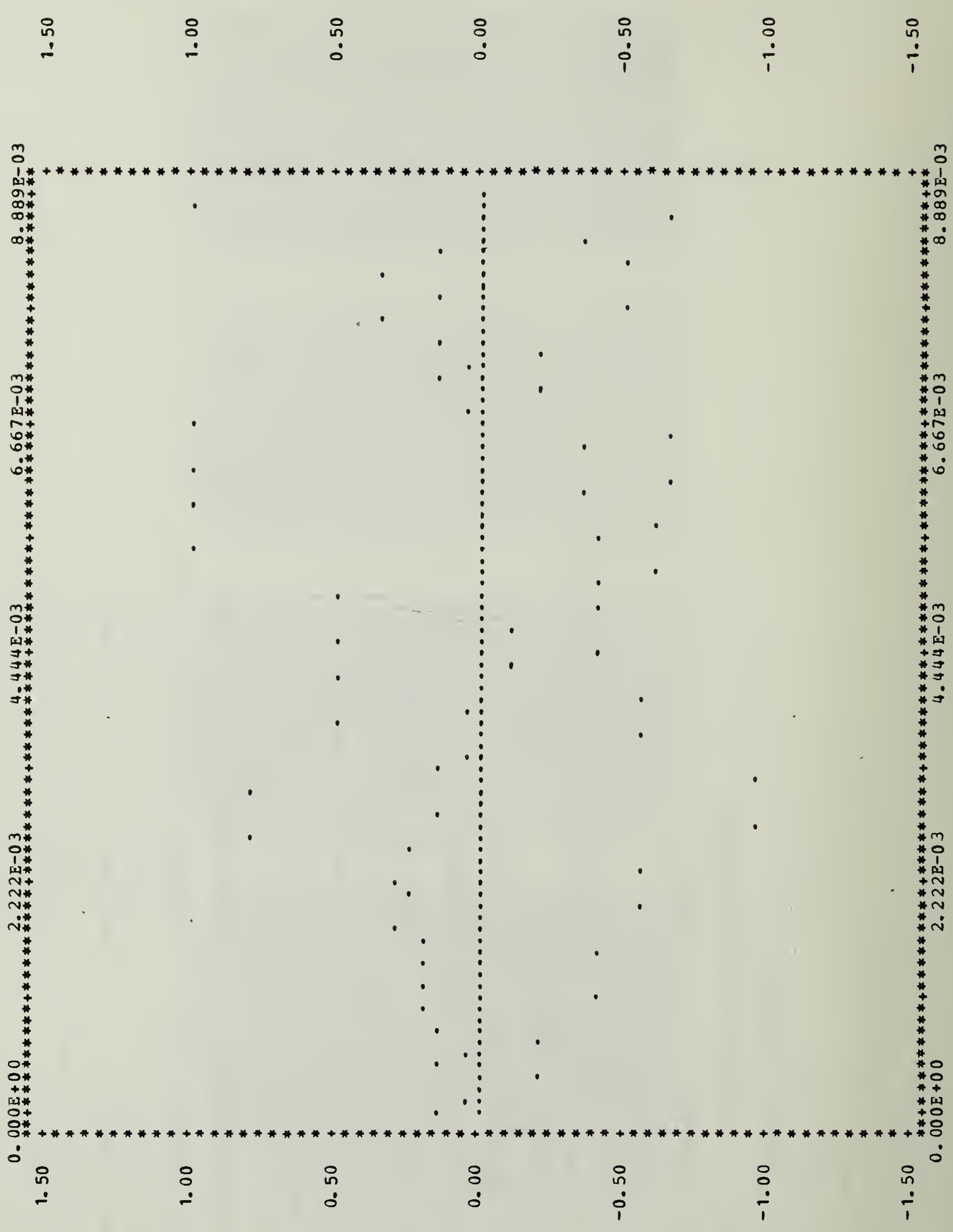
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 6   0.9941197242066054E+00   0.2448428085097390E+00    0.8874388910038866E-01   0.1407886371080798E+00
 7   0.1026103523087546E+01   0.2821921014461165E+00   -0.1299944649149154E-01   0.1698637724238030E+00
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18   0.2752879991704121E+01   0.1810579104882114E+01   -0.2526590473117368E+02   0.8308910926769993E+01
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27   0.2677625104741695E+01   0.1830946288086045E+01   -0.2260532808915164E+02   0.9890794785552860E+01
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  5   0.9221266466053553E+02      0.1071786719672733E+03      0.1442114658669020E+03      0.2146134760517165E+03
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 13   0.8754097356965494E+02      0.9914268128277373E+02      0.1325186914190332E+03      0.1965513339618076E+03
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 32   0.8700976947091932E+02      0.1029713688274607E+03      0.1450598111534421E+03      0.2273903600923206E+03
 33   0.6506228822272112E+02      0.6565478505946402E+02      0.8528614697432775E+02      0.1260397997430225E+03
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MODULATION TECHNIQUE = MSK
BIPOLAR LOGIC
BAUD OR SYMBOL RATE =        1200 HZ
BITS PER BINARY CODE WORD =           1
BIT RATE =  0.120000000000000E+04
CARRIER FREQUENCY =        3000 HZ
MAXIMUM CARRIER AMPLITUDE =           1 VOLT(S)
INITIAL PHASE ANGLE =           0 DEGREES
TIME BETWEEN SAMPLES =  0.111111111111111E-03 SEC
NUMBER OF SAMPLES GENERATED =         64
SEED FOR RANDOM NUMBER GENERATOR =            1
NUMBER OF TIMES SIMULATION REPEATS =          100
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   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.166557825885063 5E+05   0.970485381923380 4E+08
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.542366623761090 7E+04   0.611869154829385 8E+07
     MEAN VARIANCE         VARIANCE OF THE VARIANCES
 0.462390954801450 8E+01   0.430939444371419 0E+02
     MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.504720684500192 4E+03   0.277006313135564 7E+07
     MEAN KURTOSIS         VARIANCE OF THE KURTOSIS
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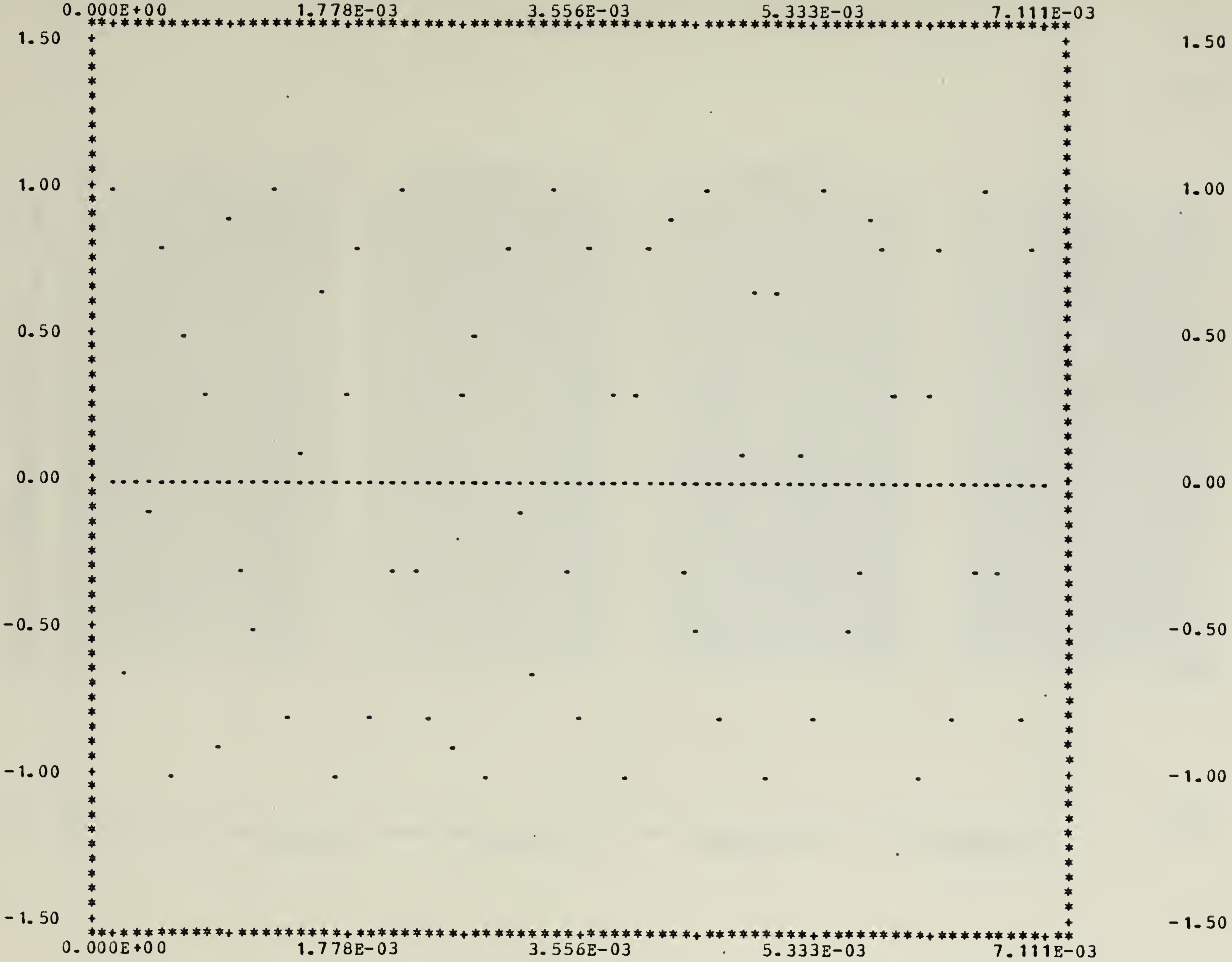
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 N         MEAN                    VARIANCE                 SKEWNESS                 KURTOSIS
  1   0.1745381057261094E+01   0.1355578995944516E+01  -0.3424362342353158E+01   0.5473118008703764E+01
  2   0.1670893117553454E+01   0.5901911630020479E+00  -0.3495315053453071E+01   0.1090755818972799E+01
  3   0.1549301951756876E+01   0.6168607541593016E+00  -0.2050204688587283E+01   0.2072568134087788E+01
  4   0.1661199892949759E+01   0.6791172245377799E+00  -0.3416316593482210E+01   0.1031766180903137E+01
  5   0.1789165204967162E+01   0.1187649235767541E+01  -0.4253824550585361E+01   0.4425773685632588E+01
  6   0.1793980989469851E+01   0.6705838354600710E+00  -0.5135274827787229E+01   0.9492102864198628E+00
  7   0.1744198082222983E+01   0.8410759608141099E+00  -0.4231013557271023E+01   0.1621868551827440E+01
  8   0.1974720124125793E+01   0.9695494611582597E+00  -0.7310166411774525E+01   0.2277449619040244E+01
  9   0.2053488485398217E+01   0.9611806657981106E+00  -0.8487669792860372E+01   0.2604980667152322E+01
 10   0.2088844746733196E+01   0.8767072712879614E+00  -0.9051519777937444E+01   0.2339329653500119E+01
 11   0.2078335081298121E+01   0.8586827233682362E+00  -0.9240745527458049E+01   0.1528701296758548E+01
 12   0.1846376751847116E+01   0.1102239221695370E+01  -0.5290548653695978E+01   0.3019964469265048E+01
 13   0.2245946499482377E+01   0.1194857291064416E+01  -0.1223253783690999E+02   0.3015304601135153E+01
 14   0.2963675540203763E+01   0.2445326920526502E+01  -0.3299670208754627E+02   0.1525288363748558E+02
 15   0.3173784304747806E+01   0.2467783740162910E+01  -0.4212913869181091E+02   0.1518478689342305E+02
 16   0.3465632704745810E+01   0.5120393955377951E+01  -0.4209380992274822E+02   0.1417059143970117E+03
 17   0.4614191970595573E+01   0.4884566208791112E+01  -0.1448217452612039E+03   0.8434809081291280E+02
 18   0.6056467485580745E+01   0.1025151080329688E+02  -0.3488271204826219E+03   0.2873969971148171E+03
 19   0.6406000917972383E+01   0.7829202751917509E+01  -0.4368456489015806E+03   0.1481115108052472E+03
 20   0.1698791308733019E+02   0.2854008167165727E+02  -0.9245547474814263E+04   0.2008740923582969E+04
 21   0.6683213299026370E+01   0.1119947335159933E+02  -0.4907458525202289E+03   0.3031919538307138E+03
 22   0.6486578159166406E+01   0.1017117379541286E+02  -0.4465802292353152E+03   0.2680409342301182E+03
 23   0.6465666718341273E+01   0.7377630480256458E+01  -0.4512761578680025E+03   0.1522694237588385E+03
 24   0.1116454812650914E+02   0.2162335800890371E+02  -0.2501564247125116E+04   0.1165597750187054E+04
 25   0.1044373719208894E+02   0.1462960849421151E+02  -0.2068981176065553E+04   0.6248220438872377E+03
 26   0.4981051119955246E+01   0.6452035401677616E+01  -0.1905233821159606E+03   0.1076197803024863E+03
 27   0.4123269596834735E+01   0.4439736504910233E+01  -0.1001918569207450E+03   0.6134152643541944E+02
 28   0.2864935711027876E+01   0.1615487880606123E+01  -0.3017501863379686E+02   0.5746676318150122E+01
 29   0.1801795405750350E+01   0.9106026395844705E+00  -0.4741745708792403E+01   0.2331085528965168E+01
 30   0.1309968810623288E+01   0.3731036902683101E+00  -0.9703918339010844E+00   0.3451406134067727E+00
 31   0.8612683866837359E+00   0.2253789614502914E+00   0.2871099110118729E+00   0.1541083993062977E+00
 32   0.6043391628396291E+00   0.7921584690864393E-01   0.2862143793099431E+00   0.1130792746883191E-01
 33   0.5680265238925039E+00   0.4907017290140923E-01   0.2752850066625604E+00   0.2607974479555311E-02
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 N          SUM  X                       SUM  X**2                     SUM  X**3                     SUM  X**4
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  2   0.1670893117553454E+03    0.3376173061659528E+03    0.7844590323160757E+03    0.2034919190393599E+04
  3   0.1549301951756876E+03    0.3011028684335374E+03    0.7144100088287587E+03    0.2026599445555989E+04
  4   0.1661199892949759E+03    0.3431911136628693E+03    0.8167784476187219E+03    0.2132708178344390E+04
  5   0.1789165204967162E+03    0.4376884874075052E+03    0.1283686155661075E+04    0.4297079886762252E+04
  6   0.1793980989469851E+03    0.3882245787684695E+03    0.9322015009721566E+03    0.2394998604752789E+04
  7   0.1744198082222983E+03    0.3874892151236301E+03    0.9960270919690049E+03    0.2814823675876644E+04
  8   0.1974720124125794E+03    0.4859373535174067E+03    0.1367850258262828E+04    0.4224573233856694E+04
  9   0.2053488485398217E+03    0.5168383818803192E+03    0.1491835026790595E+04    0.4772349863793718E+04
 10   0.2088844746733196E+03    0.5231212574529951E+03    0.1500350818620739E+04    0.4786253224795818E+04
 11   0.2078335081298121E+03    0.5169572606289023E+03    0.1435261336113773E+04    0.4284140702659404E+04
 12   0.1846376751847116E+03    0.4500323939239922E+03    0.1281911761836188E+04    0.4050916330073661E+04
 13   0.2245946499482377E+03    0.6227184396690914E+03    0.1963667979815342E+04    0.6729137619289132E+04
 14   0.2963675540203763E+03    0.1120424635892330E+04    0.4905380513832378E+04    0.2377476116996190E+05
 15   0.3173784304747807E+03    0.1251601271582480E+04    0.5689442182858819E+04    0.2854218554507767E+05
 16   0.3465632704745810E+03    0.1707980006002793E+04    0.1114619110245010E+05    0.8887814430949281E+05
 17   0.4614191970595573E+03    0.2612648808821186E+04    0.1742546143252428E+05    0.1322897499994962E+06
 18   0.6056467485580745E+03    0.4682979409916067E+04    0.4286806586636075E+05    0.4402476375446830E+06
 19   0.6406000917972383E+03    0.4878775848546135E+04    0.4186839325073341E+05    0.3915963851799988E+06
 20   0.1698791308733019E+04    0.3168438719176251E+05    0.6324822618229748E+06    0.1330157521040380E+08
 21   0.6683213299026370E+03    0.5575281861836628E+04    0.5377474040246168E+05    0.5722380556849635E+06
 22   0.6486578159166406E+03    0.5214515827243337E+04    0.4839993126034607E+05    0.4972868019579191E+06
 23   0.6465666718341274E+03    0.4910870028811991E+04    0.4176756170083457E+05    0.3879520293056626E+06
 24   0.1116454812650914E+04    0.1460542592979535E+05    0.2141030904177548E+06    0.3415942298203231E+07
 25   0.1044373719208894E+04    0.1235549589466912E+05    0.1584002090915345E+06    0.2162824361492207E+07
 26   0.4981051119955246E+03    0.3119838530726825E+04    0.2260571335915158E+05    0.1814011642212024E+06
 27   0.4123269596834735E+03    0.2139669130804281E+04    0.1304784189728246E+05    0.8978341400784285E+05
 28   0.2864935711027876E+03    0.9807189630122864E+03    0.3770017149804132E+04    0.1569116396929776E+05
 29   0.1801795405750350E+03    0.4147963297371694E+03    0.1118666456011763E+04    0.3377669865106972E+04
 30   0.1309968810623288E+03    0.2085390938171418E+03    0.3792962857370318E+03    0.7582535161578269E+03
 31   0.8612683866837359E+02    0.9649084057365937E+02    0.1296678760929258E+03    0.1977471929733572E+03
 32   0.6043391628396291E+02    0.4436495121812613E+02    0.3601070561840355E+02    0.3097912706858261E+02
 33   0.5680265238925039E+02    0.3712336030177964E+02    0.2625883421946238E+02    0.1928732784350291E+02
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MODULATION TECHNIQUE = MFSK
BIPOLAR LOGIC
BAUD OR SYMBOL RATE =        1200 HZ
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BIT RATE =  0.3600000000000000E+04
CARRIER FREQUENCY =      10800 HZ
MAXIMUM CARRIER AMPLITUDE =             1 VOLT(S)
INITIAL PHASE ANGLE =           0 DEGREES
TIME BETWEEN SAMPLES =  0.3086419753086419E-04 SEC
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SEED FOR RANDOM NUMBER GENERATOR =            1
NUMBER OF TIMES SIMULATION REPEATS =          100
   SUM OF VARIANCES          SUM OF VARIANCES**2
 0.4806181141925261E+03   0.1352273679574422E+05
   SUM OF SKEWNESS            SUM OF SKEWNESS**2
-0.1654247621695240E+04   0.5890267815807785E+06
   SUM OF KURTOSIS            SUM OF KURTOSIS**2
 0.5341287673934422E+05   0.2790612658473240E+09
    MEAN VARIANCE          VARIANCE OF THE VARIANCES
 0.1456418527856140E+02   0.2038414228878589E+03
    MEAN SKEWNESS          VARIANCE OF THE SKEWNESS
-0.5012871580894667E+02   0.1581567102109974E+05
    MEAN KURTOSIS          VARIANCE OF THE KURTOSIS
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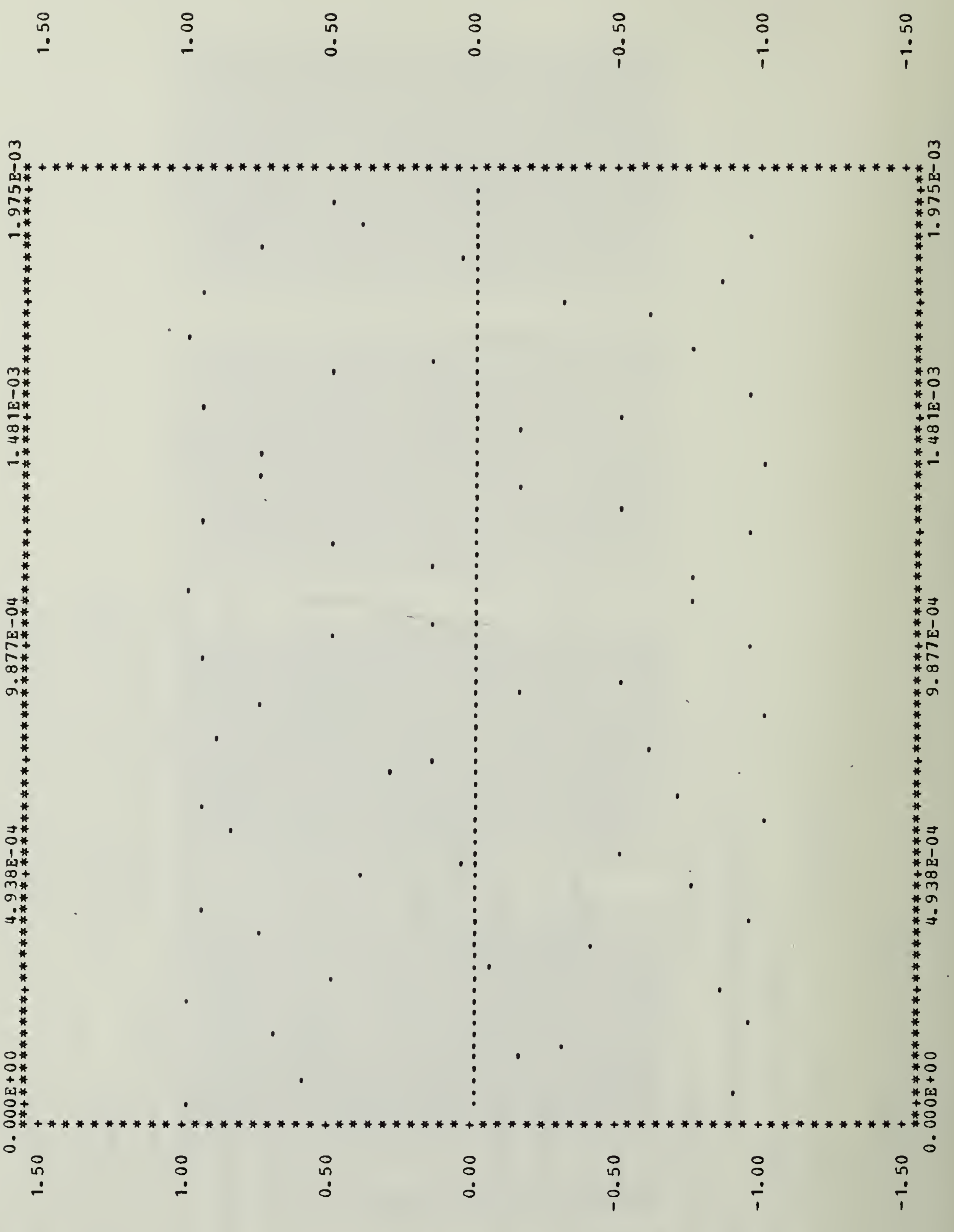
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 2   0.5802219943279051E+00   C.1692179389704175E+00    0.2881870091118721E+00   0.4962377142977341E-01
 3   0.6028101560497944E+00   0.1630844574986009E+00    0.2975209809667937E+00   0.4759923908949447E-01
 4   0.6236957775089775E+00   0.1517433865402484E+00    0.3011297117696356E+00   0.4060584454262756E-01
 5   0.6603884574738126E+00   0.1541310275696224E+00    0.3222793291193875E+00   0.5372574080695565E-01
 6   0.6914911473735869E+00   0.1625277259401340E+00    0.3303730158038245E+00   0.6338732183899803E-01
 7   0.6712915135223571E+00   0.1989459204647430E+00    0.3457384652309939E+00   0.9079440007191118E-01
 8   0.8082796112917950E+00   0.2158539044684256E+00    0.2513665218179688E+00   0.8711759471530689E-01
 9   0.8347057408743954E+00   0.2063633947272559E+00    0.2416258755581653E+00   0.7897411259783627E-01
10   0.1155203641180799E+01   0.3253381023466752E+00   -0.3616711703060194E+00   0.3009444434532169E+00
11   0.1405578654040239E+01   0.5901481998178570E+00   -0.1545347282296657E+01   0.6485308087822852E+00
12   0.1653469595833664E+01   0.1006408909069761E+01   -0.3264525934540579E+01   0.1839454693919151E+01
13   0.3282094270411689E+01   0.8604653034726285E+01   -0.2794322254332445E+02   0.1742698305978736E+03
14   0.5652678805043730E+01   0.4459844156194543E+02    0.1192554149182590E+03   0.8446317926807378E+04
15   0.5302792986411789E+01   0.1999384407499615E+02   -0.1915066362357811E+03   0.8114244563340110E+03
16   0.4839236365113163E+01   0.3116228371110405E+02    0.1153475974583148E+03   0.5030156057294299E+04
17   0.4799926056893745E+01   0.1627827150809915E+02   -0.9300212955009531E+02   0.1027015195900844E+04
18   0.4973004323275781E+01   0.1660039482645575E+02   -0.1210599846314087E+03   0.9267637549193778E+03
19   0.4949076398807320E+01   0.3195721379055708E+02    0.1586666023965808E+03   0.6953906279136898E+04
20   0.5240481051222312E+01   0.1710861900951835E+02   -0.1294472248356874E+03   0.1518760678679011E+04
21   0.5676550996298115E+01   0.4183417025969290E+02    0.1323276886342935E+03   0.8939299980725979E+04
22   0.6101993574152731E+01   0.1635330658894298E+02   -0.3215862356984157E+03   0.7932740986113413E+03
23   0.6259114577537281E+01   0.2770207472842645E+02   -0.2779436555304097E+03   0.1949698968797135E+04
24   0.6284446589130466E+01   0.2662812884562886E+02   -0.2772962242103021E+03   0.2129199108385613E+04
25   0.5742277487325188E+01   0.1282122464430269E+02   -0.2785797147037739E+03   0.4954058112039018E+03
26   0.5170868203869401E+01   0.2976675343581255E+02   -0.3721000245806551E+02   0.2486653253210702E+04
27   0.5917383281247872E+01   0.2149629222581870E+02   -0.2452121102148178E+03   0.1728196939758512E+04
28   0.5541030766931423E+01   0.3540159389584892E+02   -0.2604124431555488E+02   0.4059766140333669E+04
29   0.5288745936690563E+01   0.1787438125039946E+02   -0.2028946595998615E+03   0.6603169983834629E+03
30   0.5074754282284268E+01   0.3131561713839394E+02    0.1173219615183484E+01   0.2905905006347744E+04
31   0.4253003494334969E+01   0.2577288744924743E+02    0.5235457234353824E+02   0.2345083299105233E+04
32   0.1937545429384470E+01   0.2626549296496931E+01   -0.3005281031163669E+01   0.2094124943834442E+02
33   0.1137815044472511E+01   0.1207462920504103E+01    0.1860809816827437E+01   0.7168925235852774E+01
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 2  0.5802219943279051E+02  0.5041833222825649E+02  0.4924866419931451E+02  0.5142222707838669E+02
 3  0.6028101560497944E+02  0.5248336971603924E+02  0.5198860611495787E+02  0.5530202080413826E+02
 4  0.6236957775089775E+02  0.5392223755573740E+02  0.5320690223250621E+02  0.5634238544784942E+02
 5  0.6603884574738126E+02  0.5887026320585678E+02  0.6163707688778974E+02  0.7120408044653105E+02
 6  0.6914911473735869E+02  0.6390624555767724E+02  0.6997710939622378E+02  0.8513957160811946E+02
 7  0.6712915135223571E+02  0.6475887573872325E+02  0.7486363842363333E+02  0.9592693526928423E+02
 8  0.8082796112917950E+02  0.8670112954537567E+02  0.1047097320382813E+03  0.1354378623407661E+03
 9  0.8347057408743954E+02  0.9010334346286568E+02  0.1104451869673761E+03  0.1456174802950561E+03
10  0.1155203641180799E+03  0.1656580173920585E+03  0.2710400270962173E+03  0.4903643576994201E+03
11  0.1405578654040239E+03  0.2559898070513248E+03  0.5297764265612851E+03  0.1179902655990948E+04
12  0.1653469595833664E+03  0.3730306524325403E+03  0.9771395920102751E+03  0.2769882764951451E+04
13  0.3282094270411689E+03  0.1929074930424826E+04  0.1404546651472015E+05  0.1119512581698045E+06
14  0.5652678805043730E+03  0.7610523481931659E+04  0.1345945203020359E+06  0.2735139972972573E+07
15  0.5302792986411789E+03  0.4791351909098425E+04  0.5144805558206787E+05  0.6012440154264541E+06
16  0.4839236365113163E+03  0.5426886947142667E+04  0.8563708401825700E+05  0.1562683895259645E+07
17  0.4799926056693745E+03  0.3915477894466569E+04  0.4247394212718559E+05  0.5361723252608621E+06
18  0.4973004323275782E+03  0.4116516287751081E+04  0.4436220702445909E+05  0.5477857354242532E+06
19  0.4949076398807320E+03  0.5613099885388315E+04  0.9430696930018190E+05  0.1917395613042084E+07
20  0.5240481051222312E+03  0.4440017446764327E+04  0.5136623107738203E+05  0.7232624679783723E+06
21  0.5676550996298115E+03  0.7363905977066910E+04  0.1321928860530092E+06  0.2783296553532304E+07
22  0.6101993574152731E+03  0.5342409910205477E+04  0.5819256414204924E+05  0.7220823402526333E+06
23  0.6259114577537281E+03  0.6660156927588188E+04  0.8943038733047049E+05  0.1328899427697067E+07
24  0.6284446589130466E+03  0.6585611648880613E+04  0.8853229778507997E+05  0.1345801576503997E+07
25  0.5742277487325188E+03  0.4566676313930133E+04  0.4421664614948079E+05  0.4878553805504906E+06
26  0.5170868203869401E+03  0.5620696388324199E+04  0.7812306487180346E+05  0.1177282884327380E+07
27  0.5917383281247872E+03  0.5629675420075235E+04  0.6841454562789571E+05  0.9772311809625675E+06
28  0.5541030766931423E+03  0.6575059991697107E+04  0.1005531003016690E+06  0.1706205303321739E+07
29  0.5288745936690563E+03  0.4566647102075641E+04  0.4657187623964849E+05  0.5195716873974923E+06
30  0.5074754282284268E+03  0.5675559199257252E+04  0.8137290080877166E+05  0.1264367017074687E+07
31  0.4253003494334969E+03  0.4360319729758042E+04  0.5725121463102471E+05  0.8334021441901511E+06
32  0.1937545429384470E+03  0.6354366094460613E+03  0.2642217333585245E+04  0.1248684163529250E+05
33  0.1137815044472511E+03  0.2490011366727044E+03  0.7771080847880242E+03  0.2822352571960914E+04
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CARRIER FREQUENCY =       2400 HZ
MAXIMUM CARRIER AMPLITUDE =           1 VOLT(S)
INITIAL PHASE ANGLE =          0 DEGREES
TIME BETWEEN SAMPLES =  0.6784342273548912E-04 SEC
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SEED FOR RANDOM NUMBER GENERATOR =           1
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   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.1732359062524069E+06   0.9850778236273860E+10
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.3533192079165041E+06   0.4536060891356758E+11
    MEAN VARIANCE         VARIANCE OF THE VARIANCES
 0.2401785212724214E+02   0.4130538703065308E+04
    MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.5249572916739602E+04   0.2794176160813870E+09
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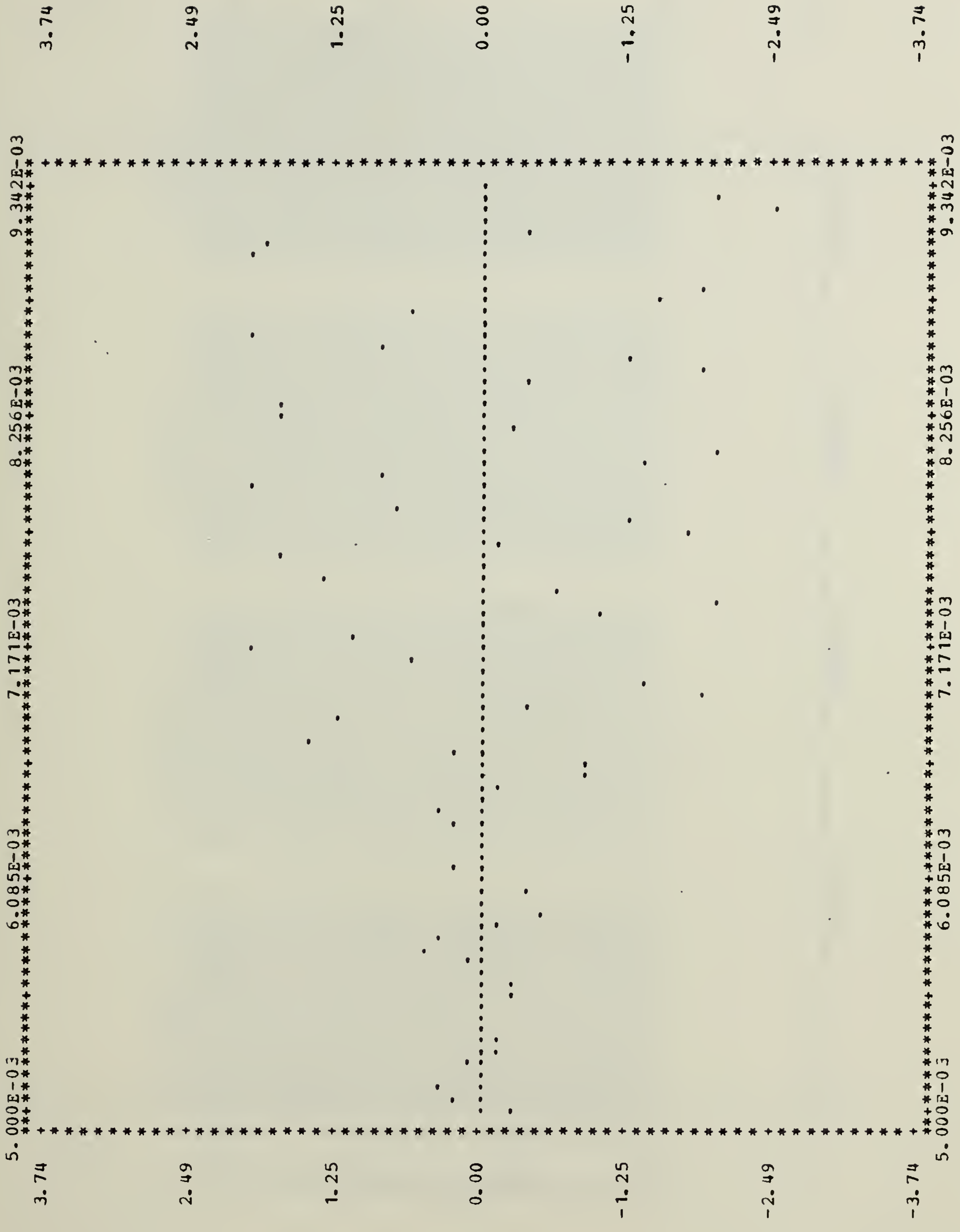
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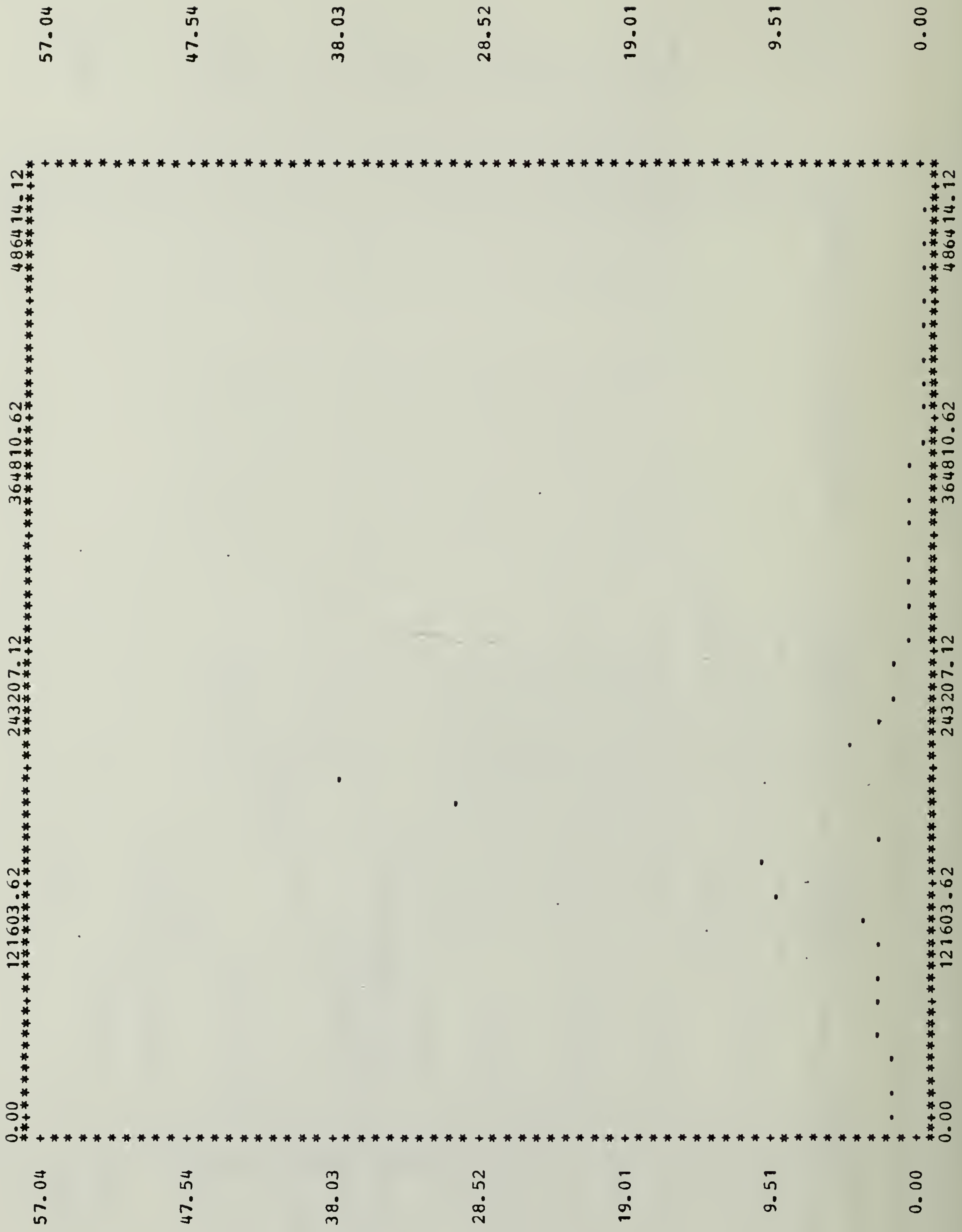
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  2  C.1783934079105657E+01   0.1373900592274223E+01   -0.4000383957156492E+01   0.5076096043644750E+01
  3  0.1881639570810958E+01   0.1391153714557888E+01   -0.5219656911680200E+01   0.5267763272060726E+01
  4  0.2045686771930169E+01   0.1468678508208007E+01   -0.7699351745328097E+01   0.5884490676168223E+01
  5  0.2297388544402002E+01   0.1644047467555237E+01   -0.1261209753570515E+02   0.7239435166189224E+01
  6  0.2683505678955374E+01   0.1999006273090073E+01   -0.2311823186803285E+02   0.1024292414275401E+02
  7  0.3312924180891911E+01   0.2756479367453149E+01   -0.4950242176250788E+02   0.1834851180285642E+02
  8  0.4514755520309362E+01   0.4811195957225893E+01   -0.1408993176802396E+03   0.5414450274312225E+02
  9  0.9536555141797188E+01   0.2327656842676565E+02   -0.1505196860526031E+04   0.1409137635928702E+04
 10  0.2195585557239151E+02   0.1129481209797817E+03   -0.1990155013949577E+05   0.2735320445369462E+05
 11  0.3232856430932140E+02   0.2402926487517075E+03   -0.6527459761041918E+05   0.1283904731804624E+06
 12  0.3329064024908647E+02   0.2623808601021426E+03   -0.7047843429734775E+05   0.1648935745345857E+06
 13  0.2012368604390696E+02   0.1051549869380090E+03   -0.1496394469756025E+05   0.3059724135122297E+05
 14  0.7502438388978744E+01   0.1396155254214945E+02   -0.7105602094481494E+03   0.4730046115964915E+03
 15  0.4016348508681620E+01   0.4194625326863587E+01   -0.9514782451504106E+02   0.4603296277462294E+02
 16  0.2970080794310893E+01   0.2376936951023241E+01   -0.3349528176027253E+02   0.1564937982990288E+02
 17  0.2390874625765719E+01   0.1616678403564954E+01   -0.1494345472058580E+02   0.7763585773794798E+01
 18  0.2016812253485666E+01   0.1211509773096788E+01   -0.7479041281848517E+01   0.4629945683853585E+01
 19  0.1753574112083879E+01   0.9704493989317589E+00   -0.3959409356771873E+01   0.3114448386156138E+01
 20  0.1558493513598559E+01   0.8148158249946477E+00   -0.2125930435216646E+01   0.2271002271430383E+01
 21  0.1408735774632585E+01   0.7084187564785975E+00   -0.1102582833912087E+01   0.1754746256637649E+01
 22  0.1290826693315262E+01   0.6327165569438174E+00   -0.5020678660303746E+00   0.1417160155580148E+01
 23  0.1196276693709804E+01   0.5773557484689719E+00   -0.1363393565939444E+00   0.1185743805976271E+01
 24  0.1119472616149126E+01   0.5361642063822957E+00    0.92643778905969C9E-01   0.1021682879331106E+01
 25  0.1056567176528774E+01   0.5052688758882325E+00    0.2389420417312620E+00   0.9026889684670851E+00
 26  0.1004854132567686E+01   0.4821360846597600E+00    0.3337377691836187E+00   0.8152494762041542E+00
 27  0.9623989485715112E+00   0.4650482001544234E+00    0.3956861449378448E+00   0.7508171701876838E+00
 28  C.9278127756762294E+00   0.4528007126313904E+00    0.4362793202635347E+00   0.7038029740335077E+00
 29  0.9001115711570695E+00   0.4445161706018519E+00    0.4627541658592416E+00   0.6704545675391549E+00
 30  0.8786288878768683E+00   0.4395214050389312E+00    0.4797259791699269E+00   0.6481934210539040E+00
 31  0.8629671538189785E+00   0.4372540540716741E+00    0.4901293234968129E+00   0.6351869105735284E+00
 32  0.8529998029052858E+00   0.4371419567298135E+00    0.4957619571123395E+00   0.6299589957549181E+00
 33  0.8490527574548856E+00   0.4382132490394413E+00    0.4975782018316388E+00   0.6304885575454902E+00
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  2  0.1783934079105657E+03  0.4542582384946031E+03  0.1394577701660524E+04  0.4823443801265942E+04
  3  0.1881639570810958E+03  0.4917809651853957E+03  0.1545984386736991E+04  0.5476301191979648E+04
  4  0.2045686771930169E+03  0.5638826091976001E+03  0.1853679535368173E+04  0.6851959557828961E+04
  5  0.2297388544402002E+03  0.6905601116829235E+03  0.2442646091043520E+04  0.9659305428541077E+04
  6  0.2683505678955374E+03  0.9180218939344913E+03  0.3638487164735292E+04  0.1597192190773616E+05
  7  0.3312924180891911E+03  0.1370438120211696E+04  0.6475137258677694E+04  0.3353247956116903E+05
  8  0.4514755520309362E+03  0.2514610140581750E+04  0.1589201479119533E+05  0.1095168622809752E+06
  9  0.9536555141797188E+03  0.1139896867150364E+05  0.1574118170391285E+06  0.2406790106482331E+07
 10  0.2195585557239151E+04  0.5938782336856992E+05  0.1825164485184334E+07  0.6097112730194072E+08
 11  0.3232856430932141E+04  0.1283025792566120E+06  0.5707027578545261E+07  0.2739699803410351E+09
 12  0.3329064024908647E+04  0.1368023779695217E+06  0.6393219475235099E+07  0.3266222349853693E+09
 13  0.2012368604390696E+04  0.5090661770623646E+05  0.1495899359077720E+07  0.4897850625075236E+08
 14  0.7502438388978744E+03  0.7010851879714993E+04  0.7548211554455331E+05  0.8952526070200140E+06
 15  0.4016348508681620E+03  0.2028373441678403E+04  0.1169897042246145E+05  0.7429632439420937E+05
 16  0.2970080794310893E+03  0.1117454750624743E+04  0.4842988519051916E+04  0.2330127244219820E+05
 17  0.2390874625765719E+03  0.7316793095659672E+03  0.2610458719032500E+04  0.1044932950102081E+05
 18  0.2016812253485666E+03  0.5266926341175751E+03  0.1625310013580066E+04  0.5684185523967754E+04
 19  0.1753574112083879E+03  0.4035767071513206E+03  0.1112159628710498E+04  0.3503146647320578E+04
 20  0.1558493513598559E+03  0.3235569698673484E+03  0.8144108665461795E+03  0.2358656873687845E+04
 21  0.1408735774632585E+03  0.2685871051643480E+03  0.6279392110129216E+03  0.1697266410506734E+04
 22  0.1290826693315262E+03  0.2292622943549593E+03  0.5043601709341667E+03  0.1286755414806408E+04
 23  0.1196276693709804E+03  0.2002660118897543E+03  0.4188711664557241E+03  0.1017735231758019E+04
 24  0.1119472616149126E+03  0.1784021502626242E+03  0.3577695558724314E+03  0.8339267628334791E+03
 25  0.1056567176528774E+03  0.1616550385647335E+03  0.3130255874735007E+03  0.7042934667581610E+03
 26  0.1004854132567686E+03  0.1487046551551519E+03  0.2797068731648117E+03  0.6107399469756730E+03
 27  0.9623989485715112E+02  0.1386609454364429E+03  0.2546677115393676E+03  0.5422335522854365E+03
 28  0.9278127756762294E+02  0.1309109252213106E+03  0.2358431093725300E+03  0.4918077124087745E+03
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 32  0.8529998029052858E+02  0.1160379200918972E+03  0.2009954318637255E+03  0.4010352890071484E+03
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CARRIER FREQUENCY =        2400 HZ
MAXIMUM CARRIER AMPLITUDE =            1 VOLT(S)
INITIAL PHASE ANGLE =          0 DEGREES
TIME BETWEEN SAMPLES =  0.678434227354891 2E-04 SEC
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SEED FOR RANDOM NUMBER GENERATOR =             1
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   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.101407177000488 7E+07   0.409728085125490 2E+12
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.406227834900129 4E+07   0.731640699449116 2E+13
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 0.729182211261824 8E+02   0.480294006585378 2E+05
     MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.307294475759056 6E+05   0.118301943697162 2E+11
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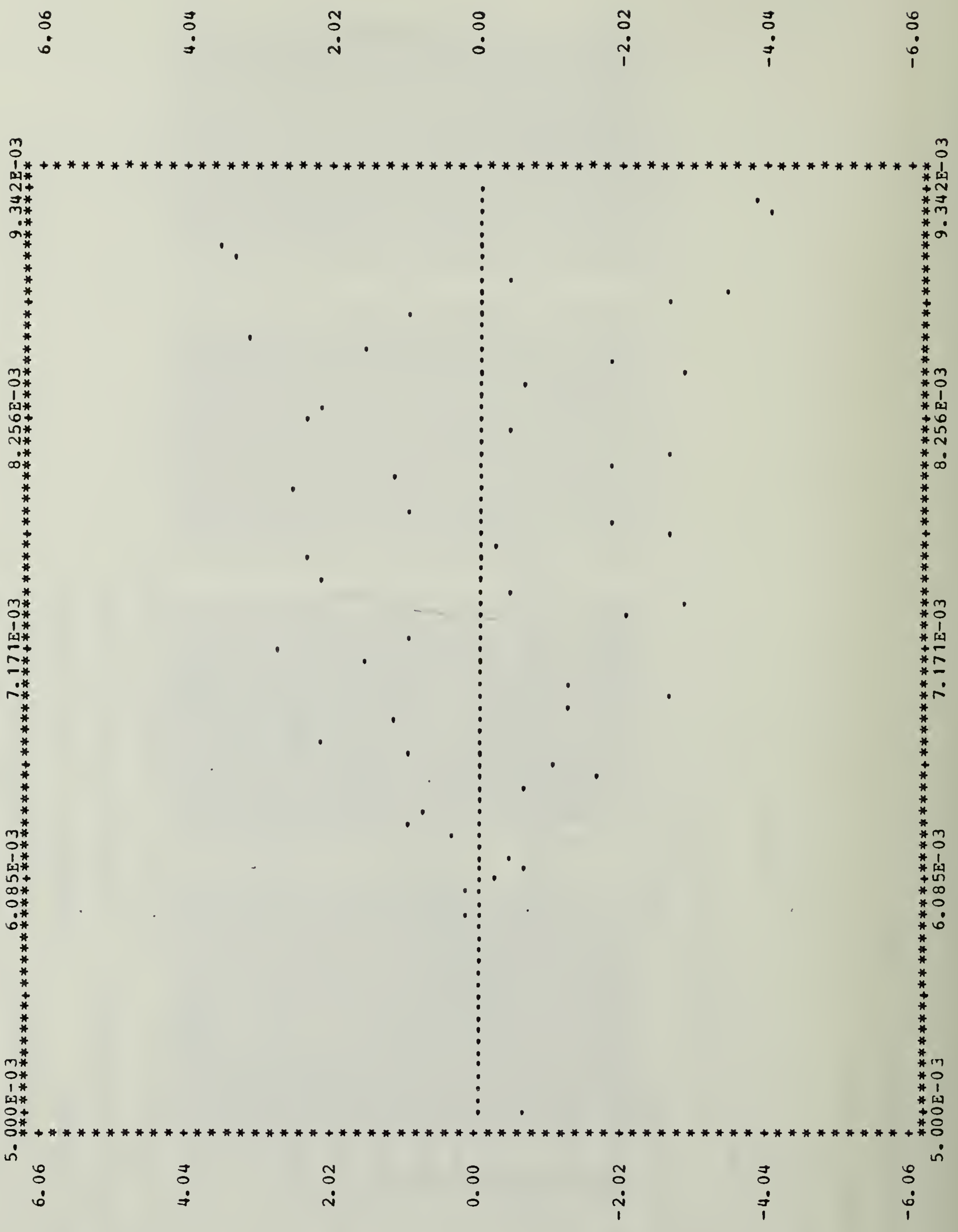
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  2   0.2945575697221625E+01   0.3963052008893856E+01   -0.2762424375864902E+02   0.4671417524690146E+02
  3   0.3112787561988349E+01   0.4013664962406092E+01   -0.3461233461524047E+02   0.4850914397069039E+02
  4   0.3392105668005165E+01   0.4231239933942908E+01   -0.4843388090938981E+02   0.5378883312445481E+02
  5   0.3814330994522609E+01   0.4728891936605361E+01   -0.7479410396850161E+02   0.6524120630247199E+02
  6   0.4448304769119560E+01   0.5729652172852198E+01   -0.1284525151380006E+03   0.8996407668008533E+02
  7   0.5446496163994199E+01   0.7783957150351074E+01   -0.2538211393046406E+03   0.1516517560198072E+03
  8   0.7211506188528557E+01   0.1268735131795587E+02   -0.6307639983631189E+03   0.3676854627938201E+03
  9   0.1182998791891019E+02   0.3364874592461898E+02   -0.2975891422630522E+04   0.2649556822476361E+04
 10   0.3274265467688794E+02   0.2556600916018281E+03   -0.6721840706282554E+05   0.1518592350520692E+06
 11   0.6156246406139704E+02   0.8689415173941595E+03   -0.4582781585774253E+06   0.1681219443777066E+07
 12   0.6100251528818768E+02   0.9210714604234481E+03   -0.4398108606697874E+06   0.2110501110881329E+07
 13   0.2812765033735517E+02   0.2028099038820981E+03   -0.4176513439780750E+05   0.1123404978932170E+06
 14   0.1015812424255807E+02   0.2737735240302546E+02   -0.1830285725010282E+04   0.2059205431509025E+04
 15   0.6628403769520118E+01   0.1163426581120765E+02   -0.4778087399330668E+03   0.3921429848253429E+03
 16   0.5078543964081808E+01   0.6821526275457762E+01   -0.2010092890344462E+03   0.1416395150637668E+03
 17   0.4157230014381144E+01   0.4647332376945644E+01   -0.1029639727889250E+03   0.6900108261574451E+02
 18   0.3542750915854995E+01   0.3461262937976936E+01   -0.5935416050628737E+02   0.3992858476875006E+02
 19   0.3103594576952411E+01   0.2741122158514052E+01   -0.3705758280624042E+02   0.2593028736908622E+02
 20   0.2774726489396073E+01   0.2272700955298311E+01   -0.2450838813526847E+02   0.1831531891184402E+02
 21   0.2520030316711311E+01   0.1953542956434740E+01   -0.1692610534720381E+02   0.1379948511978922E+02
 22   0.2317746477011871E+01   0.1729435681738751E+01   -0.1208678115494804E+02   0.1094947853779263E+02
 23   0.2153989967659938E+01   0.1569343871400643E+01   -0.8860737242201525E+01   0.9067922695257138E+01
 24   0.2019613499068920E+01   0.1453979589914899E+01   -0.6634305010569030E+01   0.7782303804931697E+01
 25   0.1908689264383096E+01   0.1369702175090221E+01   -0.5057161812398873E+01   0.6871911971119896E+01
 26   0.1816480620725851E+01   0.1309778919921657E+01   -0.3914078123461568E+01   0.6227684238310211E+01
 27   0.1739579447958521E+01   0.1269582830244330E+01   -0.3071345782683535E+01   0.5780159160620986E+01
 28   0.1675806662637884E+01   0.1244888298908247E+01   -0.2444977856656303E+01   0.5477247049124202E+01
 29   0.1623715877942706E+01   0.1232393728379181E+01   -0.1980397742371957E+01   0.5283799338809050E+01
 30   0.1582439224057063E+01   0.1229375405035280E+01   -0.1642043586278724E+01   0.5175383378260868E+01
 31   0.1551645793430460E+01   0.1233261198408628E+01   -0.1407564173157425E+01   0.5133272082149876E+01
 32   0.1531605663858521E+01   0.1241058308193479E+01   -0.1264836121919516E+01   0.5139553554635057E+01
 33   0.1523648147115839E+01   0.1247661080839741E+01   -0.1212277766568493E+01   0.5165584746963301E+01
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  3  0.3112787561988349E+03  0.1366297471885140E+04  0.7359858586642650E+04  0.4522323418839895E+05
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-0.7876831322230185E+06   0.1444178694786092E+12
   SUM OF KURTOSIS            SUM OF KURTOSIS**2
 0.2375351460755018E+07   0.1504008831530188E+13
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 0.6703981152488534E+02   0.2458205556000923E+05
     MEAN SKEWNESS          VARIANCE OF THE SKEWNESS
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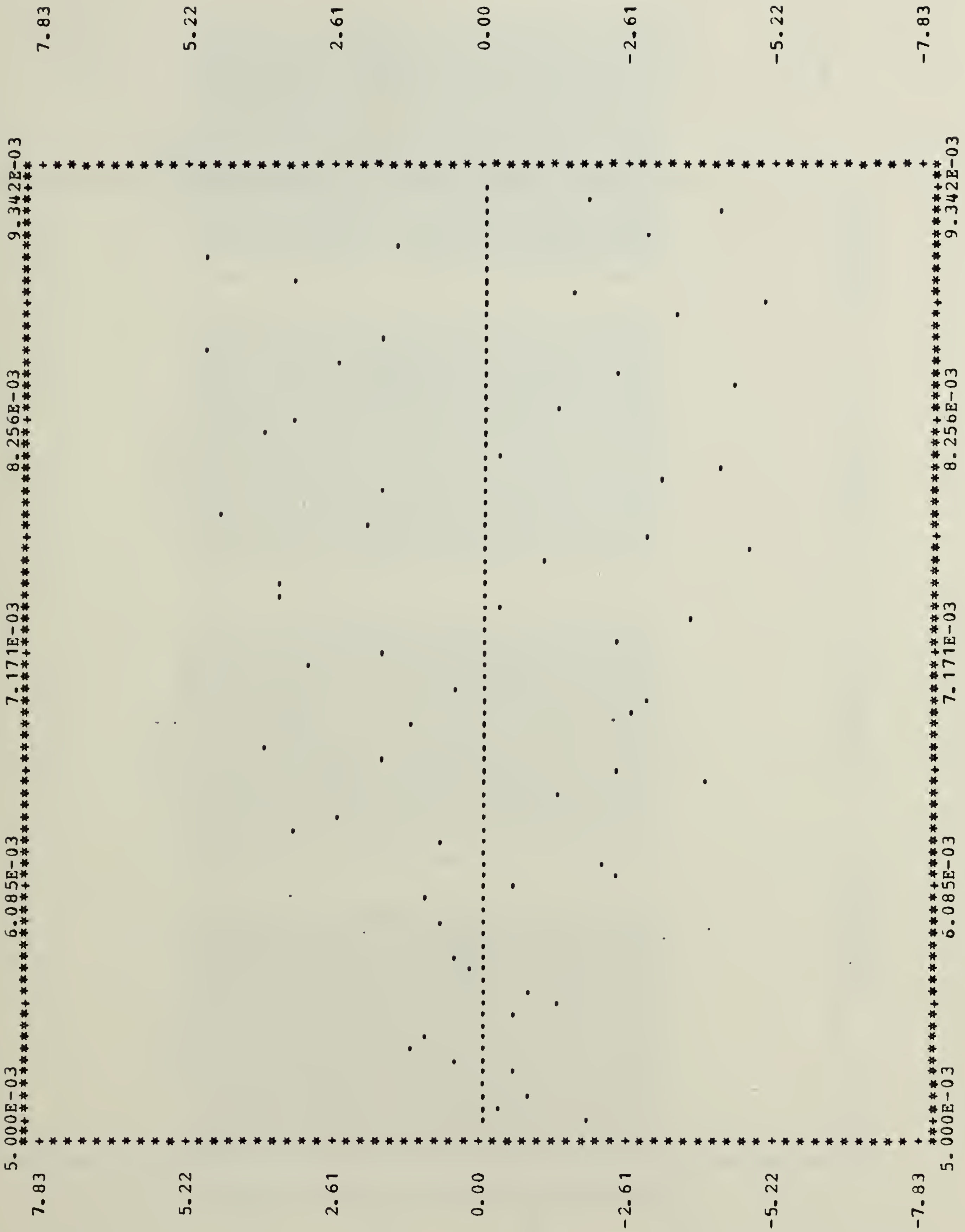
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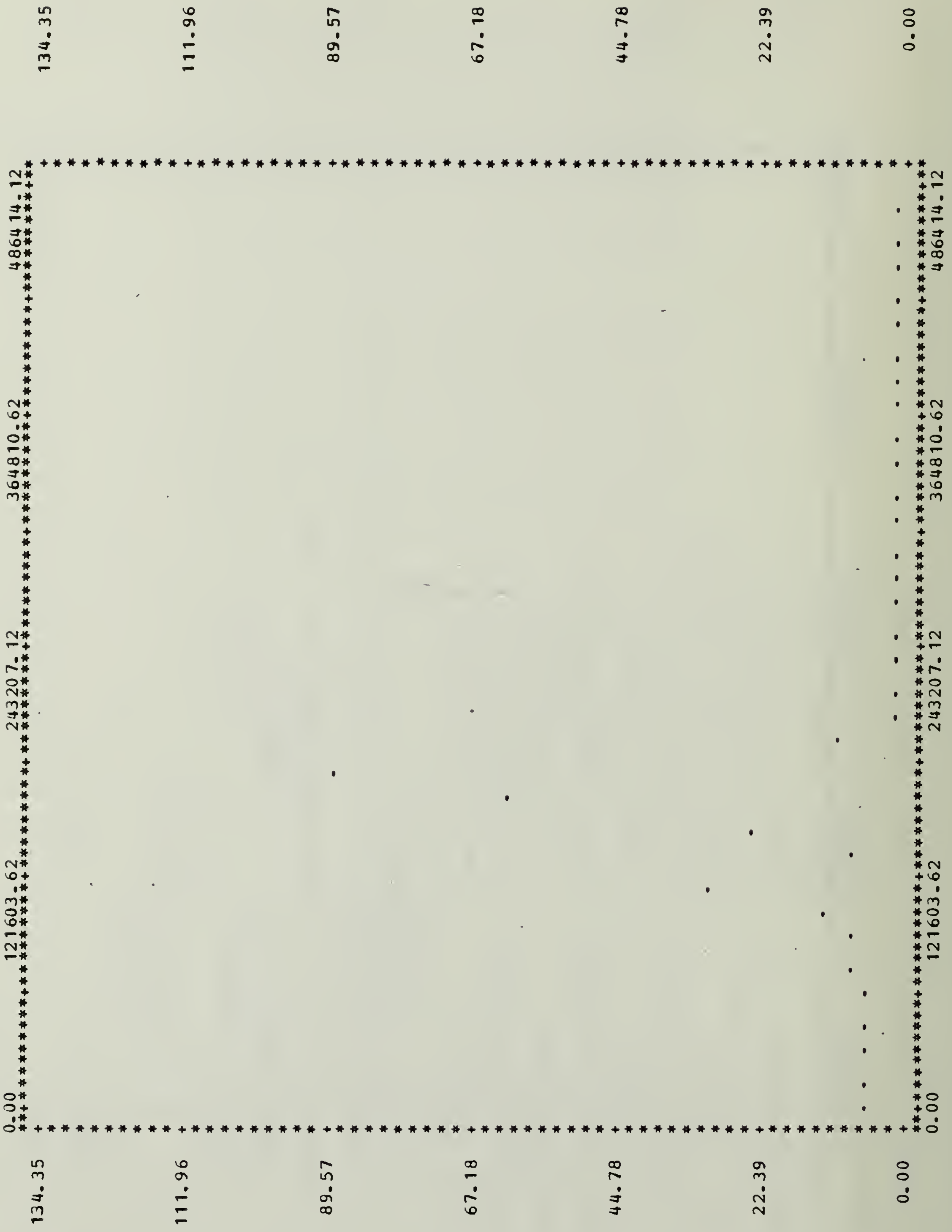
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  4   0.3472939022742847E+01   0.4207631276200674E+01   -0.5205508235858120E+02   0.6262547090742004E+02
  5   0.3969306386409815E+01   0.4860943786245437E+01   -0.8500175932943047E+02   0.8273400379153577E+02
  6   0.4735423482398556E+01   0.6300931752245403E+01   -0.1566149435795907E+03   0.1321350345761201E+03
  7   0.6018537756096500E+01   0.9736414158625507E+01   -0.3457034404393740E+03   0.2903044306984410E+03
  8   0.8654258686250665E+01   0.2089270222273523E+02   -0.1095988817483587E+04   0.1229022976292699E+04
  9   0.2281137743621147E+02   0.1439177760640681E+03   -0.2193236345074323E+05   0.5403321656593276E+05
 10   0.4754546111151572E+02   0.4646395551694064E+03   -0.2077441296070791E+06   0.5503560665874106E+06
 11   0.4244750014125263E+02   0.3748277455711410E+03   -0.1463406628119970E+06   0.4240689354081044E+06
 12   0.4734966449442010E+02   0.4555200840149120E+03   -0.2070845754790160E+06   0.4079376089497462E+06
 13   0.4636502495407004E+02   0.5858023419797556E+03   -0.1907034976555182E+06   0.9229169440607270E+06
 14   0.1775571715328273E+02   0.7836469157643520E+02   -0.1046518127146919E+05   0.1312130526653664E+05
 15   0.8010362291212992E+01   0.1596765263482768E+02   -0.8825082674162869E+03   0.6106026606095356E+03
 16   0.5748360868725290E+01   0.7781191394513882E+01   -0.3051632597123039E+03   0.1547481205147622E+03
 17   0.4587361831012248E+01   0.4764166354630095E+01   -0.1458247303643428E+03   0.6122038538089117E+02
 18   0.3859990888844249E+01   0.3291449429627744E+01   -0.8182688020467373E+02   0.3123619875679458E+02
 19   0.3356671073359412E+01   0.2458185419647806E+01   -0.5067489115592908E+02   0.1885213610174446E+02
 20   0.2985704246868344E+01   0.1947285393959427E+01   -0.3354116060432313E+02   0.1288351792221858E+02
 21   0.2700289329982362E+01   0.1617844173346278E+01   -0.2327974567069668E+02   0.9657495559635674E+01
 22   0.2474887178278520E+01   0.1393588316418582E+01   -0.1674673133820691E+02   0.7685551297040409E+01
 23   0.2293436153883331E+01   0.1235603072617695E+01   -0.1238328622708189E+02   0.6375226655986307E+01
 24   0.2143603457021659E+01   0.1129741939228789E+01   -0.9340535778002867E+01   0.5530298158106696E+01
 25   0.2017352208785796E+01   0.1065020962976242E+01   -0.7145984024478282E+01   0.5008270937598276E+01
 26   0.1909802109242861E+01   0.1031153159062995E+01   -0.5524790323883738E+01   0.4698582156733970E+01
 27   0.1817803178471110E+01   0.1020234834778769E+01   -0.4307541772447900E+01   0.4531591295706342E+01
 28   0.1739297395622849E+01   0.1026428800839872E+01   -0.3385787401612433E+01   0.4465390207474467E+01
 29   0.1673014887490447E+01   0.1045320201357048E+01   -0.2688643953287969E+01   0.4474563821840981E+01
 30   0.1618309679485713E+01   0.1073390686558981E+01   -0.2169671349142156E+01   0.4543413084630725E+01
 31   0.1575127269274742E+01   0.1107432254242980E+01   -0.1799539780561719E+01   0.4660898333893368E+01
 32   0.1544328394719743E+01   0.1143084440129354E+01   -0.1563241471185823E+01   0.4811604062719301E+01
 33   0.1530498278895295E+01   0.1165859218662538E+01   -0.1470070156508873E+01   0.4923039669179051E+01
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  2   0.2941193920455125E+03   0.1257116740200380E+04   0.6679597518767498E+04   0.4099902143818628E+05
  3   0.3144223362768182E+03   0.1381163386303369E+04   0.7520938683542618E+04   0.4741984235567450E+05
  4   0.3472939022742847E+03   0.1622686041912871E+04   0.9288699702861901E+04   0.6151115249264073E+05
  5   0.3969306386409816E+03   0.2056772753757673E+04   0.1284062910987031E+05   0.9218510865065588E+05
  6   0.4735423482398556E+03   0.2866215799237462E+04   0.2057189533450305E+05   0.1680977610919490E+06
  7   0.6018537756096500E+03   0.4586184673859834E+04   0.4099147345992035E+05   0.4127460555429674E+06
  8   0.8654258686250665E+03   0.9557996860905298E+04   0.1235740116398711E+06   0.1788354599317327E+07
  9   0.2281137743621147E+04   0.6628375388407253E+05   0.2238763050033797E+07   0.8396436177827680E+08
 10   0.4754546111151572E+04   0.2720564031924366E+06   0.1757861427920527E+08   0.1241206409612254E+10
 11   0.4244750014125263E+04   0.2172869736357072E+06   0.1267544219743408E+08   0.8194713555490152E+09
 12   0.4734966449442010E+04   0.2692955610908911E+06   0.1709630770902248E+08   0.1164219318416618E+10
 13   0.4636502495407004E+04   0.2729659857551496E+06   0.1846793135009938E+08   0.1382943828406290E+10
 14   0.1775571715328273E+04   0.3928465362880496E+05   0.9830103694208338E+06   0.2663547206451179E+08
 15   0.8010362291212992E+03   0.7997388014496647E+04   0.9110191858964195E+05   0.1136318940332887E+07
 16   0.5748360868725290E+03   0.4074703215766091E+04   0.3314353704488787E+05   0.2972652853806565E+06
 17   0.4587361831012248E+03   0.2576041325971184E+04   0.1666045021145127E+05   0.1194261062431947E+06
 18   0.3859990888844249E+03   0.1815806459729208E+04   0.9864395218518330E+04   0.5970034454704064E+05
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   SUM OF KURTOSIS            SUM OF KURTOSIS**2
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-0.4554420485574342E+04   0.1638058362173805E+09
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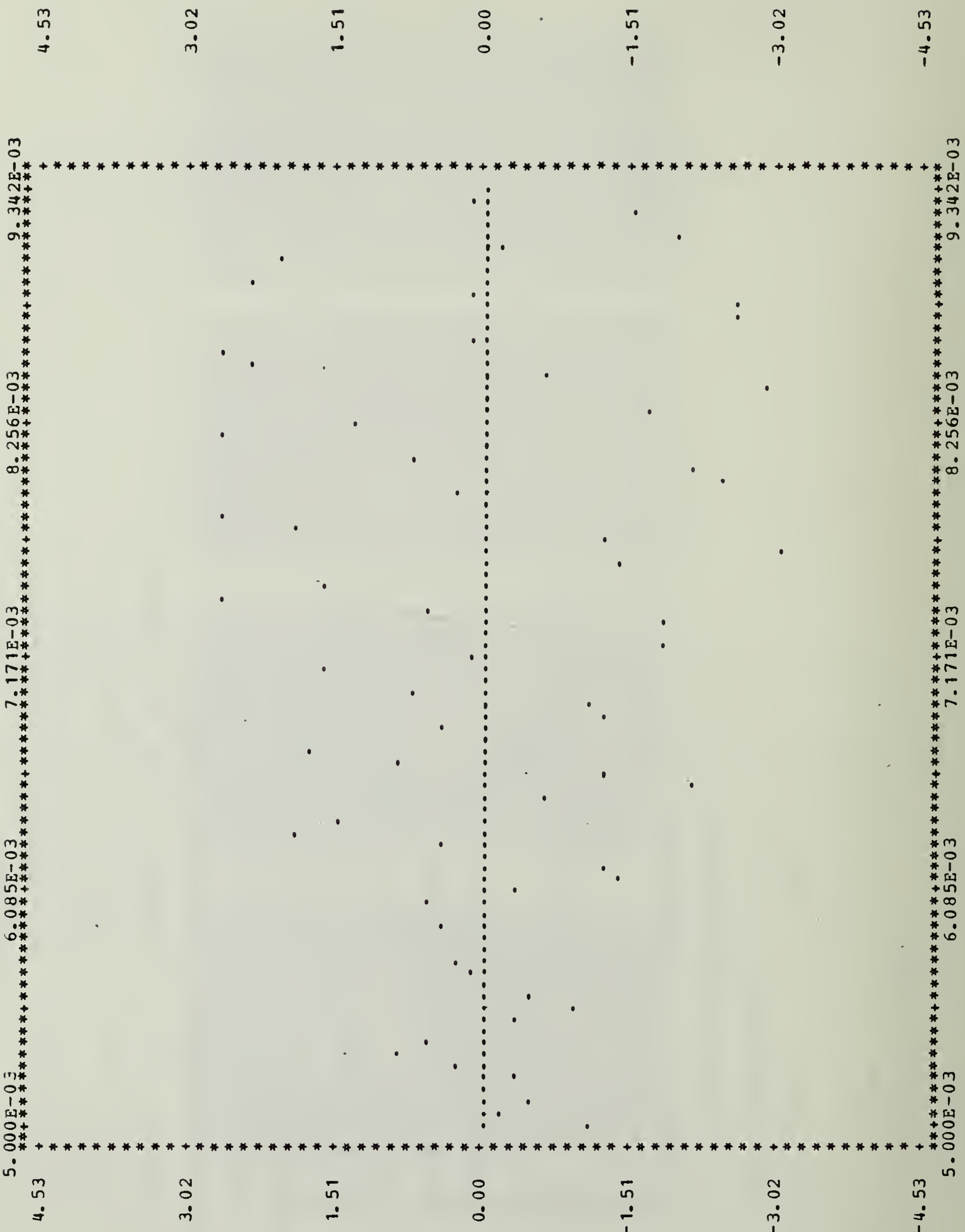
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 3   0.1822080267905823E+01    0.1637975366559496E+01    -0.3033602018908517E+01    0.1051811011425401E+02
 4   0.2024944483212605E+01    0.1696003179844438E+01    -0.5852717582052459E+01    0.1149726415338565E+02
 5   0.2329575301573474E+01    0.1889410056086123E+01    -0.1162556661054461E+02    0.1396880835853768E+02
 6   0.2799618459186339E+01    0.2351081202562522E+01    -0.2485697728770199E+02    0.2003885906538744E+02
 7   0.3593606690701501E+01    0.3517560421894356E+01    -0.6221532265140116E+02    0.3923065739628220E+02
 8   0.5250268678825291E+01    0.7679872826672729E+01    -0.2240112630638912E+03    0.1615596553464001E+03
 9   0.1468732445728772E+02    0.5698432351652923E+02    -0.5766331711517894E+04    0.7700144626832553E+04
10   0.2971531933822615E+02    0.1977041525414051E+03    -0.4980046600273765E+05    0.1015887560620818E+06
11   0.1946196225072521E+02    0.8520733202076775E+02    -0.1338196665730689E+05    0.3082167317768066E+05
12   0.2493319558019601E+02    0.1203157758015537E+03    -0.2953935348818128E+05    0.3229216284253984E+05
13   0.2955681866542102E+02    0.2229606796898662E+03    -0.4852116398403028E+05    0.1430962797654248E+06
14   0.1134843594184110E+02    0.2883361550590456E+02    -0.2628615664034768E+04    0.2014017364065328E+04
15   0.4970090484803092E+01    0.5007521697074969E+01    -0.1926957672498994E+03    0.6163959197677531E+02
16   0.3532757103156359E+01    0.2436613452379979E+01    -0.6195368080461159E+02    0.1530304581177205E+02
17   0.2812436795395693E+01    0.1543256466260907E+01    -0.2803994388113845E+02    0.6634640987626415E+01
18   0.2369246425223995E+01    0.1116129068281124E+01    -0.1499345615149528E+02    0.3767765889897674E+01
19   0.2067752681199091E+01    0.8730631986165904E+00    -0.8863085844789377E+01    0.2483963240368716E+01
20   0.1852664563048547E+01    0.7086180491037625E+00    -0.5611531249491262E+01    0.1721796443868016E+01
21   0.1691049257918267E+01    0.5969980314448385E+00    -0.3716680154916490E+01    0.1275128193869637E+01
22   0.1564485152670945E+01    0.5228065905688973E+00    -0.2532982447521070E+01    0.1015577885269764E+01
23   0.1462724537501172E+01    0.4737758456720625E+00    -0.1755262251553210E+01    0.8592948826267097E+00
24   0.1379361198878535E+01    0.4420632119864455E+00    -0.1224165844748508E+01    0.7627903599458743E+00
25   0.1310212971454939E+01    0.4225151882274944E+00    -0.8506267979152597E+00    0.7026301237469474E+00
26   0.1252466606083759E+01    0.4116512857478918E+00    -0.5821187634403218E+00    0.6656761386153749E+00
27   0.1204196957391062E+01    0.4070568429211903E+00    -0.3863199563233570E+00    0.6442916119914803E+00
28   0.1164070364847772E+01    0.4070406361202367E+00    -0.2426723420547243E+00    0.6339971166406047E+00
29   0.1131163935402371E+01    0.4104109765706129E+00    -0.1377979566892886E+00    0.6322034788189101E+00
30   0.1104905018984923E+01    0.4162098554263231E+00    -0.6292504569035784E-01    0.6371923425461106E+00
31   0.1085094957871504E+01    0.4234143765176991E+00    -0.1239972092372565E-01    0.6472465033331667E+00
32   0.1072017799482293E+01    0.4305494285120794E+00     0.1715449376312383E-01    0.6596579907407305E+00
33   0.1066896145745031E+01    0.4345943867280897E+00     0.2713543267703411E-01    0.6678549630950203E+00
```

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 N          SUM X                     SUM X**2                  SUM X**3                  SUM X**4
 1   0.1639783109841063E+03   0.4381044880269750E+03   0.1504001389749991E+04   0.6028224494587657E+04
 2   0.1694119010472507E+03   0.4513240625687009E+03   0.1556598039393050E+04   0.6283642510452042E+04
 3   0.1822080267905823E+03   0.4941572115585657E+03   0.1733826810843475E+04   0.7151628698908221E+04
 4   0.2024944483212605E+03   0.5779443308139159E+03   0.2105563762633040E+04   0.9029491598424876E+04
 5   0.2329575301573474E+03   0.7297437041226407E+03   0.2852037850613845E+04   0.1304690135038802E+05
 6   0.2799618459186339E+03   0.1016543390755379E+04   0.4484530491794313E+04   0.2284824450720208E+05
 7   0.3593606690701501E+03   0.1639639386513001E+04   0.8872323134501433E+04   0.5444320652383947E+05
 8   0.5250268678825291E+03   0.3516839529825987E+04   0.2747886674934024E+05   0.2395389115966948E+06
 9   0.1468732445728772E+04   0.2721319799950061E+05   0.5792905345227176E+06   0.1354096031979063E+08
10   0.2971531933822615E+04   0.1078727314388748E+06   0.4459771346830303E+07   0.2026499395458332E+09
11   0.1946196225072521E+04   0.4631232333492131E+05   0.1290035804802437E+07   0.4129848397914642E+08
12   0.2493319558019601E+04   0.7407768598838439E+05   0.2462712101444010E+07   0.8847358410767536E+08
13   0.2955681866542102E+04   0.1094336602513548E+06   0.4676695051500612E+07   0.2225674204211198E+09
14   0.1134843594184110E+04   0.1573322776769165E+05   0.2470236163714422E+06   0.4233144694722940E+07
15   0.4970090484803092E+03   0.2965924590723445E+04   0.2001280415057830E+05   0.1474973714749340E+06
16   0.3532757103156359E+03   0.1489262006775789E+04   0.7092160168252687E+04   0.3695846281762211E+05
17   0.2812436795395693E+03   0.9437624629693893E+03   0.3576862297172163E+04   0.1488190681227194E+05
18   0.2369246425223995E+03   0.6718296401034992E+03   0.2153178579687351E+04   0.7608053377373551E+04
19   0.2067752681199091E+03   0.5139933717236453E+03   0.1447004702900242E+04   0.4515033391001683E+04
20   0.1852664563048547E+03   0.4133897851788587E+03   0.1049991495597069E+04   0.2974218440064030E+04
21   0.1691049257918267E+03   0.3450675643836312E+03   0.8069812120149764E+03   0.2118738265791955E+04
22   0.1564485152670945E+03   0.2965192317591039E+03   0.6488788033678661E+03   0.1604859418202128E+04
23   0.1462724537501172E+03   0.2608601159823359E+03   0.5412606378313685E+03   0.1277349367688637E+04
24   0.1379361198878536E+03   0.2340279896838212E+03   0.4654833373950505E+03   0.1058943962953624E+04
25   0.1310212971454939E+03   0.2134948066914001E+03   0.4107767092907294E+03   0.9081718957376042E+03
26   0.1252466606083759E+03   0.1976207372245383E+03   0.3705937259151374E+03   0.8013993822923571E+03
27   0.1204196957391062E+03   0.1853076586681869E+03   0.3407906981781624E+03   0.7244971790085427E+03
28   0.1164070364847772E+03   0.1758030044075860E+03   0.3186620053773817E+03   0.6686943101747503E+03
29   0.1131163935402371E+03   0.1685838715559886E+03   0.3024018213639951E+03   0.6283944137293207E+03
30   0.1104905018984923E+03   0.1632862857850134E+03   0.2907919853211530E+03   0.5999720029213764E+03
31   0.1085094957871504E+03   0.1596611300350684E+03   0.2830162758953530E+03   0.5810861131486764E+03
32   0.1072017799482293E+03   0.1575466096633816E+03   0.2785493263166431E+03   0.5702822834018495E+03
33   0.1066896145745031E+03   0.1568515828666411E+03   0.2770931137498631E+03   0.5667653419404973E+03
```

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QPRS CLASS 5 FILTER
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BAUD OR SYMBOL RATE =          1200 HZ
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BIT RATE =  0.240000000000000E+04
CARRIER FREQUENCY =        2400 HZ
MAXIMUM CARRIER AMPLITUDE =             1 VOLT(S)
INITIAL PHASE ANGLE =           0 DEGREES
TIME BETWEEN SAMPLES =  0.678434227354891 2E-04 SEC
NUMBER OF SAMPLES GENERATED =           64
SEED FOR RANDOM NUMBER GENERATOR =            1
NUMBER OF TIMES SIMULATION REPEATS =          100
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 0.242217786507317 6E+04   0.134853836921845 7E+07
   SUM OF SKEWNESS           SUM OF SKEWNESS**2
-0.820216075504924 9E+06   0.204913894994457 8E+12
   SUM OF KURTOSIS           SUM OF KURTOSIS**2
 0.358270392726342 5E+07   0.478288944229002 5E+13
    MEAN VARIANCE         VARIANCE OF THE VARIANCES
 0.733993292446416 9E+02   0.365860043315896 2E+05
    MEAN SKEWNESS         VARIANCE OF THE SKEWNESS
-0.248550325910583 3E+05   0.576648117831478 0E+10
    MEAN KURTOSIS         VARIANCE OF THE KURTOSIS
 0.108566785674649 2E+06   0.137310212277596 6E+12
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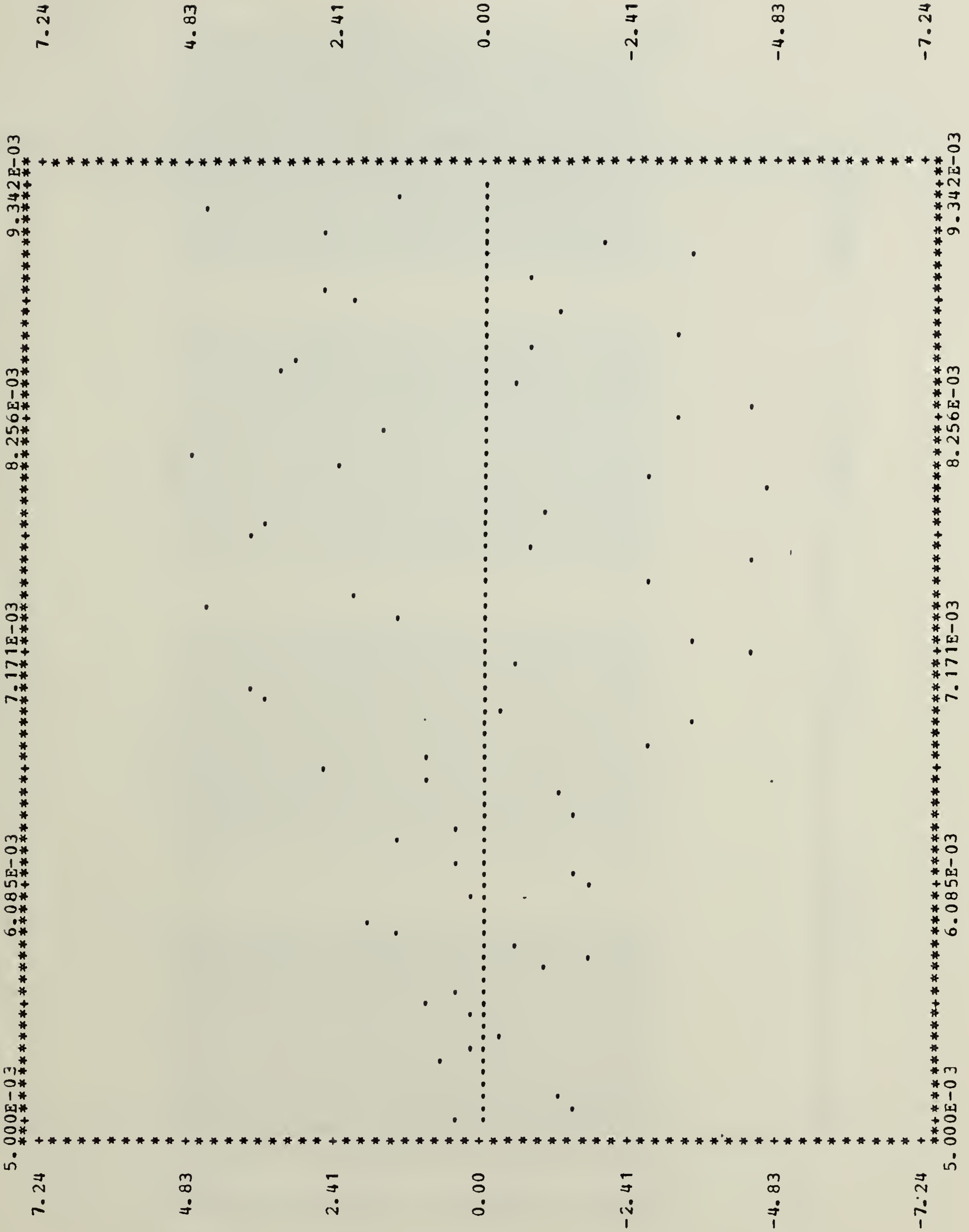
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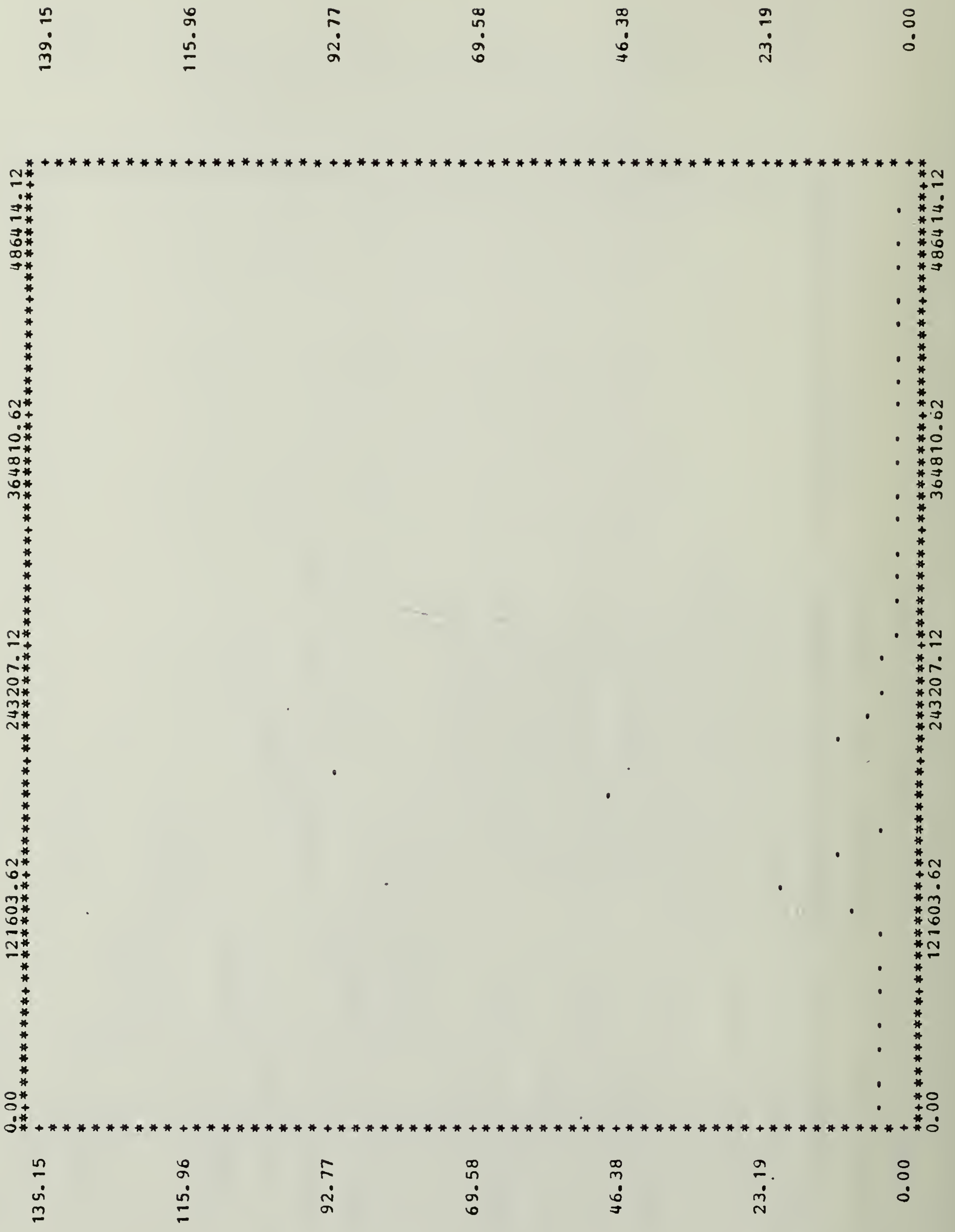
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0.00

```
 N          MEAN                       VARIANCE                   SKEWNESS                    KURTOSIS
  1   0.3175007969977690E+01    0.5114157186225571E+01   -0.3647377245722682E+02    0.6390177902993634E+02
  2   0.3240619944765044E+01    0.5086102701788736E+01   -0.3945722174718513E+02    0.6384581606339765E+02
  3   0.3418492879921329E+01    0.5172192798243949E+01   -0.4849017265821298E+02    0.6741248641994679E+02
  4   0.3720050986691612E+01    0.5489382820690838E+01   -0.6651291925211635E+02    0.7734383790401080E+02
  5   0.4188073611507133E+01    0.6215059554191426E+01   -0.1016999797030395E+03    0.9959832869899236E+02
  6   0.4921214356587952E+01    0.7760498167346390E+01   -0.1769255927986075E+03    0.1526183467386106E+03
  7   0.6164676833203001E+01    0.1134896285448964E+02   -0.3719888818360394E+03    0.3136503593616817E+03
  8   0.8734938742447645E+01    0.2239794782070082E+02   -0.1126894580418845E+04    0.1163666961030995E+04
  9   0.2001458895916663E+02    0.1331245996682923E+03   -0.1451737131188666E+05    0.4314997043974916E+05
 10   0.5409232156107556E+02    0.7186407819046712E+03   -0.3060942961486485E+06    0.1245883717653442E+07
 11   0.3071091723336924E+02    0.2359866864671304E+03   -0.5416809541898984E+05    0.1854316904737086E+06
 12   0.4125066118058745E+02    0.4007672219572611E+03   -0.1350387560075282E+06    0.3465758238469681E+06
 13   0.5405198483591909E+02    0.7711366140096073E+03   -0.2996435115512078E+06    0.1753359099945396E+07
 14   0.1566444696486908E+02    0.4844857365619617E+02   -0.7151724018508688E+04    0.5637426265450937E+04
 15   0.8027426339157971E+01    0.1187759149364716E+02   -0.8962200092443305E+03    0.3718418536813451E+03
 16   0.5774108803249598E+01    0.5966604758607288E+01   -0.3115922473316341E+03    0.1010149760039774E+03
 17   0.4596310476428844E+01    0.3860312828819921E+01   -0.1472328835908598E+03    0.4684905154496522E+02
 18   0.3863417960017863E+01    0.2848711022275091E+01   -0.8198224752509745E+02    0.2796050352952778E+02
 19   0.3363155825534746E+01    0.2278343999412112E+01   -0.5072245028464429E+02    0.1915731497924338E+02
 20   0.3003261081837905E+01    0.1911527321194257E+01   -0.3385313123379364E+02    0.1406866837863103E+02
 21   0.2731904280991412E+01    0.1671831119124026E+01   -0.2389082914534472E+02    0.1105673656228376E+02
 22   0.2521234441845605E+01    0.1509330772274732E+01   -0.1761502851110826E+02    0.9136822096088569E+01
 23   0.2354205282986497E+01    0.1396522177812353E+01   -0.1345982833386097E+02    0.7843945020122483E+01
 24   0.2219851857423473E+01    0.1317021271177417E+01   -0.1059986556386777E+02    0.6935658792154644E+01
 25   0.2110603554002656E+01    0.1261545612229099E+01   -0.8569458694423458E+01    0.6286691888697518E+01
 26   0.2021075511112747E+01    0.1224594843570620E+01   -0.7092619024801998E+01    0.5826585347360673E+01
 27   0.1947570339122554E+01    0.1201959396455356E+01   -0.6000660348007621E+01    0.5506110818704212E+01
 28   0.1887571446576071E+01    0.1190243399752315E+01   -0.5187278999299626E+01    0.5290200850572500E+01
 29   0.1839396649648418E+01    0.1186660468906729E+01   -0.4584006084000971E+01    0.5153959026705035E+01
 30   0.1802007198312946E+01    0.1188759606911689E+01   -0.4146598216959648E+01    0.5078752597685412E+01
 31   0.1774907328415459E+01    0.1194148135719785E+01   -0.3847289024627549E+01    0.5048951807450610E+01
 32   0.1758112351977182E+01    0.1200173229585994E+01   -0.3670463427801961E+01    0.5048651820880867E+01
 33   0.1752263344775810E+01    0.1203202048864805E+01   -0.3611032699601022E+01    0.5055288718097053E+01
```

```
N         SUM  X                      SUM  X**2                   SUM  X**3                   SUM  X**4
 1    0.3175007969977690E+03    0.1514369122378517E+04    0.8760889731512676E+04    0.5654457975856909E+05
 2    0.3240619944765044E+03    0.1553685930117985E+04    0.9058671139123197E+04    0.5899532160598735E+05
 3    0.3418492879921329E+03    0.1680656444033433E+04    0.1004970028273070E+05    0.6728814818325367E+05
 4    0.3720050986691612E+03    0.1927326833606917E+04    0.1209021447318121E+05    C.8506168038807575E+05
 5    0.4188073611507133E+03    0.2369286953405192E+04    0.1609025441754881E+05    0.1224603791529354E+06
 6    0.4921214356587952E+03    0.3190124392916030E+04    0.2456162845660115E+05    0.2111552340434820E+06
 7    0.6164676833203001E+03    0.4923871368377453E+04    0.4626269098775424E+05    0.4826786734449781E+06
 8    0.8734938742447645E+03    0.9847312317680666E+04    0.1300977206093252E+06    0.1900367841479010E+07
 9    0.2001458895916663E+04    0.5323771248760041E+05    0.1664738912267298E+07    0.5777448275164625E+08
10    0.5409232156107556E+04    0.3637433625952424E+06    0.2783254334038806E+08    0.2329269091647567E+10
11    0.3071091723336924E+04    0.1176787256917315E+06    0.5236623185179429E+07    0.2627551467752967E+09
12    0.4125066118058745E+04    0.2098376597573313E+06    0.1212362760641124E+08    0.7613583395908520E+09
13    0.5405198483591909E+04    0.3685042312571939E+06    0.2920648079159632E+08    0.2590993316517971E+10
14    0.1566444696486908E+04    0.2933389866348303E+05    0.6142505180670135E+06    0.1392715907516543E+08
15    0.8027426339157971E+03    0.7619838920931783E+04    0.8099317131153205E+05    0.9374736197964726E+06
16    0.5774108803249599E+03    0.3924727118278573E+04    0.3015811298449788E+05    0.2550094891853301E+06
17    0.4596310476428844E+03    0.2494777969626127E+04    0.1545181999623744E+05    0.1064344796474776E+06
18    0.3863417960017863E+03    0.1774622224584093E+04    0.9384897704847650E+04    0.5573475741090785E+05
19    0.3363155825534747E+03    0.1356637766624629E+04    0.6353344174062120E+04    0.3369716251661412E+05
20    0.3003261081837905E+03    0.1091198917366450E+04    0.4642237174695144E+04    0.2252718248550863E+05
21    0.2731904280991412E+03    0.9111841380843199E+03    0.3591447001097654E+04    0.1622980981279217E+05
22    0.2521234441845605E+03    0.7850860575300507E+03    0.2905330550912102E+04    0.1239278015753117E+05
23    0.2354205282986497E+03    0.6924839470475764E+03    0.2436308763293834E+04    0.9914096961588693E+04
24    0.2219851857423473E+03    0.6231593327372087E+03    0.2104429196574328E+04    0.8239831778016403E+04
25    0.2110603554002656E+03    0.5703577518275451E+03    0.1863521952304470E+04    0.7070002419209624E+04
26    0.2021075511112747E+03    0.5297095116754564E+03    0.1685537619348139E+04    0.6232225707108218E+04
27    0.1947570339122554E+03    0.4982970028320744E+03    0.1552733308401496E+04    0.5622630355034676E+04
28    0.1887571446576071E+03    0.4741266931684075E+03    0.1453530931136841E+04    0.5176256608601879E+04
29    0.1839396649648418E+03    0.4558173898955488E+03    0.1380210324128415E+04    0.4851370285803680E+04
30    0.1802007198312946E+03    0.4424101953614247E+03    0.1327573259694673E+04    0.4620766430978244E+04
31    0.1774907328415459E+03    0.4332502678825489E+03    0.1292149119152755E+04    0.4466784878181024E+04
32    0.1758112351977182E+03    0.4279130539464874E+03    0.1271719525931649E+04    0.4378406409209604E+04
33    0.1752263344775810E+03    0.4261596857821065E+03    0.1265043353402402E+04    0.4349588740060286E+04
```

APPENDIX D

FORTRAN PROGRAM F-TEST

```
C     ******************************************************************FTE00020
C     *                                                                *FTE00030
C     * THIS PROGRAM COMPUTES THE F STATISTIC FOR A GIVEN SET OF INPUT *FTE00040
C     * DATA.  THE DATA MUST BE FORMATTED AS E23.16 IN TWO COLUMNS      *FTE00050
C     * STARTING IN THE SECOND COLUMN WITH TWO BLANK COLUMNS BETWEEN    *FTE00060
C     * THE DATA.  THIS PROGRAM IS NOT MEANT TO BE EXTREMELY VERSATILE *FTE00070
C     * AND WAS DESIGNED TO DO THE ANALYSIS FOR SPECIFIC SETS OF DATA. *FTE00080
C     * THE INPUT DATA MUST BE THE SUM OF THE OBSERVATIONS FOR A SET    *FTE00090
C     * OF N OBSERVATIONS AND THE SUM OF THE SQUARE OF THE OBSERVATIONS*FTE00100
C     * FOR THE SET OF N OBSERVATIONS.  THE INDEX FOR THE DO LOOP MUST  *FTE00110
C     * BE CHANGED TO ACCOUNT FOR THE NUMBER OR GROUPS FOR WHICH THE    *FTE00120
C     * DATA IS REPRESENTATIVE.  THE DATA IS READ IN FROM THE FILE      *FTE00130
C     * WHICH CONTAINS THE PROGRAM FORMATTED AS DESCRIBED ABOVE.        *FTE00140
C     * THE INITIALIZATION MUST BE CHANGED FOR THE NUMBER OF GROUPS     *FTE00150
C     * AND THE NUMBER OF OBSERVATIONS PER GROUP TO REFLECT THE DATA.   *FTE00160
C     *                                                                *FTE00170
C     * WRITTEN BY LCDR CRAIG D. CARLSON IN PARTIAL FULFILLMENT OF THE *FTE00180
C     * REQUIREMENTS FOR A MASTER OF SCIENCE DEGREE IN SYSTEMS          *FTE00190
C     * TECHNOLOGY (SPACE SYSTEMS OPERATIONS)*                          FTE00200
C     *                                                                *FTE00210
C     * 27 SEPTEMBER 1985                                               *FTE00220
C     *                                                                *FTE00230
C     ******************************************************************FTE00240
C                                                                       FTE00250
C     *** VARIABLE DECLARATIONS ***                                     FTE00260
C                                                                       FTE00270
      DOUBLE PRECISION SUMX(15),SUMXSQ(15),XA,XE,TOTAL,R,N,X,Y,Z,FSTAT, FTE00280
     *DF1,DF2                                                           FTE00290
C                                                                       FTE00300
C     *** INITIALIZE THE NUMBER OF OBSERVATIONS AND THE NUMBER OF GROUPSFTE00310
C                                                                       FTE00320
      R=15.D0                                                           FTE00330
      N=33.D0                                                           FTE00340
C                                                                       FTE00350
C     *** DO THE F-TEST FOR EACH OF THE SETS OF DATA PRESENT ***        FTE00360
C                                                                       FTE00370
      DO 100 J=1,3                                                      FTE00380
C                                                                       FTE00390
C                                                                       FTE00400
      DO 10 I=1,15                                                      FTE00410
         READ(5,20)SUMX(I),SUMXSQ(I)                                    FTE00420
20       FORMAT(1X,E23.16,2X,E23.16)                                    FTE00430
10    CONTINUE                                                          FTE00440
```

```
C                                                                       FTE00450
      X=0.D0                                                            FTE00460
      Y=0.D0                                                            FTE00470
      Z=0.D0                                                            FTE00480
C                                                                       FTE00490
      DO 30 I=1,15                                                      FTE00500
          X=X+SUMX(I)                                                   FTE00510
          Y=Y+SUMXSQ(I)                                                 FTE00520
          Z=Z+SUMX(I)**2                                                FTE00530
30    CONTINUE                                                          FTE00540
C                                                                       FTE00550
C                                                                       FTE00560
      XA=(Z/N)-(X**2/(R*N))                                             FTE00570
      XE=Y-(Z/N)                                                        FTE00580
      TOTAL=Y-(X**2/(R*N))                                              FTE00590
C                                                                       FTE00600
      DF1=R-1.D0                                                        FTE00610
      DF2=R*(N-1.D0)                                                    FTE00620
C                                                                       FTE00630
      FSTAT=(XA/DF1)/(XE/DF2)                                           FTE00640
C                                                                       FTE00650
C     *** OUTPUT THE RESULTS-THE FORMATS REPRESENT VARIABLE DEFINITIONS FTE00660
C                                                                       FTE00670
      WRITE(6,31) J                                                     FTE00680
31    FORMAT('1',' F-STATISTICS FOR THE',I4,' COMPONENT')               FTE00690
C                                                                       FTE00700
      WRITE(6,40) X                                                     FTE00710
40    FORMAT('0',' SUM OF SUMS =',E23.16)                               FTE00720
C                                                                       FTE00730
      WRITE(6,41) Y                                                     FTE00740
41    FORMAT('0',' SUM OF SUMS**2 =',E23.16)                            FTE00750
C                                                                       FTE00760
      WRITE(6,42) Z                                                     FTE00770
42    FORMAT('0',' SUM OF SQUARE OF SUMS =',E23.16)                     FTE00780
C                                                                       FTE00790
      WRITE(6,50) XA                                                    FTE00800
50    FORMAT('0',' AMONG GROUP SUM OF SQUARES =',E23.16)                FTE00810
C                                                                       FTE00820
      WRITE(6,51) XE                                                    FTE00830
51    FORMAT('0',' WITHIN GROUP SUM OF SQUARES =',E23.16)               FTE00840
C                                                                       FTE00850
      WRITE(6,60) TOTAL                                                 FTE00860
60    FORMAT('0',' TOTAL SUM OF SQUARES =',E23.16)                      FTE00870
C                                                                       FTE00880
      WRITE(6,70) DF1                                                   FTE00890
70    FORMAT('0',' DEGREES OF FREEDOM IN NUMERATOR =',E23.16)           FTE00900
C                                                                       FTE00910
      WRITE(6,71) DF2                                                   FTE00920
71    FORMAT('0',' DEGREES OF FREEDOM IN DENOMINATOR =',E23.16)         FTE00930
C                                                                       FTE00940
```

```
      WRITE(6,80) FSTAT                                                 FTE00950
80    FORMAT('0',' F-STATISTIC =',E23.16)                               FTE00960
C                                                                       FTE00970
100   CONTINUE                                                          FTE00980
C                                                                       FTE00990
      WRITE(6,81)                                                       FTE01000
81    FORMAT('1')                                                       FTE01010
      STOP                                                              FTE01020
      END                                                               FTE01030
```

APPENDIX E

RESULTS OF F-TEST

```
F-STATISTICS FOR THE   1 COMPONENT
SUM OF SUMS = 0.209148788229499D 02
SUM OF SUMS**2 = 0.181065546945340D 02
SUM OF SQUARE OF SUMS = 0.412809751067904D 02
AMCNG GROUP SUM OF SQUARES = 0.121188313615451D 00
WITHIN GROUP SUM OF SQUARES = 0.176937449434661D 02
TOTAL SUM OF SQUARES = 0.178149332570815D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.726506321438760D 00

F-STATISTICS FOR THE   2 COMPONENT
SUM OF SUMS = 0.230579271780502D 02
SUM OF SUMS**2 = 0.189470123401529D 02
SUM OF SQUARE OF SUMS = 0.466382512665546D 02
AMCNG GROUP SUM OF SQUARES = 0.111937175500036D 00
WITHIN GROUP SUM OF SQUARES = 0.184806298274873D 02
TOTAL SUM OF SQUARES = 0.185925670029873D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.642474646501473D 00

F-STATISTICS FOR THE   3 COMPONENT
SUM OF SUMS = 0.269373453582763D 02
SUM OF SUMS**2 = 0.212467492197418D 02
SUM OF SQUARE OF SUMS = 0.592156638135886D 02
AMCNG GROUP SUM OF SQUARES = 0.108409588168518D 00
WITHIN GROUP SUM OF SQUARES = 0.206545925816059D 02
TOTAL SUM OF SQUARES = 0.207630021697744D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.556736224277577D 00
```

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F-STATISTICS FOR THE   4 COMPONENT
SUM OF SUMS = 0.3175688631627065D 02
SUM OF SUMS**2 = 0.2621104542300214D 02
SUM OF SQUARE OF SUMS = 0.8070513093726266D 02
AMONG GROUP SUM OF SQUARES = 0.1347180903696015D 00
WITHIN GROUP SUM OF SQUARES = 0.2540399411362951D 02
TOTAL SUM OF SQUARES = 0.2553871220399911D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04

F-STATISTIC = 0.5624997485041869D 00
F-STATISTICS FOR THE   5 COMPONENT
SUM OF SUMS = 0.3669104349531116D 02
SUM OF SUMS**2 = 0.3380633740317695D 02
SUM OF SQUARE OF SUMS = 0.1069682473356158D 03
AMONG GROUP SUM OF SQUARES = 0.1721940248396148D 00
WITHIN GROUP SUM OF SQUARES = 0.3273665492982079D 02
TOTAL SUM OF SQUARES = 0.3290884895466041D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.5579331866788867D 00

F-STATISTICS FOR THE   6 COMPONENT
SUM OF SUMS = 0.4160097878948431D 02
SUM OF SUMS**2 = 0.4313236642020094D 02
SUM OF SQUARE OF SUMS = 0.1408215358007360D 03
AMONG GROUP SUM OF SQUARES = 0.2544544005119440D 00
WITHIN GROUP SUM OF SQUARES = 0.4172415106219358D 02
TOTAL SUM OF SQUARES = 0.4197860546270552D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.6468757561623442D 00
```

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F-STATISTICS FOR THE   7 COMPONENT
SUM OF SUMS = 0.4810387092348111D 02
SUM OF SUMS**2 = 0.5206409381611744D 02
SUM OF SQUARE OF SUMS = 0.1964653659903027D 03
AMONG GROUP SUM OF SQUARES = 0.4219987280210724D 00
WITHIN GROUP SUM OF SQUARES = 0.5009944015621441D 02
TOTAL SUM OF SQUARES = 0.5052143888423548D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.8934632362547178D 00

F-STATISTICS FOR THE   8 COMPONENT
SUM OF SUMS = 0.5623255941290002D 02
SUM OF SUMS**2 = 0.8590285622098203D 02
SUM OF SQUARE OF SUMS = 0.3070018365343552D 03
AMONG GROUP SUM OF SQUARES = 0.9619512065933320D 00
WITHIN GROUP SUM OF SQUARES = 0.8283283785563848D 02
TOTAL SUM OF SQUARES = 0.8379478906223181D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1231824736914027D 01

F-STATISTICS FOR THE   9 COMPONENT
SUM OF SUMS = 0.9931605295569187D 02
SUM OF SUMS**2 = 0.4043531056175881D 03
SUM OF SQUARE OF SUMS = 0.1416642417283150D 04
AMONG GROUP SUM OF SQUARES = 0.7590638589699638D 01
WITHIN GROUP SUM OF SQUARES = 0.3901866814447566D 03
TOTAL SUM OF SQUARES = 0.3977773200344562D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.2063499133280512D 01
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F-STATISTICS FOR THE  10 COMPONENT
SUM OF SUMS = 0.2029942628781924D 03
SUM OF SUMS**2 = 0.1757564757819924D 04
SUM OF SQUARE OF SUMS = 0.7655692250451960D 04
AMONG GROUP SUM OF SQUARES = 0.4908580866354581D 02
WITHIN GROUP SUM OF SQUARES = 0.1681007835315404D 04
TOTAL SUM OF SQUARES = 0.1730093643978950D 04
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3097309684192641D 01

F-STATISTICS FOR THE  11 COMPONENT
SUM OF SUMS = 0.2004773302247246D 03
SUM OF SUMS**2 = 0.1811875077561617D 04
SUM OF SQUARE OF SUMS = 0.7980439863108266D 04
AMONG GROUP SUM OF SQUARES = 0.5301029200839379D 02
WITHIN GROUP SUM OF SQUARES = 0.1732070678930534D 04
TOTAL SUM OF SQUARES = 0.1785080970938928D 04
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3246332537532912D 01

F-STATISTICS FOR THE  12 COMPONENT
SUM OF SUMS = 0.2210834652773109D 03
SUM OF SUMS**2 = 0.2165859765218944D 04
SUM OF SQUARE OF SUMS = 0.9414279932820438D 04
AMONG GROUP SUM OF SQUARES = 0.6155753358218842D 02
WITHIN GROUP SUM OF SQUARES = 0.2071716965890740D 04
TOTAL SUM OF SQUARES = 0.2133274499472928D 04
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3151731454585565D 01
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F-STATISTICS FOR THE  13 COMPONENT
SUM OF SUMS = 0.1979583434471791D 03
SUM OF SUMS**2 = 0.1904701075347160D 04
SUM OF SQUARE OF SUMS = 0.7185446672840862D 04
AMCNG GROUP SUM OF SQUARES = 0.4572946290150773D 02
WITHIN GROUP SUM OF SQUARES = 0.1832846608618751D 04
TOTAL SUM OF SQUARES = 0.1878576071520259D 04
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.2646478671459864D 01

F-STATISTICS FOR THE  14 COMPONENT
SUM OF SUMS = 0.9227736272614619D 02
SUM OF SUMS**2 = 0.2600827196886254D 03
SUM OF SQUARE OF SUMS = 0.9540726819081072D 03
AMCNG GROUP SUM OF SQUARES = 0.3863985704619236D 01
WITHIN GROUP SUM OF SQUARES = 0.2505419928695444D 03
TOTAL SUM OF SQUARES = 0.2544059785741636D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1635887377498235D 01

F-STATISTICS FOR THE  15 COMPONENT
SUM OF SUMS = 0.6880926336210145D 02
SUM OF SUMS**2 = 0.1018300362534556D 03
SUM OF SQUARE OF SUMS = 0.3695062863415098D 03
AMCNG GROUP SUM OF SQUARES = 0.5385863804584070D 00
WITHIN GROUP SUM OF SQUARES = 0.9813497339004056D 02
TOTAL SUM OF SQUARES = 0.9867355977049896D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.5821433971075596D 00
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F-STATISTICS FOR THE  16 COMPONENT
SUM OF SUMS = 0.6961387326450431D 02
SUM OF SUMS**2 = 0.1137157033969463D 03
SUM OF SQUARE OF SUMS = 0.3597053597878584D 03
AMONG GROUP SUM OF SQUARES = 0.3663260306209388D 00
WITHIN GROUP SUM OF SQUARES = 0.1101186497990677D 03
TOTAL SUM OF SQUARES = 0.1104849758296886D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3528623485827816D 00

F-STATISTICS FOR THE  17 COMPONENT
SUM OF SUMS = 0.7052854165691613D 02
SUM OF SUMS**2 = 0.1548042004914454D 03
SUM OF SQUARE OF SUMS = 0.3820324148469269D 03
AMONG GROUP SUM OF SQUARES = 0.5041406896350342D 00
WITHIN GROUP SUM OF SQUARES = 0.1509838763429761D 03
TOTAL SUM OF SQUARES = 0.1514880170326111D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3541763825767676D 00

F-STATISTICS FOR THE  18 COMPONENT
SUM OF SUMS = 0.7950452893326030D 02
SUM OF SUMS**2 = 0.1454127656122291D 03
SUM OF SQUARE OF SUMS = 0.5157161626920556D 03
AMONG GROUP SUM OF SQUARES = 0.9431815463208067D 00
WITHIN GROUP SUM OF SQUARES = 0.1402556039853086D 03
TOTAL SUM OF SQUARES = 0.1411987855316294D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.7133020797581566D 00
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F-STATISTICS FOR THE  19 COMPONENT
SUM OF SUMS = 0.8206200282896035D 02
SUM OF SUMS**2 = 0.1642503769158388D 03
SUM OF SQUARE OF SUMS = 0.5788746875066006D 03
AMCNG GROUP SUM OF SQUARES = 0.1299298669532475D 01
WITHIN GROUP SUM OF SQUARES = 0.1584616300407728D 03
TOTAL SUM OF SQUARES = 0.1597609287103052D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.8697276809711277D 00

F-STATISTICS FOR THE  20 COMPONENT
SUM OF SUMS = 0.9520048302882186D 02
SUM OF SUMS**2 = 0.2094086558414699D 03
SUM OF SQUARE OF SUMS = 0.8713219218815827D 03
AMCNG GROUP SUM OF SQUARES = 0.2671131239535162D 01
WITHIN GROUP SUM OF SQUARES = 0.2006954366226541D 03
TOTAL SUM OF SQUARES = 0.2033665678621893D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1411744637781583D 01
F-STATISTICS FOR THE  21 COMPONENT

SUM OF SUMS = 0.8994139952150146D 02
SUM OF SUMS**2 = 0.2335862791765991D 03
SUM OF SQUARE OF SUMS = 0.7245755635510632D 03
AMCNG GROUP SUM OF SQUARES = 0.1852785403586404D 01
WITHIN GROUP SUM OF SQUARES = 0.2263405235410884D 03
TOTAL SUM OF SQUARES = 0.2281933089446748D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.8682828488687504D 00
```

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F-STATISTICS FOR THE  22 COMPONENT
SUM OF SUMS = 0.1035648300735959D 03
SUM OF SUMS**2 = 0.2414810868436007D 03
SUM OF SQUARE OF SUMS = 0.9427341493765320D 03
AMONG GROUP SUM OF SQUARES = 0.2276892141650119D 01
WITHIN GROUP SUM OF SQUARES = 0.2320537453498354D 03
TOTAL SUM OF SQUARES = 0.2343306374914855D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1040764077320930D 01

F-STATISTICS FOR THE  23 COMPONENT
SUM OF SUMS = 0.9031234717154746D 02
SUM OF SUMS**2 = 0.2047768116906234D 03
SUM OF SQUARE OF SUMS = 0.7149379755971323D 03
AMONG GROUP SUM OF SQUARES = 0.1711833054881912D 01
WITHIN GROUP SUM OF SQUARES = 0.1976274319346521D 03
TOTAL SUM OF SQUARES = 0.1993392649895340D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.9187822552243536D 00

F-STATISTICS FOR THE  24 COMPONENT
SUM OF SUMS = 0.9171706807335522D 02
SUM OF SUMS**2 = 0.1900438745495707D 03
SUM OF SQUARE OF SUMS = 0.8139562480340389D 03
AMONG GROUP SUM OF SQUARES = 0.2531548763025405D 01
WITHIN GROUP SUM OF SQUARES = 0.1819043120692303D 03
TOTAL SUM OF SQUARES = 0.1844358608322557D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1476188171339999D 01
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F-STATISTICS FOR THE  25 COMPONENT
SUM OF SUMS = 0.8440126623444366D 02
SUM OF SUMS**2 = 0.1782254895437147D 03
SUM OF SQUARE OF SUMS = 0.6892901073945840D 03
AMONG GROUP SUM OF SQUARES = 0.2143851912627546D 01
WITHIN GROUP SUM OF SQUARES = 0.1713325884697689D 03
TOTAL SUM OF SQUARES = 0.1734764403823964D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1327251499840134D 01

F-STATISTICS FOR THE  26 COMPONENT
SUM OF SUMS = 0.6923579472492147D 02
SUM OF SUMS**2 = 0.1481985058366125D 03
SUM OF SQUARE OF SUMS = 0.4452980334185913D 03
AMONG GROUP SUM OF SQUARES = 0.1257250153391605D 01
WITHIN GROUP SUM OF SQUARES = 0.1437455255024266D 03
TOTAL SUM OF SQUARES = 0.1450027756558182D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.9277389287476910D 00

F-STATISTICS FOR THE  27 COMPONENT
SUM OF SUMS = 0.6366092822129744D 02
SUM OF SUMS**2 = 0.1177906819912730D 03
SUM OF SQUARE OF SUMS = 0.3935159041535181D 03
AMONG GROUP SUM OF SQUARES = 0.1233349853537058D 01
WITHIN GROUP SUM OF SQUARES = 0.1138555229497378D 03
TOTAL SUM OF SQUARES = 0.1150888728032749D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.1149027974258136D 01
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F-STATISTICS FOR THE  28 COMPONENT
SUM OF SUMS = 0.538759249486525D 02
SUM OF SUMS**2 = 0.1186133442790129D 03
SUM OF SQUARE OF SUMS = 0.2792595957915495D 03
AMONG GROUP SUM OF SQUARES = 0.8575190985312517D 00
WITHIN GROUP SUM OF SQUARES = 0.1158207483210974D 03
TOTAL SUM OF SQUARES = 0.1166782674196286D 03
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.7853366268738306D 00

F-STATISTICS FOR THE  29 COMPONENT
SUM OF SUMS = 0.4536144151906700D 02
SUM OF SUMS**2 = 0.6564305139058856D 02
SUM OF SQUARE OF SUMS = 0.1919053830677748D 03
AMONG GROUP SUM OF SQUARES = 0.5472802462192574D 00
WITHIN GROUP SUM OF SQUARES = 0.6372399755991081D 02
TOTAL SUM OF SQUARES = 0.6427127780613007D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.9109723144851782D 00

F-STATISTICS FOR THE  30 COMPONENT
SUM OF SUMS = 0.3732568029970994D 02
SUM OF SUMS**2 = 0.5705765228634419D 02
SUM OF SQUARE OF SUMS = 0.1284820507967475D 03
AMONG GROUP SUM OF SQUARES = 0.3560162347433721D 00
WITHIN GROUP SUM OF SQUARES = 0.5577283177837672D 02
TOTAL SUM OF SQUARES = 0.5612884801312009D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.148500000000000D 04
F-STATISTIC = 0.6770886363437515D 00
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F-STATISTICS FOR THE  31 COMPONENT
SUM OF SUMS = 0.2973876286269883D 02
SUM OF SUMS**2 = 0.4217833610659068D 02
SUM OF SQUARE OF SUMS = 0.7726205204918280D 02
AMONG GROUP SUM OF SQUARES = 0.1830245094226048D 00
WITHIN GROUP SUM OF SQUARES = 0.4140571558609885D 02
TOTAL SUM OF SQUARES = 0.4158874009552145D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.4688645251806333D 00

F-STATISTICS FOR THE  32 COMPONENT
SUM OF SUMS = 0.2142367689889270D 02
SUM OF SUMS**2 = 0.1414820425416038D 02
SUM OF SQUARE OF SUMS = 0.3565723402182890D 02
AMONG GROUP SUM OF SQUARES = 0.5058971897285643D-01
WITHIN GROUP SUM OF SQUARES = 0.1379163191394209D 02
TOTAL SUM OF SQUARES = 0.1384222163291495D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3890854828465455D 00

F-STATISTICS FOR THE  33 COMPONENT
SUM OF SUMS = 0.1732004830070321D 02
SUM OF SUMS**2 = 0.1115582097066481D 02
SUM OF SQUARE OF SUMS = 0.2312899538600082D 02
AMONG GROUP SUM OF SQUARES = 0.3130057176754676D-01
WITHIN GROUP SUM OF SQUARES = 0.1092453101680480D 02
TOTAL SUM OF SQUARES = 0.1095583158857235D 02
DEGREES OF FREEDOM IN NUMERATOR = 0.1400000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.1485000000000000D 04
F-STATISTIC = 0.3039120267386334D 00
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   F-STATISTICS OF MEAN VARIANCE, SKEWNESS AND KURTOSIS

F-STATISTICS FOR THE   1 COMPONENT
SUM OF SUMS = 0.111161743942250D 05
SUM OF SUMS**2 = 0.431942577749392D 07
SUM OF SQUARE OF SUMS = 0.1861260733960752D 08
AMONG GROUP SUM OF SQUARES = 0.3143833877400904D 06
WITHIN GROUP SUM OF SQUARES = 0.3755407373518861D 07
TOTAL SUM OF SQUARES = 0.4069790761258952D 07
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.480000000000000D 03
F-STATISTIC = 0.2870223636519026D 01

F-STATISTICS FOR THE   2 COMPONENT
SUM OF SUMS =-0.3062348822555926D 07
SUM OF SUMS**2 = 0.7751235739069674D 12
SUM OF SQUARE OF SUMS = 0.2376364181020636D 13
AMONG GROUP SUM OF SQUARES = 0.5306562101878761D 11
WITHIN GROUP SUM OF SQUARES = 0.7031125381184634D 12
TOTAL SUM OF SQUARES = 0.7561781591372509D 12
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.480000000000000D 03
F-STATISTIC = 0.2587626620217669D 01

F-STATISTICS FOR THE   3 COMPONENT
SUM OF SUMS = 0.1087692759875071D 08
SUM OF SUMS**2 = 0.1368235571001090D 14
SUM OF SQUARE OF SUMS = 0.3521258942662316D 14
AMONG GROUP SUM OF SQUARES = 0.8280430048704694D 12
WITHIN GROUP SUM OF SQUARES = 0.1261530754556778D 14
TOTAL SUM OF SQUARES = 0.1344335055043825D 14
DEGREES OF FREEDOM IN NUMERATOR = 0.140000000000000D 02
DEGREES OF FREEDOM IN DENOMINATOR = 0.480000000000000D 03
F-STATISTIC = 0.2250444214596077D 01
```

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