AN ACOUSTIC DIGITAL DATA LINK

by

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United States
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THESIS

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ABSTRACT

A design study of various possible methods of developing an underwater data link to monitor a deep ocean capsule was undertaken. The capsule is designed to remain on the ocean floor for a year, and the data link is required to periodically sample the data being recorded and send it to a surface buoy for relay to a shore station. A comparative engineering evaluation of the possible systems was made and a final design proposed.

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I. INTRODUCTION

The underwater capsule [1] is a self contained unit, which has been designed to help study the ocean by gathering data from a fixed point on the ocean floor for periods of up to one month. A few capsules have been built and several dozen drops have been successfully made to depths of 4000 meters. It is now desired to modify the capsule so that it may be used in experiments requiring that the capsule remain on station for one year.

In normal operation, the capsule is dropped to the ocean floor from a surface ship. The ship may then return to port while the capsule, at preset intervals, reads the data and stores it on magnetic tape. After the required time, the ship returns and the capsule is recalled to the surface by an acoustical command from the ship. Due to the long period of time that the instrument capsule must remain on station, it is necessary to periodically monitor its operation so that any malfunctions may be detected and corrected before too much data is lost. Rather than have the ship remain on station, it is expected that an unmanned surface unit such as "Buoy Bravo" will be anchored above the capsule to act as a relay station.

"Buoy Bravo" [2], built by General Dynamics, although not designed for this purpose, is ideally suited for it. The buoy is designed to be anchored at some point on the ocean, where it records meteorological and oceanographic data for periods of a year or more. The data is stored on magnetic tape and also in a temporary data register. The buoy has a radio link which allows a shore station to recover data from the temporary data register. The buoy may also respond to preprogrammed commands from the shore station. Assuming that the data is supplied to the buoy in proper form, the buoy has the capability to handle all the data, and commands to the capsule without impairing its normal functions.

II. EVALUATION OF POSSIBLE SYSTEMS

An investigation of the possible systems can best be accomplished by dividing the effort into three major areas. They are data sampling, data transmission, and the buoy interface.

Data is taken by means of five transducers [1]. One transducer is used to determine the pressure, another the temperature, and the last three are used to determine current direction and magnitude.

Pressure is sensed by the Vibrotron pressure transducer, built by United Control Corporation. A one centimeter long tungsten wire is stretched between a rigid frame and a diaphram and encased in a dry atmosphere at low pressure. Pressure on the diaphram causes it to inflect, changing the natural frequency of the wire. By connecting the wire in the feedback circuit of an amplifier, an oscillator whose frequency is a function of pressure is obtained.

Temperature is measured by use of a Hewlett-Packard temperature probe. A temperature resolution of 10^{-5} °C is obtained by mixing the output of two crystal oscillators. One crystal is cut for zero temperature sensitivity and the other for high sensitivity. The output frequency will vary 1000 ± 5 Hz. per degree of temperature change.

The current measurements are accomplished by three pairs of indirectly heated thermistors mounted in the proper position. Above a threshold of one millimeter per second, the cooling of the thermistor pairs is a function of the current. The resistance of the thermistor pairs is then converted into pulse trains with the frequency linearly dependent on the temperature difference between the thermistor pairs.

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After the capsule has been recovered, the three readings may be interpolated in a computer to determine current magnitude and direction.

The outputs of the five transducers are applied to the inputs of five 16 bit binary counters. The counters are gated on for a period of 120 seconds, during which time the number cycles in the input signal is counted. During the time period, the counters will overflow several times; thus only the least significant bits are retained. The missing bits may be inferred by the transducer calibration and the expected value of the data.

A 16 bit counter is used to keep a count of the number of readings taken by the capsule. Five 16 bit coincidence gates wired across the counter yield outputs when predetermined numbers occur. The gates allow programming of the operation of the capsule according to the sample number. At present, three of the gates are in use, leaving two for use in the data link.

At the end of the two minute timing interval, the five data registers and the sample counter are scanned by a diode matrix and fed into the seven channel incremental magnetic tape recorder at the rate of 32 six bit words per second. A vertical parity bit, generated by the recorder, is recorded by the seventh channel, and a horizontal parity bit is placed at the end of the data.

To give a complete check of the operation of the capsule, it is necessary to sample the data being recorded on the magnetic tape, and also make a few circuit checks. The circuit checks are to be made by the capsule, and will be supplied to the data link for transmission. The circuit checks were not within the scope of this paper. It is the responsibility of the designer of the capsule to provide the checks in the proper form for transmission. The proper format will be discussed later in this paper.

Since the capsule will be taking only two or three readings per day, the data link must either interrogate during the data recording period, or have some form of temporary memory which may store the data several hours. Since power is a problem, the memory must be capable of storing the data with the power off.

One method of accomplishing the memory would be to use the tape recorder in the capsule. Since the tape recorder's read and write head are combined in one unit, it would be necessary to add a second read head. The recorder would then be configured so that it would always maintain a loop of tape containing the last recorded data. When it is desired to sample the data, the tape would be stepped past the read head. The present recorder used in the capsule can not be configured for this type of operation, and no recorder has been found which can perform this operation and still meet the requirements of the capsule.

Since the data rate of the tape recorder is much faster than the data rate of the data link, a temporary data register would be needed to provide temporary storage and to convert the data from the parallel form in which it comes from the tape recorder to a series format for transmission.

A second method of accomplishing the long term storage would be to use a magnetic core memory. Due to the high cost of the core, it would only become competitive to the tape recorder if the entire memory was changed to a magnetic core device. An advantage which would result from switching to a core memory would be that any data could be sampled at any time. The disadvantages of the core would be the increase in the complexity of the capsule it would cause, and the reduced storage capability.

If it is acceptable to limit the allowable interrogation periods to the times when the capsule is making recordings, a very simple method of sampling the data may be used. This method would consist of using the same temporary data register discussed earlier for use with the tape recorder. As the data was recorded on the tape, it would be immediately read off the tape and fed into the register for transmission. A series of flip-flops wired in the form of shift registers would be all that would be required to perform the storage of the data. The data would be read into the shift registers in a parallel form and then one register would be emptied at a time to place the data in a series format.

Once the data has been sampled, there are two methods by which it may be transmitted to the surface. Data transmission may be accomplished by using a hard line between the capsule and the buoy. This line could be incorporated in the anchor line for the capsule. The second method would be to use an acoustic link between the capsule and the buoy. The acoustic method would place some severe restrictions on the data link.

The speed of sound in water is a function of temperature, pressure, and salinity; all of which vary with depth. The variations in the speed of sound with depth, tend to make the sea a very dispersive media for sound waves traveling in the horizontal direction, and not as dispersive for waves traveling in the vertical direction. Distortion of sound waves traveling in the vertical direction is caused by variations in the attenuation with frequency, and multipath interference.

The attenuation of sound waves in water increases with increasing frequency [3]. Thus the signal frequency must be kept low to minimize the power required and the bandwidth low to reduce distortion caused by the higher frequency components being attenuated. Even at low frequencies, the transmission loss can be very large. The transmission loss may be calculated by:

$$Tl = 20 \log r + \alpha r(10^{-3}) = 79 + 14.8 = 104 \text{ db}$$

?

Adding 10 db for the required signal to noise ratio, the transmitter must put out a signal which is greater than 114 db above the noise level. Taking the highest noise level to be -30 db (above one microbar) yields 84 dbm required. The transducer in the capsule will produce a signal of 90 dbm at 8 KHz when 140 watts peak power is applied to the input. By keeping the power level to just greater than the minimum required, only the first surface echo pulse will arrive with sufficient strength to interfere with the desired pulse. Thus, if the signal consists of CW bursts at a single frequency, the proper spacing may be calculated so that the echo pulses may be separated from the desired signal.

Since the receiving hydrophone must be placed below the surface, it is necessary to calculate the proper depth so that the surface echo pulse can be separated from the direct signal. Using a worst case analysis and assuming the fastest value for the speed of sound, the necessary depth such that the echo pulse returns after the end of the desired signal is found to be:

$$2d = vT$$

$$d = \frac{(1525)(10 \times 10^{-3})}{2} \text{ meters} = 7.625 \text{ meters}$$

To be safe the design depth for the hydrophone might be 15 meters. Next, the necessary delay between pulses may be calculated. Again taking a worst case analysis, assume the slowest possible value for the speed of sound yielding:

$$T = \frac{2d}{v} = \frac{30}{1470} = 20.4 \text{ msec.}$$

Since the maximum pulse length is 10 msec., the leading edges of the pulses must be at least 30.4 msec. apart. Thus the maximum possible data rate would be 32.5 bits per second.

The two major disadvantages with using an acoustical data link may be said to be the high power requirement and the low data rate. There are still several reasons why one might still consider using it. First the system is only required to send 136 bits each time the capsule is interrogated, so the slow data rate would not cause any problems. Second the acoustic link would be easy to implement and would require very few additions to the capsule.

At first glance, the use of the hard line seems to offer many advantages over the acoustical link. "Buoy Bravo" presently uses a hard line to receive information from sensors spaced along the anchor line to a depth of 500 meters [4]. If a transmitter unit similar to the ones used in the sensors were mounted in the capsule and the hard line extended for the full length of the anchor line, the capsule could be treated as just another sensor on the line. The interface problem with the buoy would be eliminated since the buoy is already configured for this operation. Work has been done by J. H. Saxman [5] on the use of a hard line for this purpose.

The main drawback to the use of the hard line is the question of its reliability. General Dynamics revealed that although the transmitter units would work perfectly over the entire length of the line, they were having problems with cable breakage. The breakage is caused both by handling of the cable during the anchoring of the buoy, and due to the severe strain and flexing the line receives on station. At extreme depths an insulated wire may behave like a capillary tube. Any cracks or leaks in the insulation will cause the line to fill with water, and may possibly force the water right up into the buoy.

III. FINAL DESIGN

It was decided that the acoustical link would best meet the requirements of the system, providing the most reliable system for the minimum cost and development time. The design uses, where possible, components either in the capsule already or those available commercially. Maximum use is made of integrated circuits to save space, weight, and power requirements while increasing the reliability. Where possible the number of different circuits used is held to a minimum to make fabrication easy.

The receivers, used in the data link, are the most critical part of the system. It is necessary to provide a unit which reliably detects the signal pulses, and ignores spurious signals caused by natural and man-made noise. The three channel Remaco command receiver presently used in the capsule has been retained for use in the data link, and a single channel unit made by the same company is used in the surface unit.

The receiver [1] uses a very unique method to provide a secure system. The receiver consists of an amplifier, three filters and three level detectors, as shown in fig. 2. The gain of the amplifier is high enough to over-drive it, causing the output to be a constant amplitude square wave with random pulse width. Noise in the 14-15 KHz band causes the output to be spread uniformly over the 14-15 KHz, so each of the detectors will detect a signal yielding an output of about .1 volts.

If a signal 10 decibels above the noise level and tuned to the frequency of one of the filters is present, the output energy of the amplifier will be concentrated at the signal frequency and odd harmonics. The level detector, which is connected to the filter tuned to the signal frequency, will have an output of 3-4 volts. More than one large signal present will cause the energy to be divided between the sum and difference frequencies, as well as, the original frequencies and harmonics. The resulting detector output would be about one volt.

Outputs at more than one detector may be accomplished by alternating between the signal frequencies every .33 seconds. The time constants of the detectors are such that they will rapidly charge to their maximum value and slowly discharge.

The decoder compares the outputs of the three detectors and produces one of eight logic signals. They correspond to no signal and seven command. The most secure commands are the ones requiring two frequencies present and one missing. These secure commands are reserved for the most critical functions in the capsule. There will be at least two less secure commands available for use in the data link.

The transmitter [1] in the capsule is normally used only during the positioning and the recovery of the capsule. The transmitter is used to acknowledge commands from the surface ship and to send a few spontaneous codes when something goes wrong in the capsule. To enable the transmitter to be used by several different circuits, it is set up so that it remains in the standby condition until a logic signal is applied to its input. A series of gates as shown in fig. 3, provides priority to the most important circuits. The length of the transmitted pulse is determined by the length of the input pulse.

The data is stored on the tape in digital form [6]. The write head is always saturated in either a positive or negative sense. If a one is present at the input at the same time a write pulse is received, the head will saturate in the other direction and the tape is stepped one unit. A zero causes the head to remain saturated in whatever direction it is at the time, and the tape is stepped one unit. Thus a one appears on the tape as a flux change and a zero as no flux change. The tape recorder wave forms are shown in fig. 4.

As the tape is stepped, a flux change causes a voltage pulse at the read head. The sign of the pulse will depend on the direction of the flux change. The pulses are fullwave rectified and applied to the output terminal and a test circuit. The test circuit checks the output signal against the input signal to make sure that the proper symbol has been recorded.

As the data is received from the tape recorder, it must be converted from parallel form to series form before it may be transmitted over the data link. This is accomplished by storing the data in seven 17 bit shift registers. The data is loaded into the shift registers in parallel form, and then the registers are emptied one at a time to place the data in a series format. In addition to the seven shift registers, another 17 bit shift register is used to store circuit checks in the form of a 17 bit logic signal generated by the capsule. This information is fed into the register by the same diode matrix which feeds the input signal to the tape recorder. Provision is made for adding a ninth register later if more circuit checks are desired.

Provision was made for two different methods of controlling the operation of the data link. The normal method would be to have the capsule's program clock control the daily operation of the data link. The clock would be set so that the data link would sample the data being recorded once per day. If more frequent samplings are desired, such as when a malfunction is suspected, a sample command may be sent by the surface unit.

Control by the surface unit is accomplished as follows: when the surface unit receives a command from buoy bravo's control unit, the transmitter is turned on and the proper signal is sent to the capsule. If the signal is received by the capsule receiver, a latching relay is set. In normal operation, this relay is set by the capsule's clock.

Normally, all circuits in the capsule, except the clock and receiver, are turned off. If the relay has been set, at the time the capsule turns on to take a reading, the logic circuits for the data link would be turned on and set in a standby condition. As the readings are fed into the tape recorder, they would be at the same time fed into registers for the data link. After the recordings have been made, the capsule would turn itself off and the logic circuits in the data link would begin to send the data to the surface. After the last bit of information has been sent, the circuit would turn itself off.

All operations are synchronized by a timing pulse T supplied by the capsule clock. The timing signal consists of a series of pulses whose leading edges are 5 msec apart. The timing pulses are used to generate control pulses P, C, D, E, T1, CL1, CL2, CL3, and CL4. Control pulse P causes the transmitter to turn on and provides a shift pulse for the shift registers. T1 causes the ring counter to shift. Pulses CL1, CL2, CL3, and CL4 are used to clear the flip-flops at the proper times. The logic diagrams are shown in Figs. 5-8.

The operation of the circuit is as follows: a start pulse triggers FF1 causing it to set, allowing the timing pulses T to be fed through

N1 to FF2 and N3. FF's 2 through 5 form a ripple counter. Every tenth pulse at T causes an output at C. An output at C causes the counter to be reset and also sets FF7, causing the transmitter to be turned on. The voltage at A and its compliment B are a function of the bit to be sent. If the bit is a one, A is one, while a zero causes B to be one. After FF7 has been set, it is reset on one of the next two timing pulses, depending whether A or B is set at one. Resetting FF7 turns the transmitter off and shifts the register being emptied one bit to the right.

The number of shift pulses are counted by FF's 8 through 12. Every 17 pulses, a pulse is generated at T1. A pulse at T1 shifts the ring counter, selecting a new data register to be emptied. The number of pulses at T1 are counted by FF's 13 through 16. After 8 pulses all data registers have been emptied so a pulse is sent to turn off the latching relay, which cuts power to the circuits.

Fig. 6 shows the reset logic. A pulse at C1 resets all flip-flops and places the circuit in a standby mode. While the data is being transmitted, pulses at C, D, and E reset predetermined flip-flops for proper circuit operation.

The conversion of the data from a parallel to a series format is accomplished by a ring counter and three stages of read out logic as shown in Fig. 7. The ring counter is used to select the register to be emptied by inhibiting the trigger pulses from reaching the other registers, and by controling the read out logic.

To follow the logic, assume that the first register is being read and note the logic levels shown on Fig. 7. N301 has an input of zero from the ring counter, while N's 302-308 each have an input of one. Thus the output of N301 depends on the input from the register, but the outputs of the others are held at zero by the ring counter. In the second stage N's 310 and 311 have all their inputs held at zero so their outputs must be a logic level of one. The output of N309, on the other hand, is a function of the input from N301. In the third stage, N312 has two inputs held at zero, while the third input is a function of N309.

The circuit operation would be similar when the other registers are being emptied. The output at A and its complement B are a function of the register being emptied. The signals at A and B are fed into the control section to control the length of the transmitted pulse.

The data comes to the surface as a string of 136 pulses, of either 5 or 10 msec. duration, spaced with their leading edges 50 msec. apart. As each pulse is received at the surface, a series of timing operations are performed to determine if the pulse is a one or zero and the receiver is gated to block the echo pulses. After all the data has been received, it is fed into buoy bravo's memory and the surface unit goes back to its standby state. A suitable surface unit for the data link has been designed by J. H. Saxman [5].

IV. SUMMARY

The data link may be accomplished by either of two methods. They are: a hardwire link using the mooring line, or an acoustical link. The advantages of the hardwire system are the low power requirement, easy interface to the buoy, and the availability of manufactured components.

The disadvantages of the system are: the high cost of the cable and transmitter units (estimated at $8000), and the low reliability of the cable. If further research yields a cable which is more reliable, the hardline method would make a very good system.

The low cost and reliability of the acoustical system are its main advantages. The acoustical link also integrates very well with the other circuits in the capsule, providing a very flexible system. The disadvantages of the acoustical link are its high power requirements and the need for more circuitry to interface to the buoy.

All the circuits for the data link have been simulated on a logic patch board and have been found to work satisfactorily. The only modification of the capsule required is the addition of the circuits described in the final design. The data link will greatly enhance the operation of the capsule and make the capsule a more valuable instrument for studying the ocean.

APPENDIX A

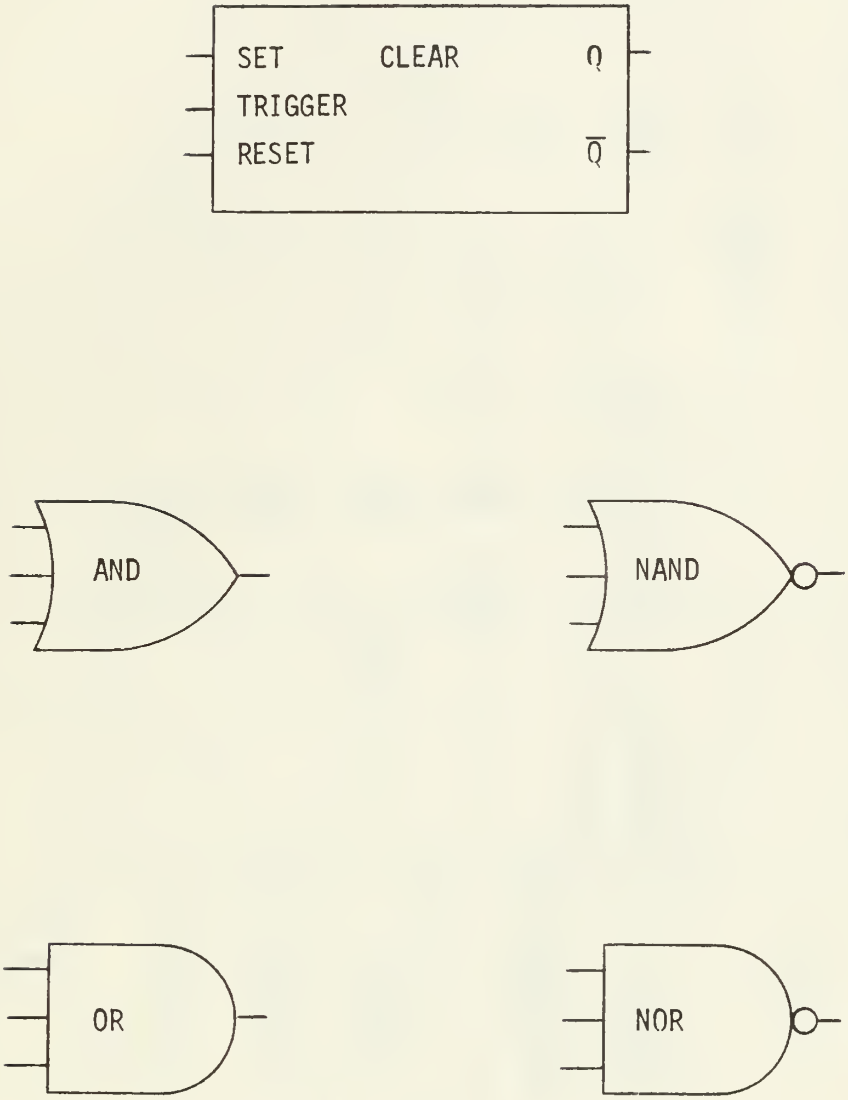

FIGURE 1 LOGIC SYMBOLS USED

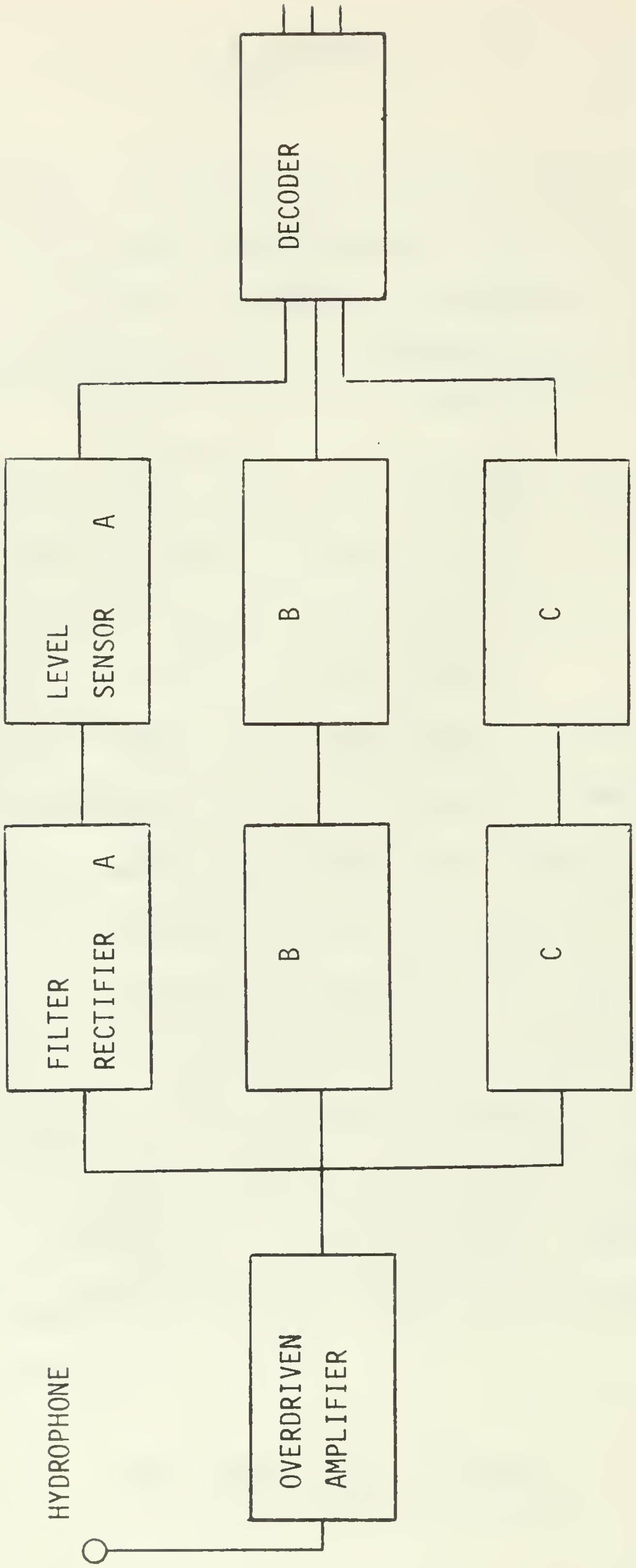

FIGURE 2 BLOCK DIAGRAM OF THE RECEIVER IN THE CAPSULE [1]

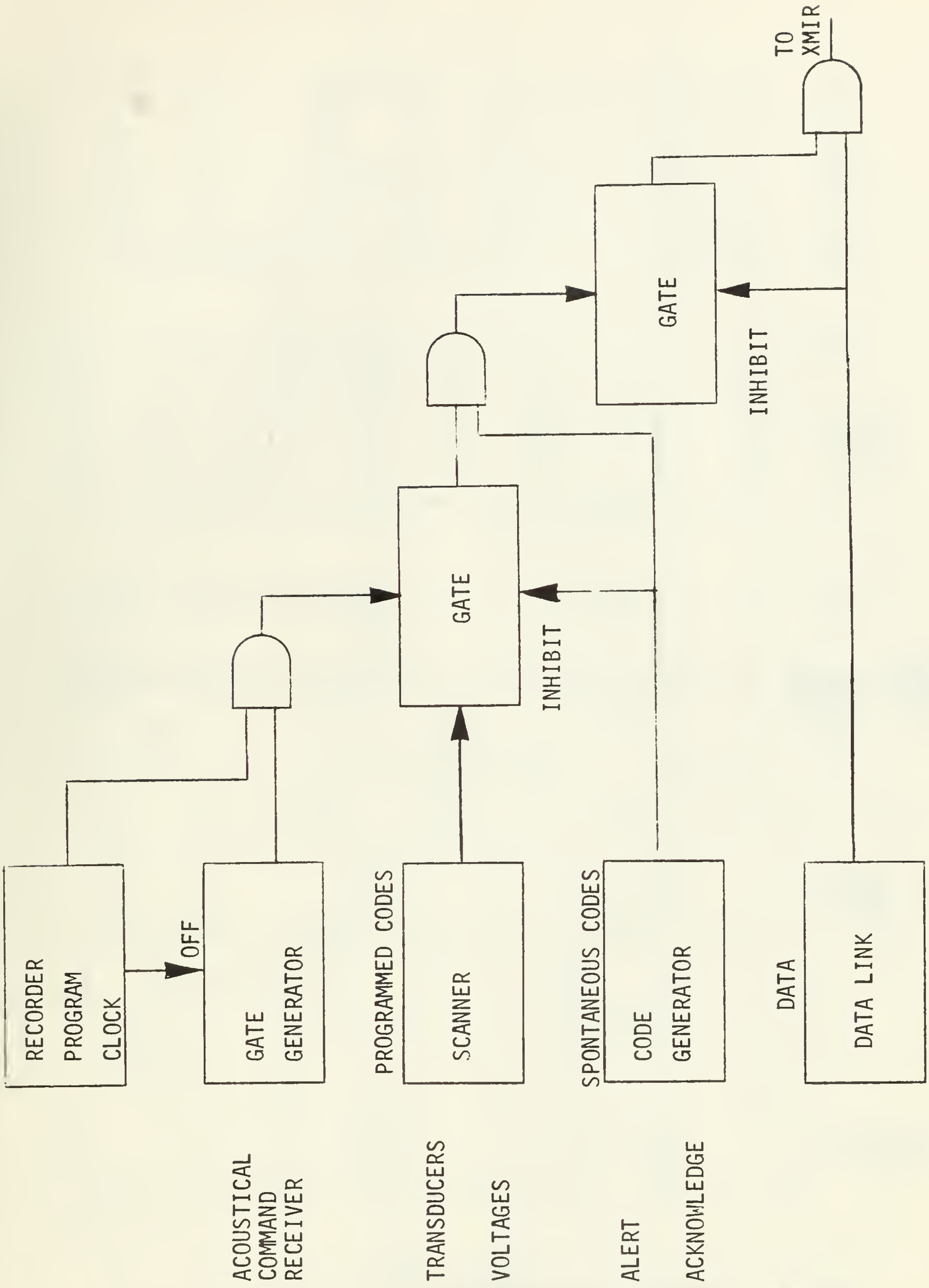

FIGURE 3 CONTROL LOGIC FOR THE TRANSMITTER

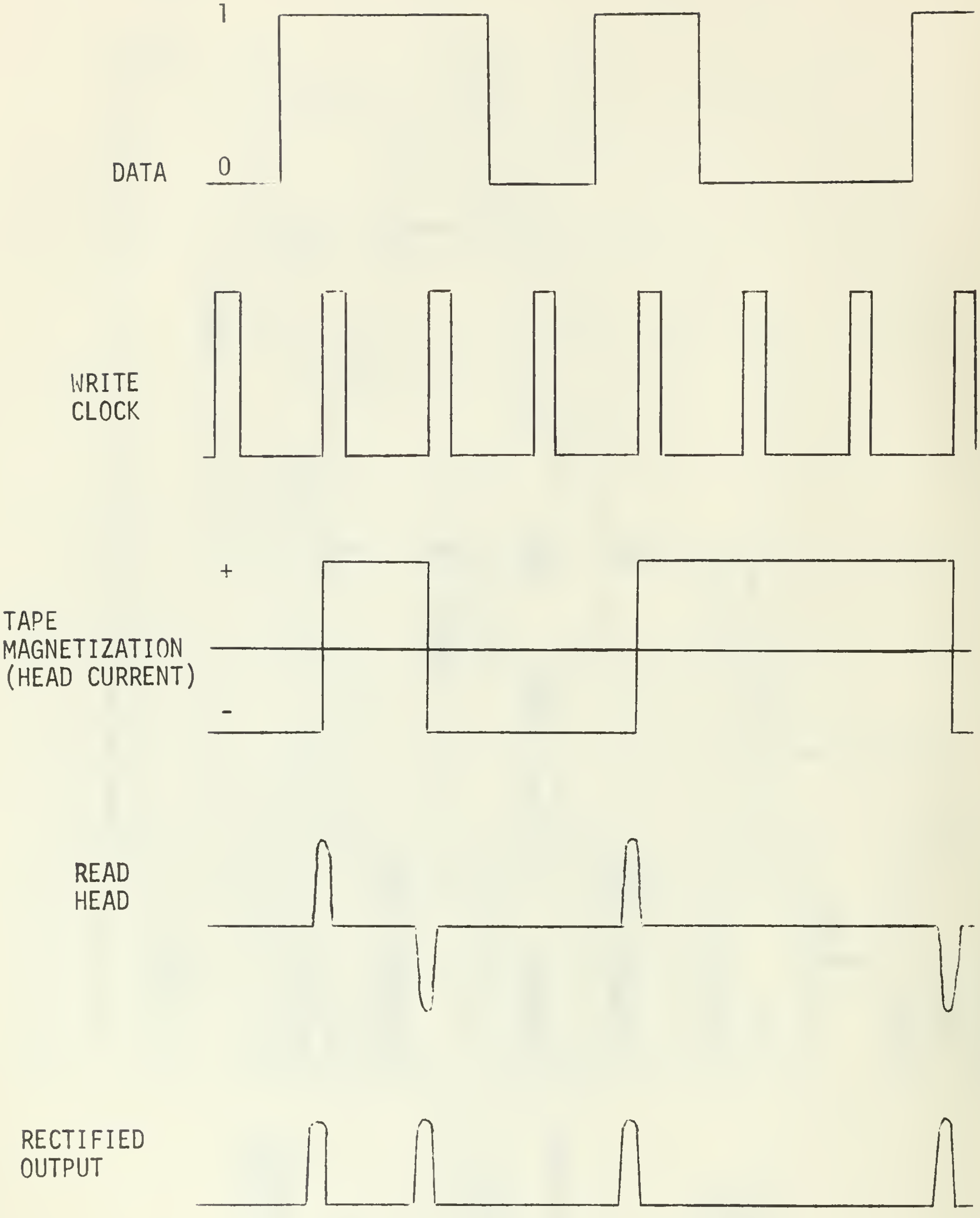

FIGURE 4 TAPE RECORDER WAVEFORMS [6]

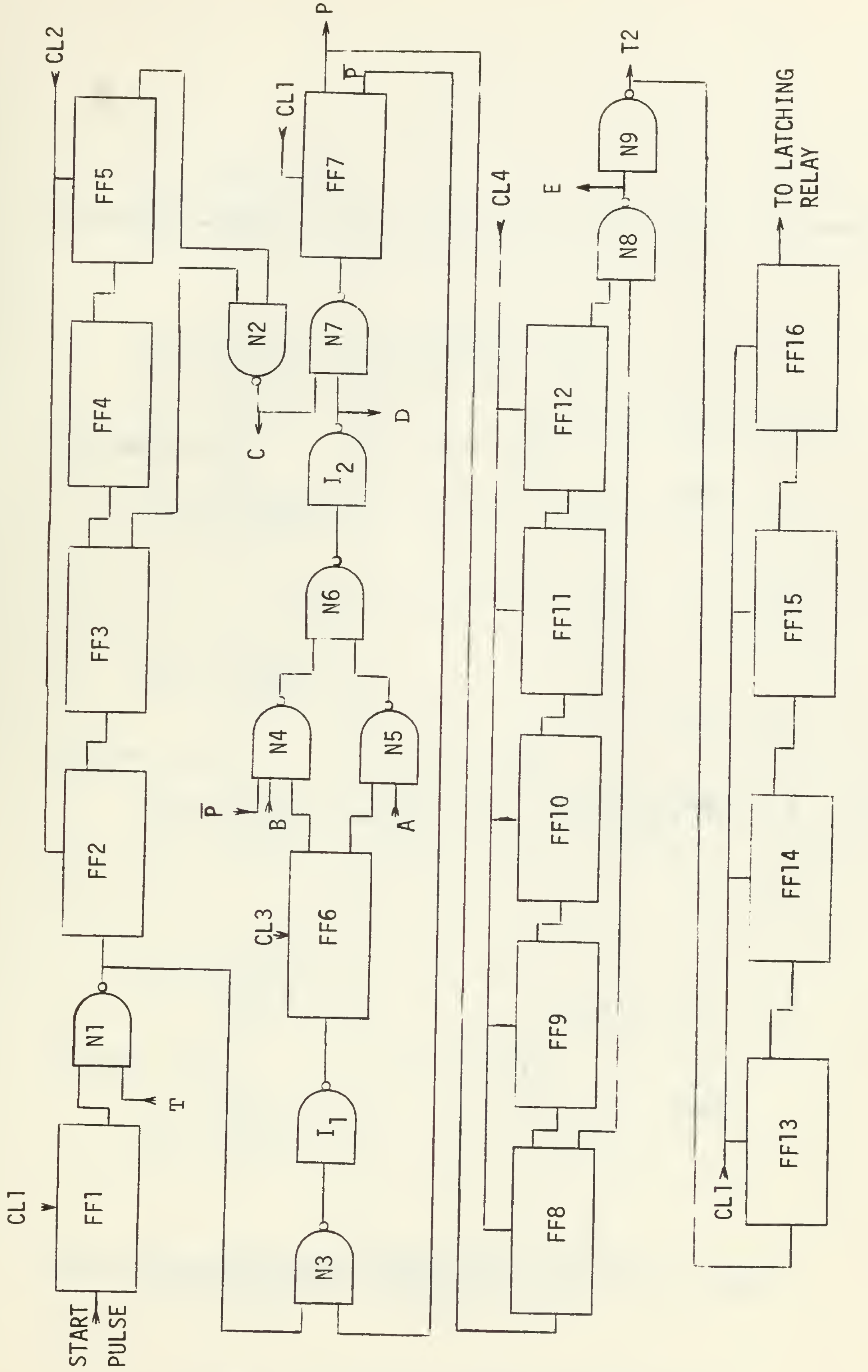

FIGURE 5 LOGIC FOR CONTROL SECTION

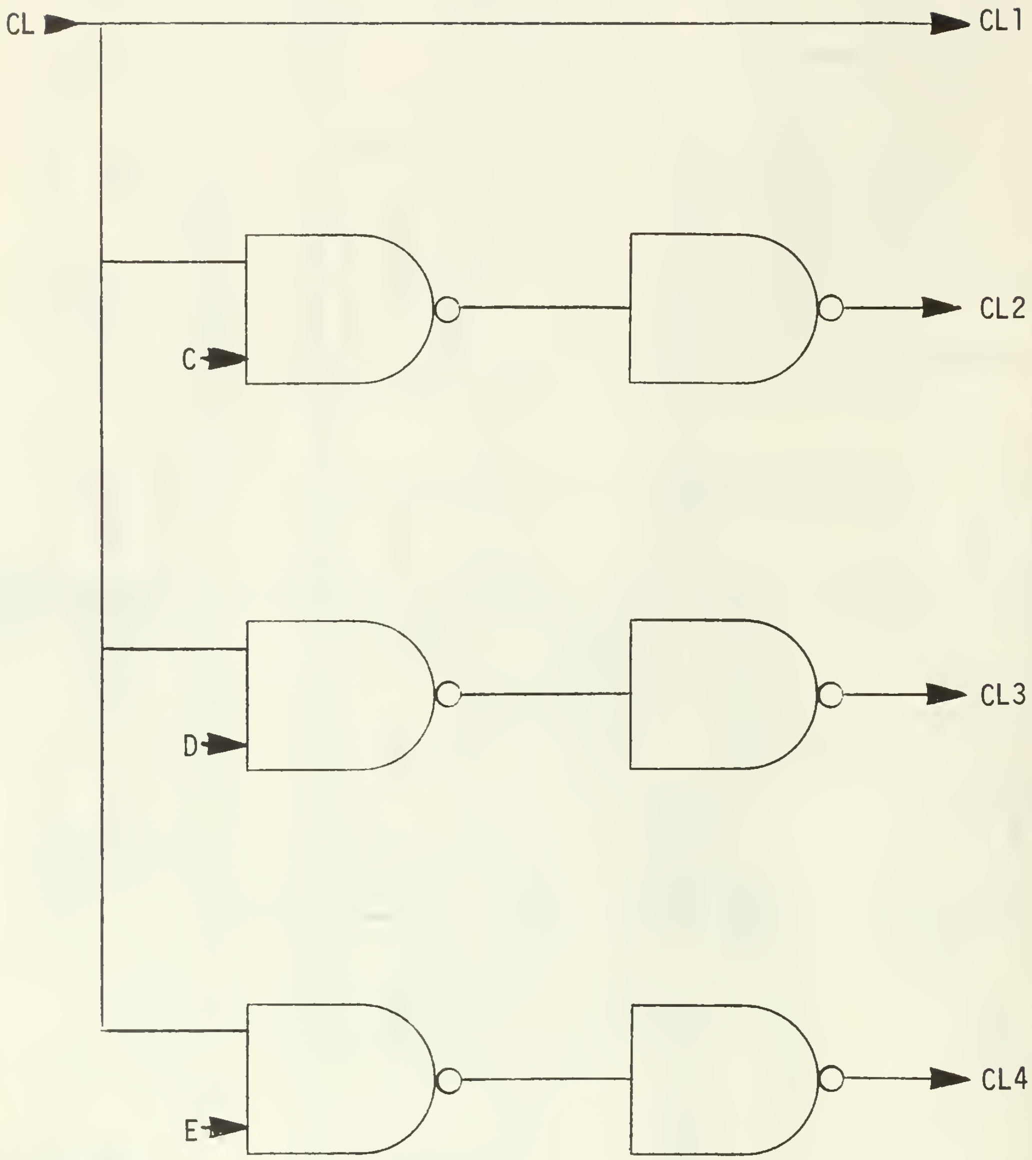

FIGURE 6 RESET LOGIC FOR CONTROL SECTION AND DATA REGISTER

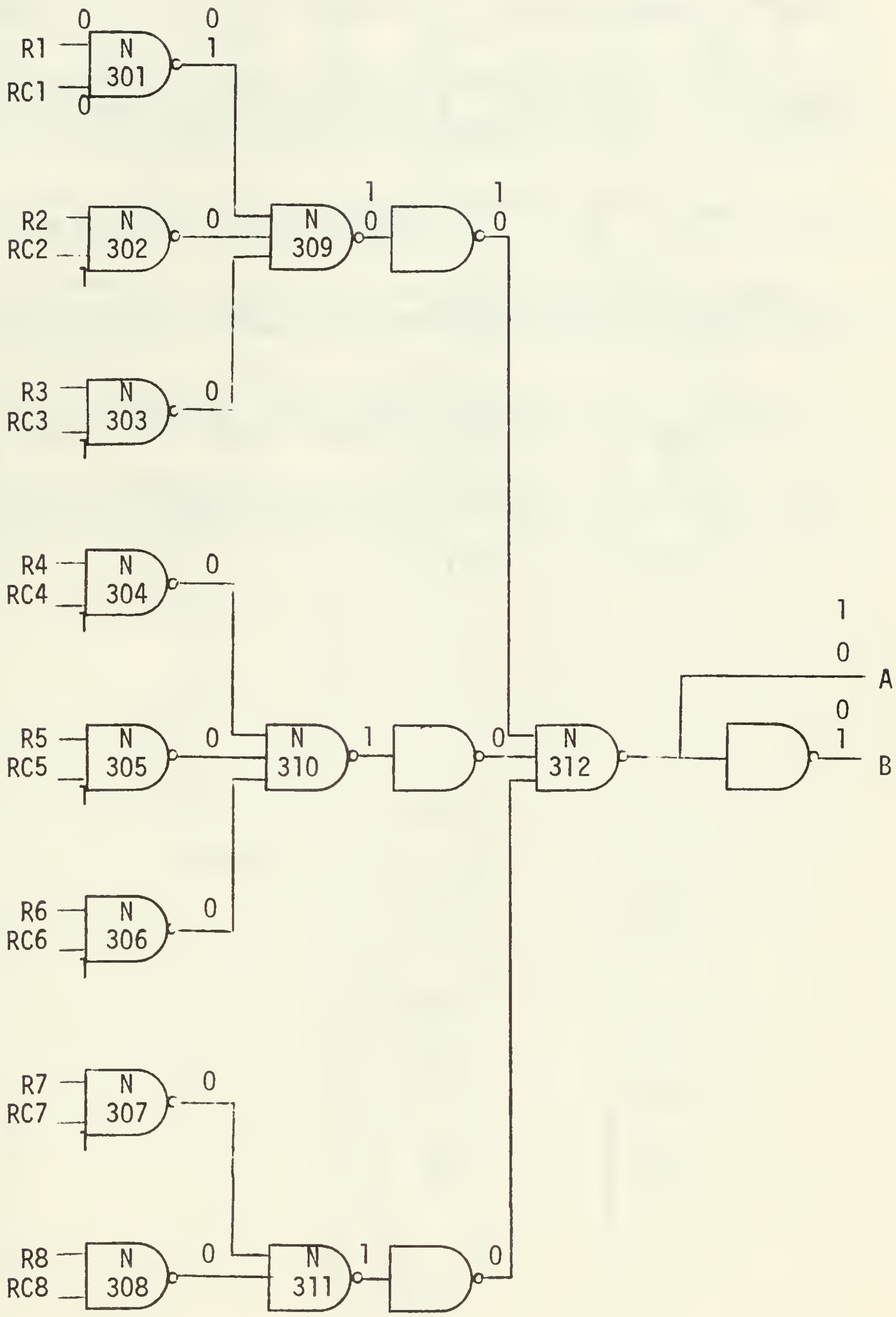

FIGURE 7 DATA READ OUT LOGIC FOR DATA REGISTER

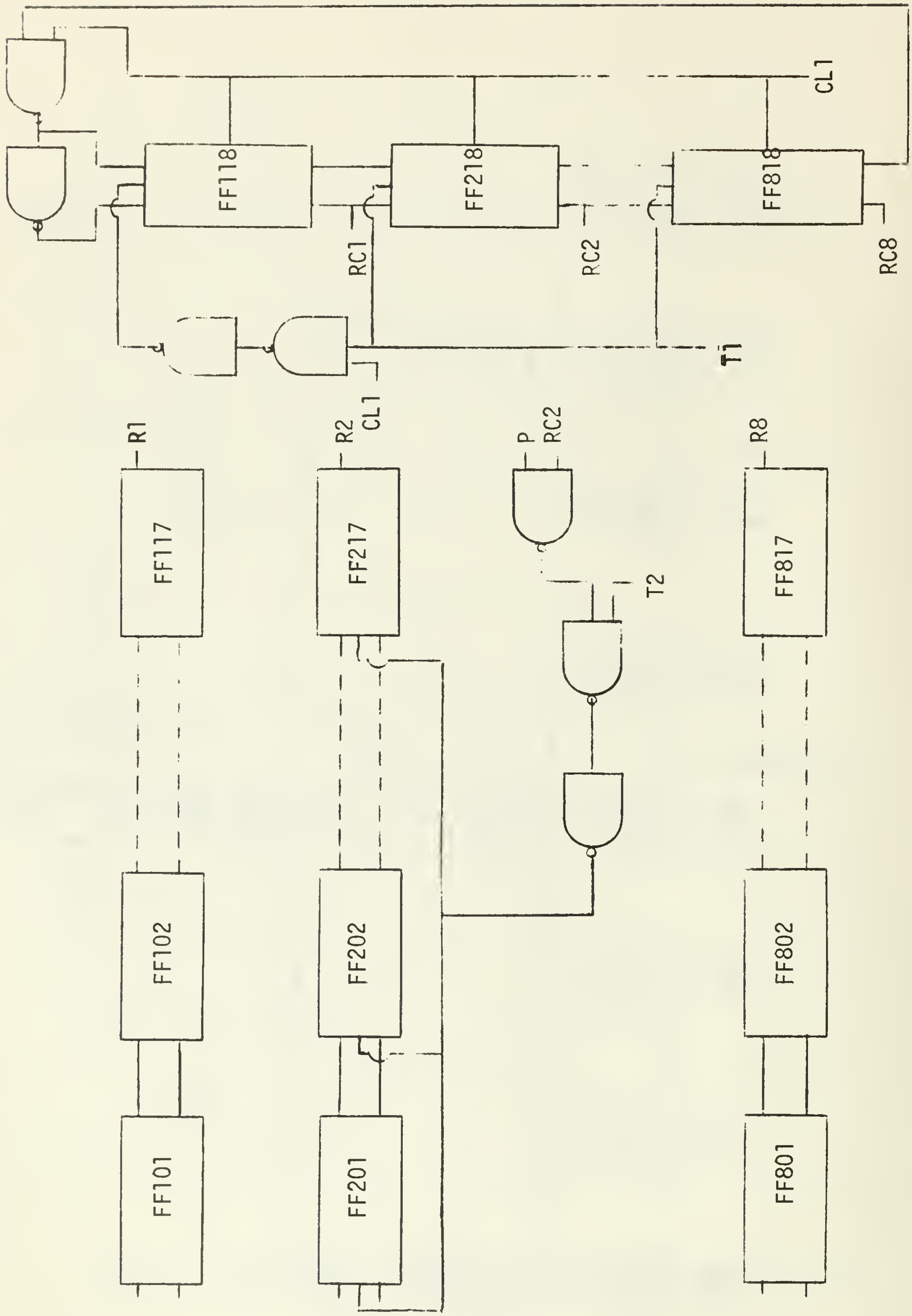

FIGURE 8 TEMPORARY DATA REGISTER

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13. ABSTRACT

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