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A MICROWAVE LANDING SYSTEM AND ITS ASSOCIATED ANTENNA PROBLEM

A Thesis

By

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Lieutenant Commander USN

May 24, 1947

A MICROWAVE LANDING SYSTEM AND ITS ASSOCIATED ANTENNA PROBLEM

A Thesis

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Partial Fulfilment of the Requirements
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in Engineering Electronics

By

Archibald John McEwan

Lieutenant Commander USN

May 24, 1947

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Dean of the Naval Postgraduate School

TABLE OF CONTENTS

28990

LIST OF FIGURES AND ILLUSTRATIONS

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A MICROWAVE LANDING SYSTEM AND ITS ASSOCIATED ANTENNA PROBLEM

I. A BRIEF HISTORY OF LANDING SYSTEMS

The problem of landing an aircraft on a narrow runway when ceilings are low and visability poor is indeed a complex one. It is evident that any equipment meeting this exacting requirement must have the highest precision and dependability.

Techniques for the landing of aircraft under adverse weather conditions have been a subject of discussion and development since 1928.

With the development of the radio range system in 1928 the Bureau of Standards for the Aeronautics Branch of the Department of Commerce devised a system to bring an aircraft down to the runway. This system utilized one leg of the radio range aligned with the desired runway for directional guidance,several marker beacons located on the course for distance information and a barometric altimeter for height data. This method suffered from two basic faults;barometric altimeter errors were bad and effects of transmission lines,terrain and railroad tracks at the low frequencies used caused false courses and bends in the range leg.

In an attempt to eliminate the barometric altimeter and yet obtain height information,a system was proposed by the Bureau of Standards in 1929 in which guidance in the vertical plane was obtained by a constant-intensity glide path (defined as the locus of all points along the localizer where the field intensity is the same as that at the desired touch-down point on the runway). The runway localizer operated on 278 kc., the glide path on 90.8 mc. and the marker beacons on 3105 kc. A cross-pointer meter in the aircraft provided a visual indication of the position of the aircraft with respect to the localizer and glide path. The beacons used for distance information were identified by different modulations. Tests at this time indicated that the system had great possibilities; however the localizer still had course bends, and the long drawn out low altitude constant-intensity glide path depended on too many factors which were likely to vary such as receiver sensitivity and transmitter power output.

In the early part of 1933 the Airways Division of the Department of Commerce, resorting to the aural range system, devised a method whereby the pilot, by using the cone of silence directly over the range station, timed turns, specified rates of descent, the radio range legs and a barometric altimeter could fly an aircraft down to a point 500 feet over the end of the runway. This system with the substitution of the radio (absolute) altimeter for the not too reliable barometric altimeter is in use at the present time.

A year later the Lorenz Company in Germany developed a localizer having two legs and operating on 33.3 mc. The transmitter excited the center antenna of three vertical half-wave antennas facing the runway. The outside antennas were reflectors spaced a quarter-wave from the excited antenna. One reflector was keyed by "A" by means of a shortcircuiting relay at its center and the other keyed with an "N". By interlocking the keying and switching at the proper rate two elliptical patterns were obtained which gave a continuous signal on course and a predominant A or N to either side of the course. The main transmitter output was modulated at 1150 cycles per second. This modulated signal was rectified at the receiver and fed to a meter which indicated position relative to course. This form of visual indication was poor because of the kicking action of the needle when off course.

In 1938 the Bendix Company and United Airlines demonstrated a system employing two Yagi antennas directed in such a manner that their patterns produced an overlapping localizer course. The energy in each antenna was keyed at 70 and 90 cycle per second respectively.

By 1939 the International Telephone Development

Company (I.T.D.) installed at Indianapolis a landing system complete with localizer, glide path and two markers. The localizer operated at 109.9 mc. and utilized the newly developed paddle-type mechanical modulators. The paddles were used to detune coupled line modulating sections. Cross modulation was eliminated by anti-cross modulation bridges. The glide path, now operating at 93.9 mc. and being of the constant intensity type, still was the weakest point in the system.

At this time the Massachusetts Institute of Technology was working on a landing system in the 700 mc. range. The use of horns with a 20 degree flare and 26 ft. by 10 ft. by 2.5 ft. at the mouth was an unusual inovation. The glide path was determined by the equisignal region between the two sharp overlapping patterns produced by two horns at a slight angle to each other. Flight tests indicated a 50 mile range. Cathode-ray tube indication was used. Localizer, glide path and attitude information were combined and presented on a cathode-ray tube. Difficulty was encountered in obtaining a glide path at a low enough angle to the ground without serious ground reflections. Lack of suitable high frequency tools imposed further limitations at this time.

In 1942 a complete instrument landing system employing equi-signal techniques in both the localizer and glide path was evolved from the I.T.D. system. This system has been officially adopted by the Civil Aeronautics Administration for civil aviation and by the Army Air Forces for military aviation.

In this system lateral and vertical deviations from the desired flight path were indicated to the pilot on a cross-pointer meter and range information was obtained by three marker beacon transmitters. Localizer, glide path and marker beacon transmitters were required in the aircraft. The localizer transmitter was located on the up-wind end of the runway, the glide path transmitter about 500 feet to either side of the runway and about 800 feet up-wind from the desired touch down point and the markers were located on course at the airport boundary, 4500 feet and 4.5 miles respectively.

The localizer transmitted a modulated carrier from the sideband antenna. The sidebands from the modulated carrier combined with the pure sideband signals in the aircraft receiver and the received modulation pattern was due to the algebraic sum of both patterns. Two overlapping patterns were produced, one modulated at 90 cycles per second and the other modulated at 150 cycles per second. The equi-signal locus of points of these two patterns defined the localizer course.

The glide path which was also an equi-signal path was formed by two antennas one above the other. The upper antenna pattern was modulated at 90 cycles per second and the lower at 150 cycles per second. The design of these antennas was such that the intersection of the lower lobe of the upper antenna and the underside of the lower antenna pattern defined the glide path. This path, which was essentially linear, was adjustable from 2 degrees to 5 degrees with the ground.

The localizer operated on 110 mc. and the glide path on 330 mc. These carriers were obtained by conventional multipliers using crystals in the basic oscillator.

The receivers for the localizer and glide path were of the superheterodyne crystal controlled type. The metering circuit consisted of two band-pass filters (one for 90 cycles per second and the other for 150 cycles per second) and copper oxide rectifiers with a 150-0-150 microampere meter connected across the output to indicate the difference between the 90 cycles per second and 150 cycles per second voltages fed to the filters. The glide path receiver also incorporated an artificial course-softening feature which will be explained later in connection with a microwave landing system. Two small half-wave dipoles served as antennas.

The marker beacons transmitted a vertical pattern from a half-wave dipole a quarter-wave above the ground. The frequency was 75 mc. and each marker was given a distinct identifying modulation.

This system, although adopted as the present-day landing system, has numerous faults. At the frequencies involved the antenna patterns are formed in part by ground reflections. Any antenna system which uses a reflector with a variable dielectric coefficient is bound to have inconsistant patterns. Since the ground is effected by snow, rain and the moisture content of the atmosphere its dielectric coefficient will change effecting the patterns. The characteristics of the glide path will also be a function of the number and type of reflecting objects in the vicinity and the contour and slope of the terrain. Thus the system requires special consideration and compensations for each airport set-up. This likewise makes portable use of one equipment on any one of a number of runways on the same airport impractable. It should be mentioned that the stability and accuracy of the localizer course are quite satisfactory and suffice for present day landing techniques.

It is interesting to note at this point that all of the preceding equipments had one thing in common. The pilot received sufficient information directly on some form of indicating equipment in the plane to permit him to fly a predetermined approach path to the runway. In the later systems the aircraft was required to carry 3 receivers.

In the spring of 1943 the Radiation Laboratory of the Massachusetts Institute of Technology developed a system of landing aircraft which was not restricted to aircraft equipped with special localizer, glide path and marker receivers.

This method of landing aircraft differed from all of the preceding methods. Here sufficient information regarding the position of an aircraft with respect to a predetermined flight path is received by equipment on the ground and the pilot informed by ground personnel as to the course he should fly to bring him down this predetermined path.

The system which falls into this latter category is Radio Set AN/MPN-1A Ground Controlled Approach Radar (GCA). In this equipment accurate and continuous information regarding the location of an aircraft with respect to a predetermined flight path is presented to radar operators as lateral and vertical deviation from the selected approach path and is communicated to the pilot in the form of instructions as to the course he must fly to make the proper approach to the runway.

This equipment consists basically of two complete radar systems. The first is the "search system" consisting of a radar transmitter operating in the S Band of frequencies with a range of 30 miles and providing a 360 degree scan with PPI presentation. The information received by this system is used to locate and identify all aircraft within the search area and funnel them into a specific area off the down-wind end of the runway covered by another radar system. This second system or so-called "precision system" uses a radar transmitter operating in the X Band of frequencies. This system covers an area in space which is 20 degrees wide in azimuth, 7 degrees high in elevation and has a maximum range of 10 miles. It is this equipment which provides the ground control operators with the precise information required to guide the pilot of an aircraft over a proper approach to a runway. The major components of these two systems are duplicated in the form of

Channels A and B.

Perhaps the most unique feature of the equipment is the method of scanning used in the precision system. The antenna system consists of two antennas providing extremely narrow beams, one scanning through 7 degrees in elevation and the other 20 degrees in azimuth. These two antennas are energized alternately by an R.F. switching unit. The elevation antenna consists of a collinear array of 165 dipoles fed by probes extending into a 14 foot section of wave guide whose lateral dimension is variable and located at the focal line of a semi-cylindrical reflector of parabolic cross-section. Due to the phase relationship existing between the radiation from individual dipoles at various points in the field of the antenna, the array is highly directive and energy is radiated in a very narrow beam. If the width of the guide is increased the wavelength of the energy in the guide is decreased and the phase difference between each successive dipole is increased resulting in a shift of the antenna beam toward the load end of the waveguide. The amount of this waveguide variation is sufficient to cause the antenna beam to scan through an angle of 7 degrees. The azimuth antenna consists of a collinear array of 114 dipoles utilizing the same theory and scanning through 20 degrees in azimuth.

The GCA system of landing aircraft is unique in one detail - it can be relied upon to furnish accurate let-down information to all aircraft equipped with a conventional receiver. Since the corrective flight information is given to the pilot aurally, he is not required to observe one other instrument during that part of the flight which requires the most skill. However any system with a voice link has inherent delays - the delay on the ground while the radar operator interprets what he sees, the delay while the pilot interprets what he hears and the delay while the pilot reacts to what he interprets. During the final stage of the landing, these cumulative delays can produce errors of considerable magnitude. These errors in conjunction with the system errors limit the minimum altitude to which the aircraft can be talked down safely.

Simultaneously with the foregoing work and with the development of the klystron the Sperry Gyroscope Company was working on a microwave landing system in the 2600 mc. range. It was reasoned that higher directivity and a vertically tilted type of antenna system would eliminate the problems inherent in the low frequency glide path-localizer systems.

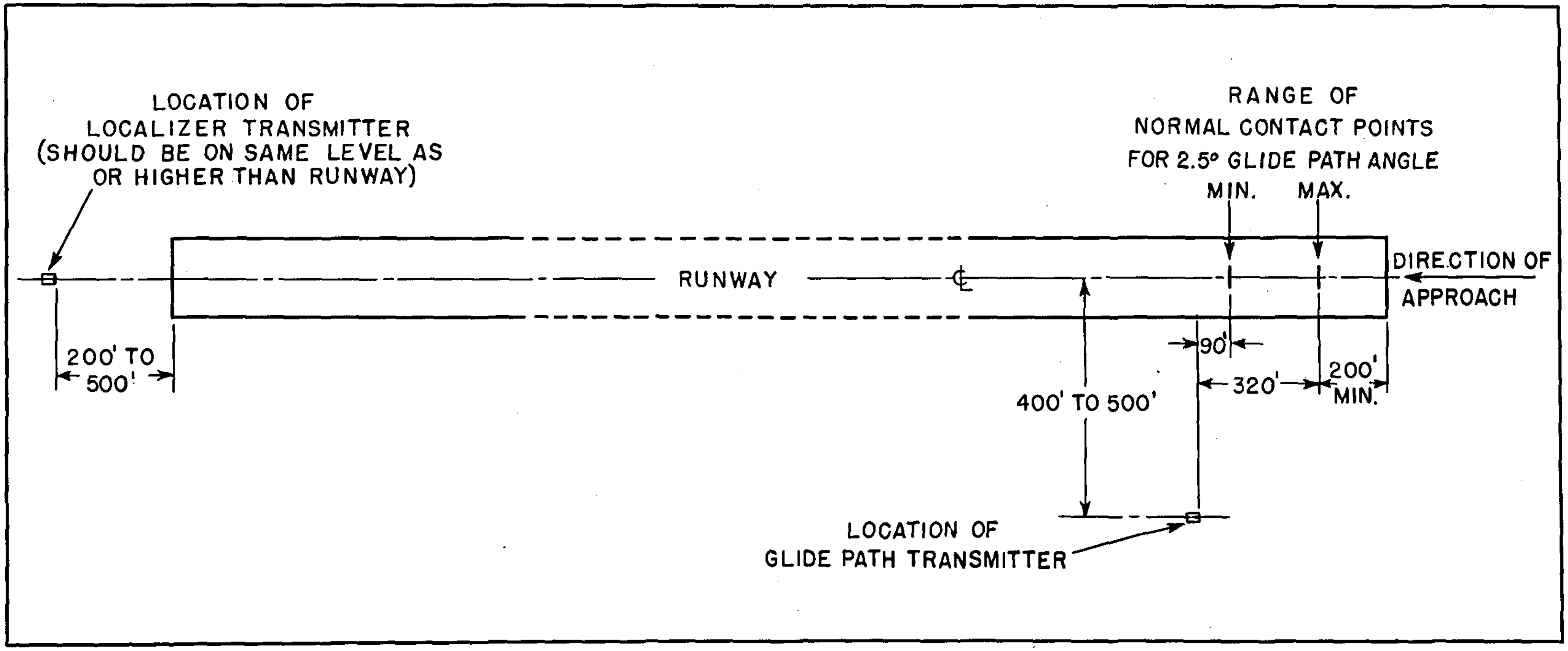
The Sperry Microwave Instrument Landing System 1/ Comprises three main components - two mobile ground transmitters and a receiver which is installed in the aircraft. The two ground transmitters project patterns in space which define the approach path. The glide path transmitter produces essentially a plane tilted at approximately 2.5 degrees to the horizontal while the localizer produces a vertical plane intersecting the center line of the runway and extending in the down-wind direction. The transmitters are located as shown on page 13. The localizer transmitter is placed 200 to 500 feet up-wind of the runway and the glide path transmitter is placed about 500 feet from the down-wind end and 400 to 500 feet to either side of the runway.

The receiving equipment in the aircraft takes the projected information and conveys it to the pilot in the form of visual meter indications.

Glide Path

The glide path transmitter, shown on page 14,

1/ Use of Microwaves for Instrument Landing. Sperry Report by Donald F. Folland, Feb. 13, 1946.

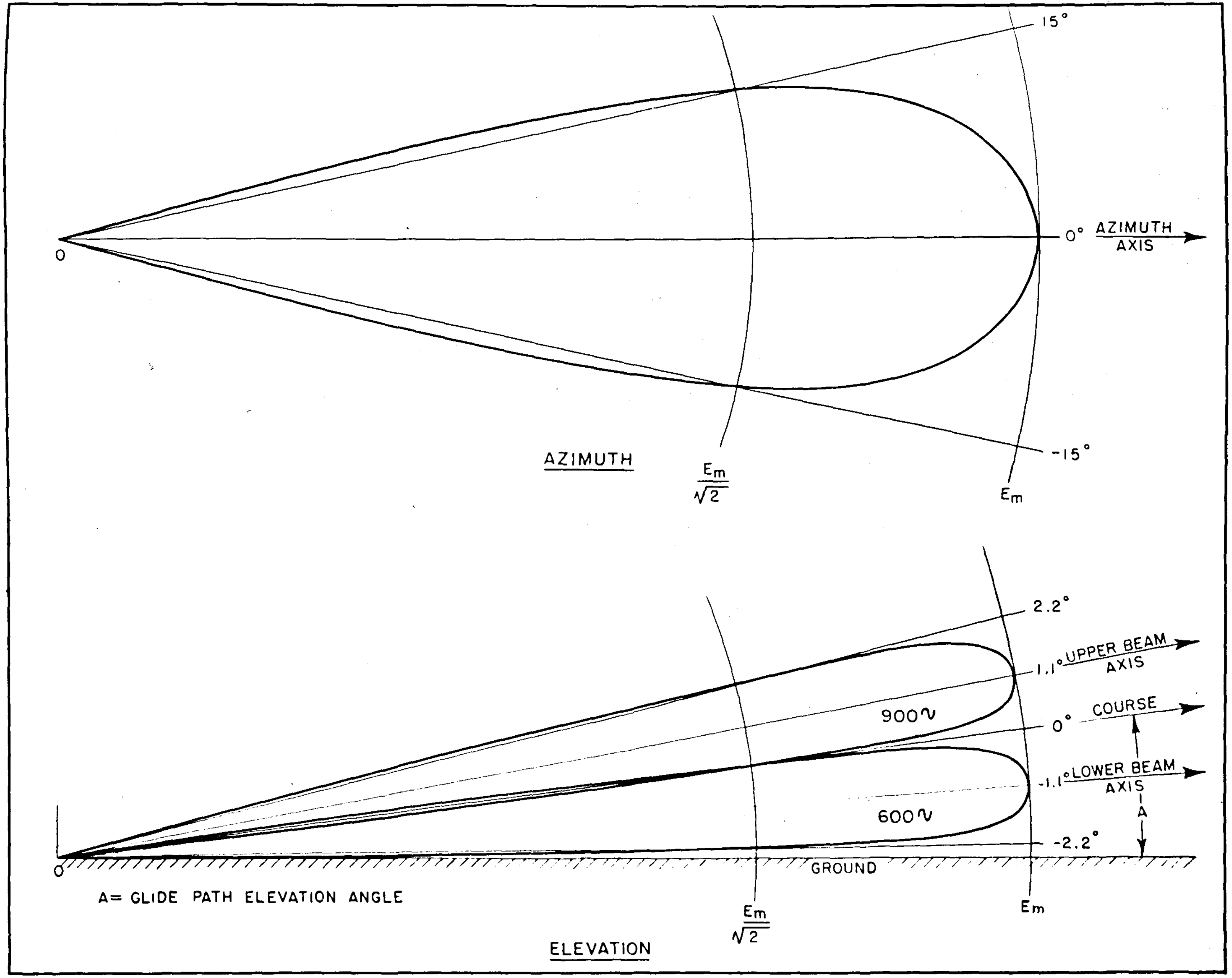

LOCATION OF
LOCALIZER TRANSMITTER
(SHOULD BE ON SAME LEVEL AS
OR HIGHER THAN RUNWAY)
RANGE OF
NORMAL CONTACT POINTS
FOR 2.5° GLIDE PATH ANGLE
MIN.
MAX.
RUNWAY
DIRECTION OF
APPROACH
200' TO
500'
90'
320'
200'
MIN.
400' TO 500'
LOCATION OF
GLIDE PATH TRANSMITTER

GLIDE PATH TRAILER

consists of a crystal controlled transmitter operating at 2617 mc. which feeds a combined mechanical modulator and switch. The output of the modulator is fed into an antenna composed of a cylindrical section of a parabola. The parabola is fed in such a manner that two beams of the desired shape one slightly above the other are transmitted into space (page 16). The intersection of these two beams provides the flat straight line glide path the angle of which will govern the rate of descent of the aircraft. The radio frequency energy in the lower beam is modulated at 600 cycles per second and that in the upper beam is modulated at 900 cycles per second. The actual glide path is produced by the equi-signal intersection of these two beams.

Since the glide path is essentially a straight line, the point of landing will be a function of the height of the aircraft antenna above the ground, the angle of the glide path and the distance the transmitter is from the down-wind end of the runway. Later it will be shown that this is also true at any fixed distance from the runway when the glide path is not a plane but has a flare that varies in a known manner as distance from the transmitter is increased.

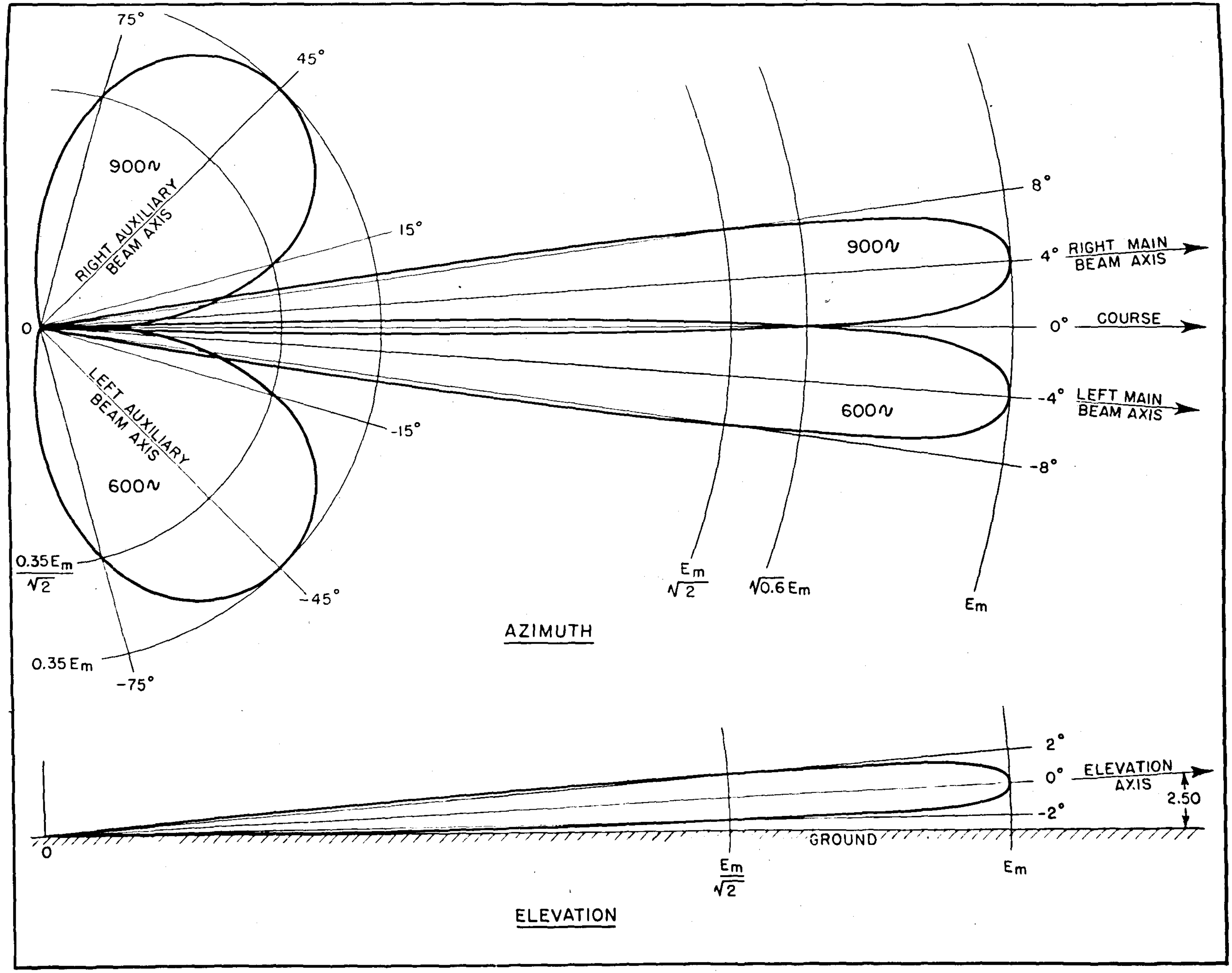
The usable range of the glide path will be limited


15°
0° AZIMUTH AXIS
-15°
O
AZIMUTH
Em/√2
Em
2.2°
1.1° UPPER BEAM AXIS
900∿
0° COURSE
-1.1° LOWER BEAM AXIS
600∿
A
-2.2°
GROUND
O
A= GLIDE PATH ELEVATION ANGLE
Em/√2
Em
ELEVATION

mainly by the maximum altitude at which interception takes place. This in turn will be dependent upon the glide path angle. For an angle of 2.5 degrees a range of 50 miles at 12,000 feet is quite feasable.

Localizer

The localizer transmitter, page 18, is very similer to the glide path transmitter with the exception of the antennas and modulator unit. Since the difference between the two transmitters is only in frequency and in the radiated patterns, many of the components can be interchanged. The localizer frequency of 2640 mc. and the glide path frequency of 2617 mc. permit use of waveguide feeds from transmitter to modulator to antennas. The same theory used to form the glide path pattern is utilized in the localizer. Two distinct beams from a segmented off-set fed parabola are combined to provide a vertical equi-signal plane aligned with the center line of the runway. The beams in this system are uni-directional due to the type of antennas used. This property reduces the possibility of ambiguity inherent in any bi-directional system. As shown on page 19, the radio frequency energy in the left hand beam is modulated at 600 cycles per second and that in the right hand beam is modulated at 900 cycles per second. However, due to the prominence of the side lobes from the main beams it is necessary


75°
45°
900∿
RIGHT AUXILIARY
BEAM AXIS
15°
0
LEFT AUXILIARY
BEAM AXIS
600∿
-15°
0.35 Em / √2
-45°
0.35 Em
-75°
8°
900∿
4° RIGHT MAIN BEAM AXIS
0° COURSE
-4° LEFT MAIN BEAM AXIS
600∿
-8°
Em / √2
√0.6 Em
Em
AZIMUTH
2°
0° ELEVATION AXIS
-2°
2.50
GROUND
0
Em / √2
Em
ELEVATION

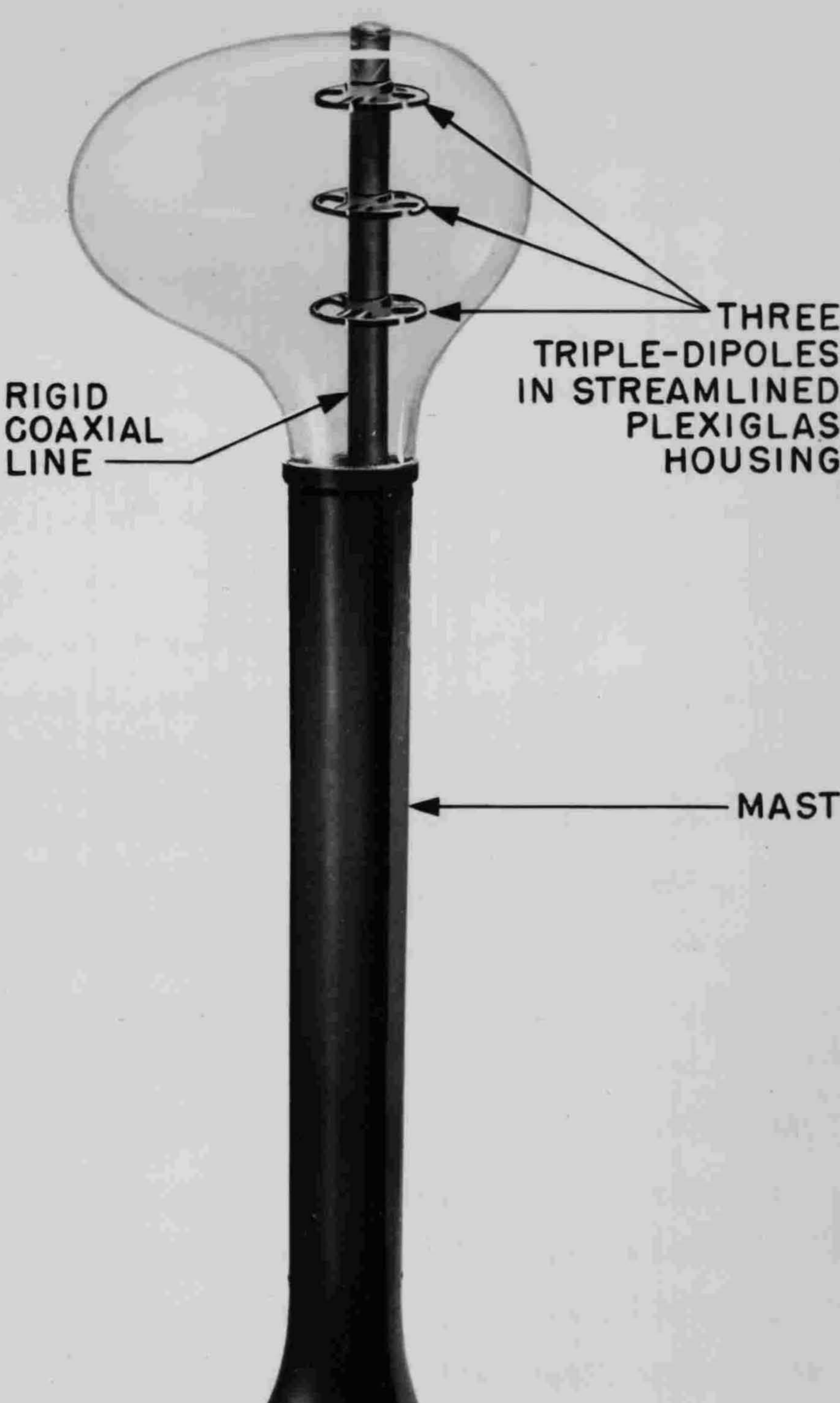
in the localizer to add auxiliary antennas to submerge them. The radio frequency patterns of these auxiliary antennas are also modulated at 600 and 900 cycles per second as shown on page 19.

The localizer antenna structure consists of a six foot paraboloid separated into two sections by a vertical separator, each section being fed by a separate waveguide. Two six foot cylindrical parabolas are located one on each side of the main paraboloid and point at 45 degrees to the center line of the runway.

Since propagation at 2600 mc. is practically linear, the equipment can be set up by optical means alone. By use of a theodolite the localizer can be aligned with the center line of the runway and by means of a calibrated tilting system with liquid levels the glide path trailer can be set at any desired glide path angle from 2.5 to 4 degrees.

Aircraft Receiver

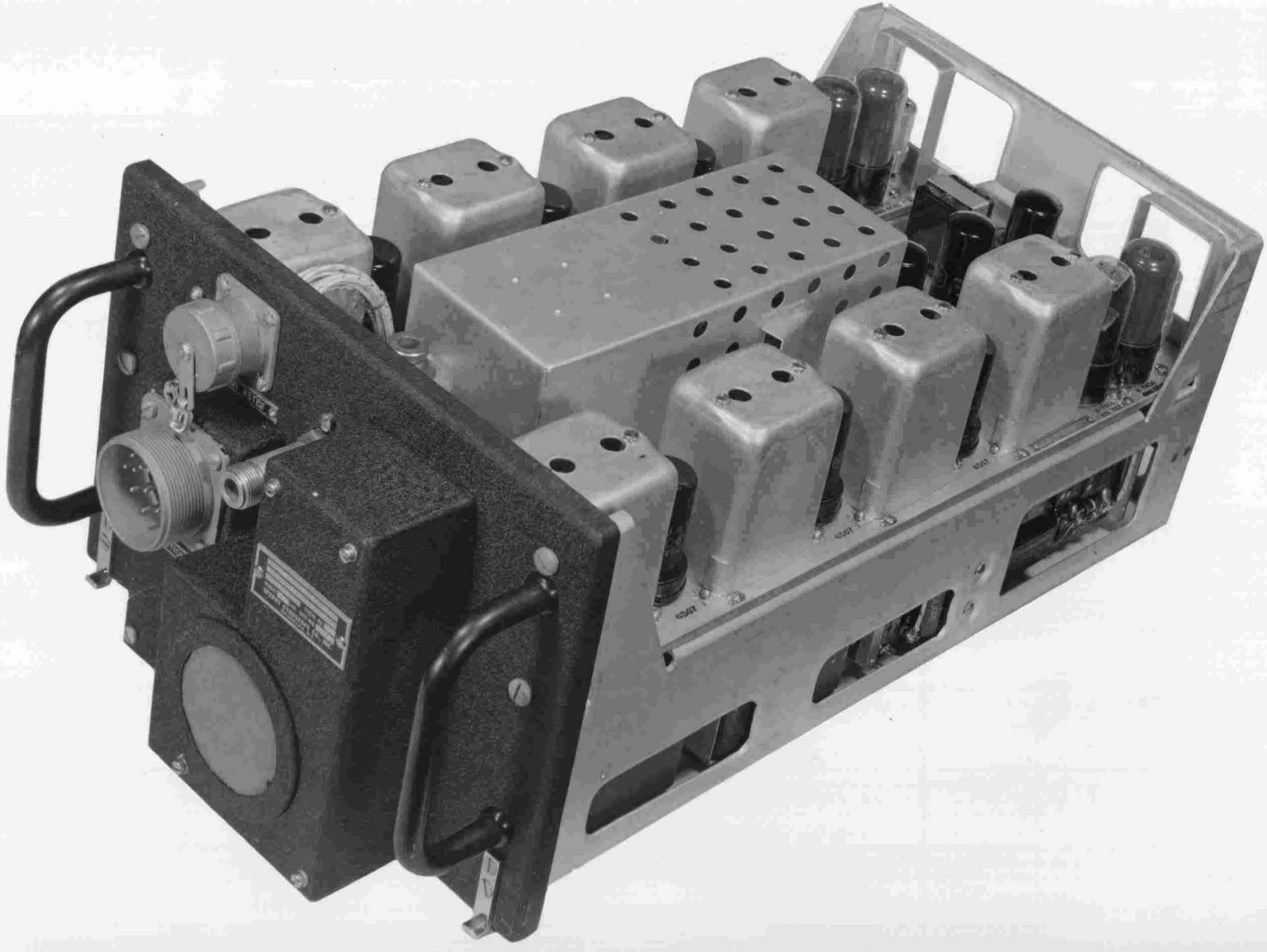
The aircraft equipment consists of a microwave antenna, a receiver, power supply, junction box, control box and a cross-pointer meter totaling 68.5 pounds. The receiver antenna (page 22) is normally mounted on top of the aircraft. This antenna consists of an array of three triple-dipoles spaced half-wave length apart on a rigid coaxial line. The azimuth field pattern

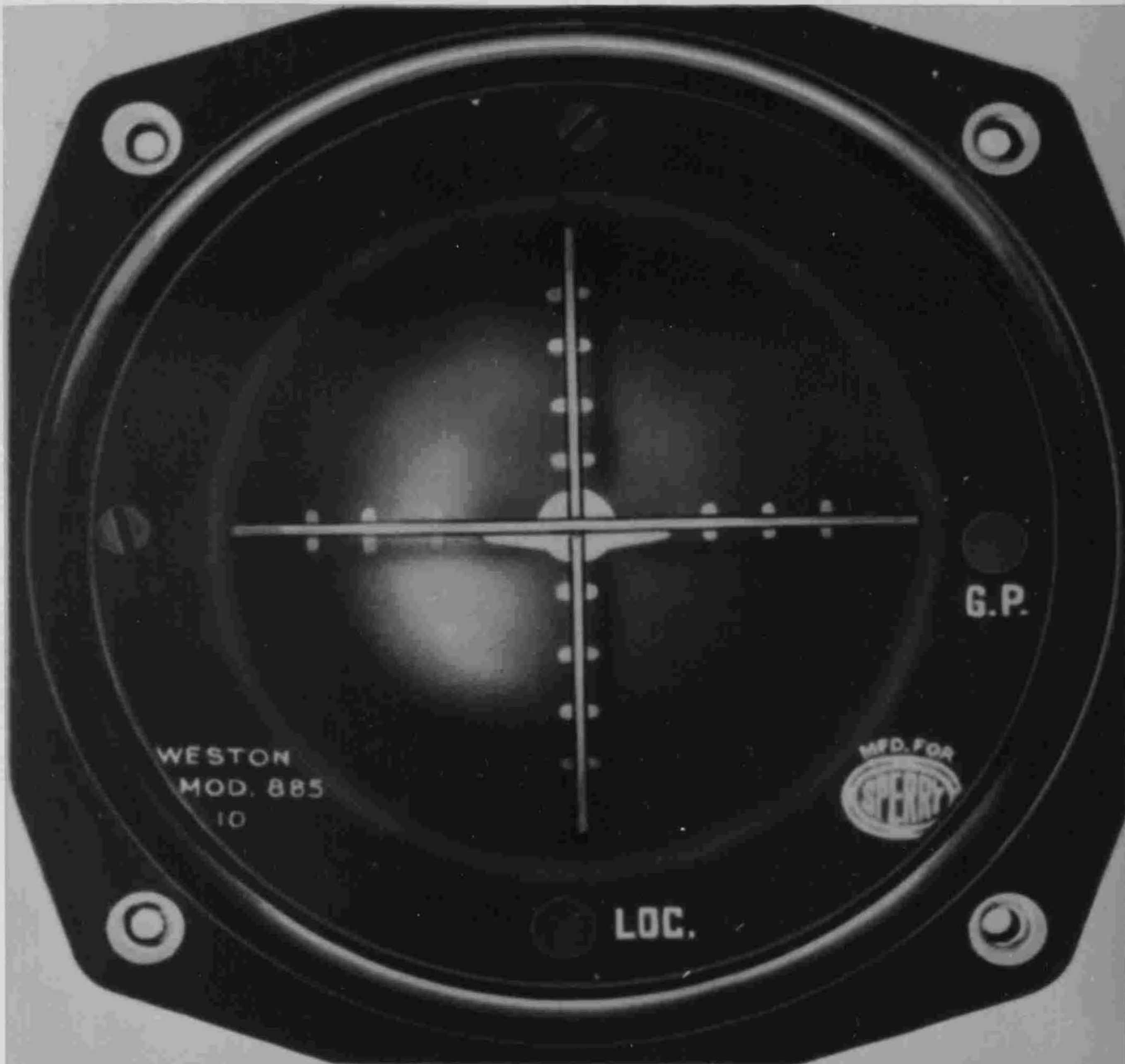

THREE
TRIPLE-DIPOLES
IN STREAMLINED
PLEXIGLAS
HOUSING
RIGID
COAXIAL
LINE
MAST

of the antenna is approximately circular. The elevation pattern is fan shaped and ranges from 22.5 degrees below the horizontal plane to approximately 22.5 degrees above (as measured at the half power points). The antenna has a gain of 3.5 to 5 dicibels over an isotropic radiator (a point source radiating a uniform pattern in all directions). Normal flight attitude changes do not effect the reception of signals. However, a sharp turn which interposes the wing structure between antenna and transmitter will blank out signals.

The aircraft receiver (page 24) is a superheterodyne type and is designed as a single unit with two I.F. channels to receive both localizer and glide path simultaneously. The signals from the two ground stations are detected in a single resonant chamber mixer and amplified in separate I.F. circuits. Provision is made in the receiver for reception of any one of three possible frequencies which the ground transmitting station may have selected. The channel selector switch is located in the control box and operates relays in the receiver unit to switch in the proper crystal for driving the local oscillator at the correct frequency.

The cross-pointer meter, page 25, gives the pilot a




G.P.
WESTON
MOD. 885
10
MFD. FOR
SPERRY
LOC.

visual presentation of the airplanes position in space with respect to the landing path. The vertical needle is actuated by the signals from the localizer and the horizontal needle is actuated by the glide path signals. The intersection of the needles represents the position of the landing path with respect to the aircraft (represented by the small plane fixed in the center of the meter). The pilot always flys the small plane, so to speak, toward the intersection of the needles. An alarm system is incorporated in the receiver. If proper signals are being received from the localizer and glide path transmitter two neon lamps flash on the cross-pointer meter. If signals should fail or become erratic the neon lamps go out.

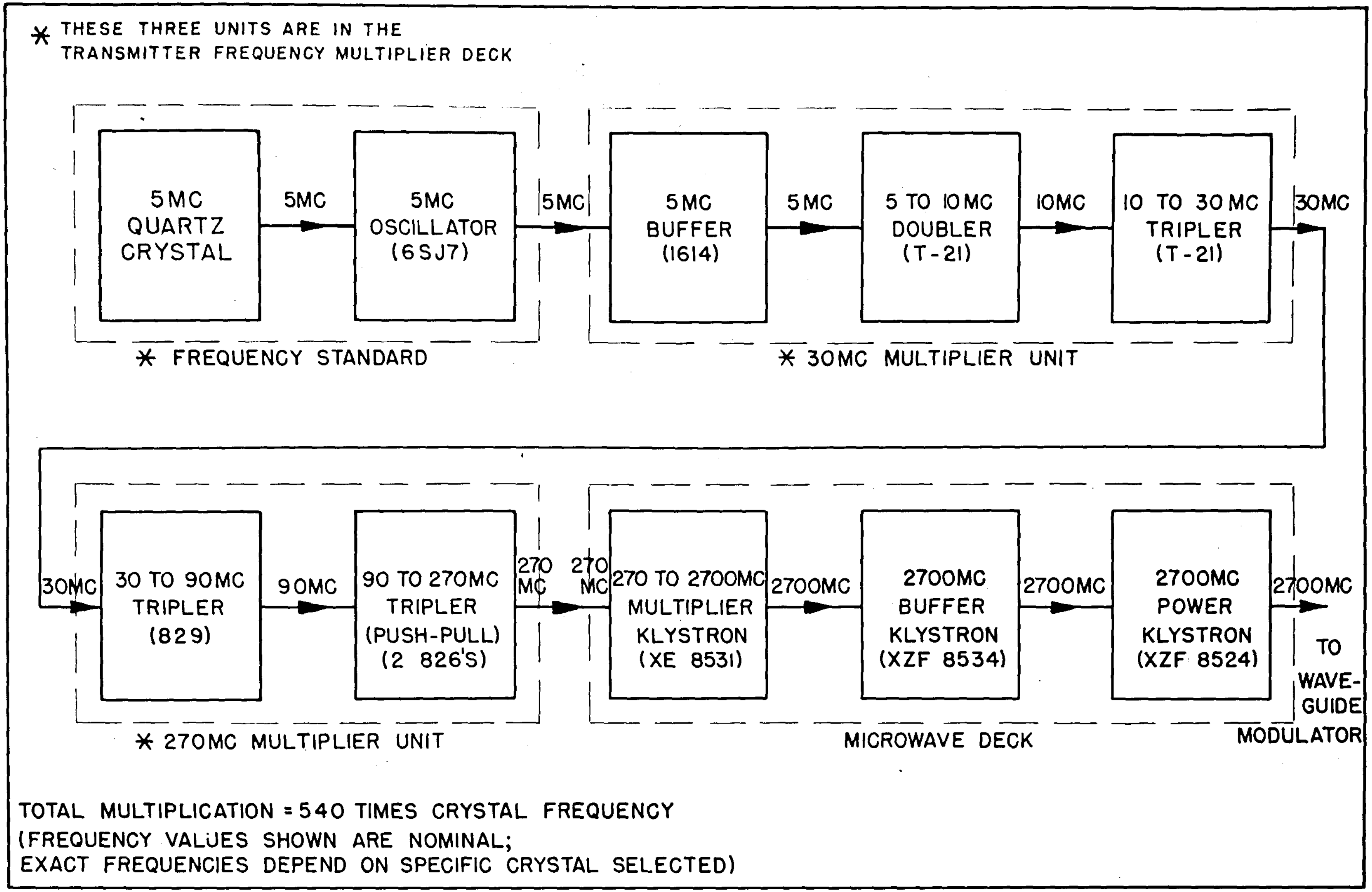
Since marker beacons only provide discontinuous range fixes it is contemplated that continuous range information obtained from proposed distance measuring equipment (DME) will complement the vertical and lateral information of the glide path and localizer giving the pilot an instantaneous three dimensional fix.

II. SPECIFIC DETAILS OF THE SPERRY MICROWAVE SYSTEM

Considering the microwave system in detail the following order will be followed: transmitter, modulator, antennas and receiving equipment. Since the glide path and localizer transmitter are very similar only one shall be considered.

Transmitter

The frequency multiplier deck of the transmitter, page 28, generates the basic R.F. signals, multiplies them is frequency, amplifies them and passes them on to the microwave deck. The basic oscillator uses a 4.87 mc. quartz crystal which is matched to the oscillator circuit. This whole assembly is enclosed in a thermostatically controlled oven. By these means a stability of plus or minus 15 cycles per second or plus or minus .0003% is achieved. The oven contains three crystals which permit operation on any one of three different channels. The output of the oscillator feeds the so-called 30 mc. unit. This chassis contains three tubes. The first is a 1614 which acts as a buffer operating Class A. The second, a T21, operating Class C, doubles the frequency from 5 to 10 mc.; and the third, also a T21 operating Class C, triples the frequency from 10 to 30 mc. The output of this unit feeds another chassis called the 370 mc. multiplier. The first tube on this chassis is an 829


* THESE THREE UNITS ARE IN THE TRANSMITTER FREQUENCY MULTIPLIER DECK
5MC QUARTZ CRYSTAL
5MC
5MC OSCILLATOR (6SJ7)
5MC
5MC BUFFER (1614)
5MC
5 TO 10MC DOUBLER (T-21)
10MC
10 TO 30MC TRIPLER (T-21)
30MC
* FREQUENCY STANDARD
* 30MC MULTIPLIER UNIT
30MC
30 TO 90MC TRIPLER (829)
90MC
90 TO 270MC TRIPLER (PUSH-PULL) (2 826'S)
270 MC
270 MC
270 TO 2700MC MULTIPLIER KLYSTRON (XE 8531)
2700MC
2700MC BUFFER KLYSTRON (XZF 8534)
2700MC
2700MC POWER KLYSTRON (XZF 8524)
2700MC
TO WAVE-GUIDE
MODULATOR
* 270MC MULTIPLIER UNIT
MICROWAVE DECK
TOTAL MULTIPLICATION = 540 TIMES CRYSTAL FREQUENCY
(FREQUENCY VALUES SHOWN ARE NOMINAL; EXACT FREQUENCIES DEPEND ON SPECIFIC CRYSTAL SELECTED)

dual pentode biased for Class C operation which multiplies the frequency from 30 to 90 mc. This signal then drives a pair of 826 tubes which triples the frequency to 270 mc. operating Class C. The output of the 826s is then fed through a coarial line to the so-called microwave deck. Here the 270 mc. power from the frequency multiplier deck is fed to a type XE 8531 klystron multiplier through a flexible coaxial line. This klystron has two resonant cavities, a buncher and a catcher. The input cavity is tuned to 264 mc. (channel A) and the output cavity tuned to 2640 mc. giving a multiplication factor of 10. The 2640 mc. output of the klystron multiplier drives a type XZF 8534 cascade amplifier klystron. This klystron is a three cavity tube having an oxide heater type cathode and operating with 650 to 800 volts on its beam. The output of the tube, about one watt, drives a type XZF 8529 bombarded cathode cascade amplifier klystron providing 100 watts CW power output. The beam voltage of the latter tube is 3750 volts.

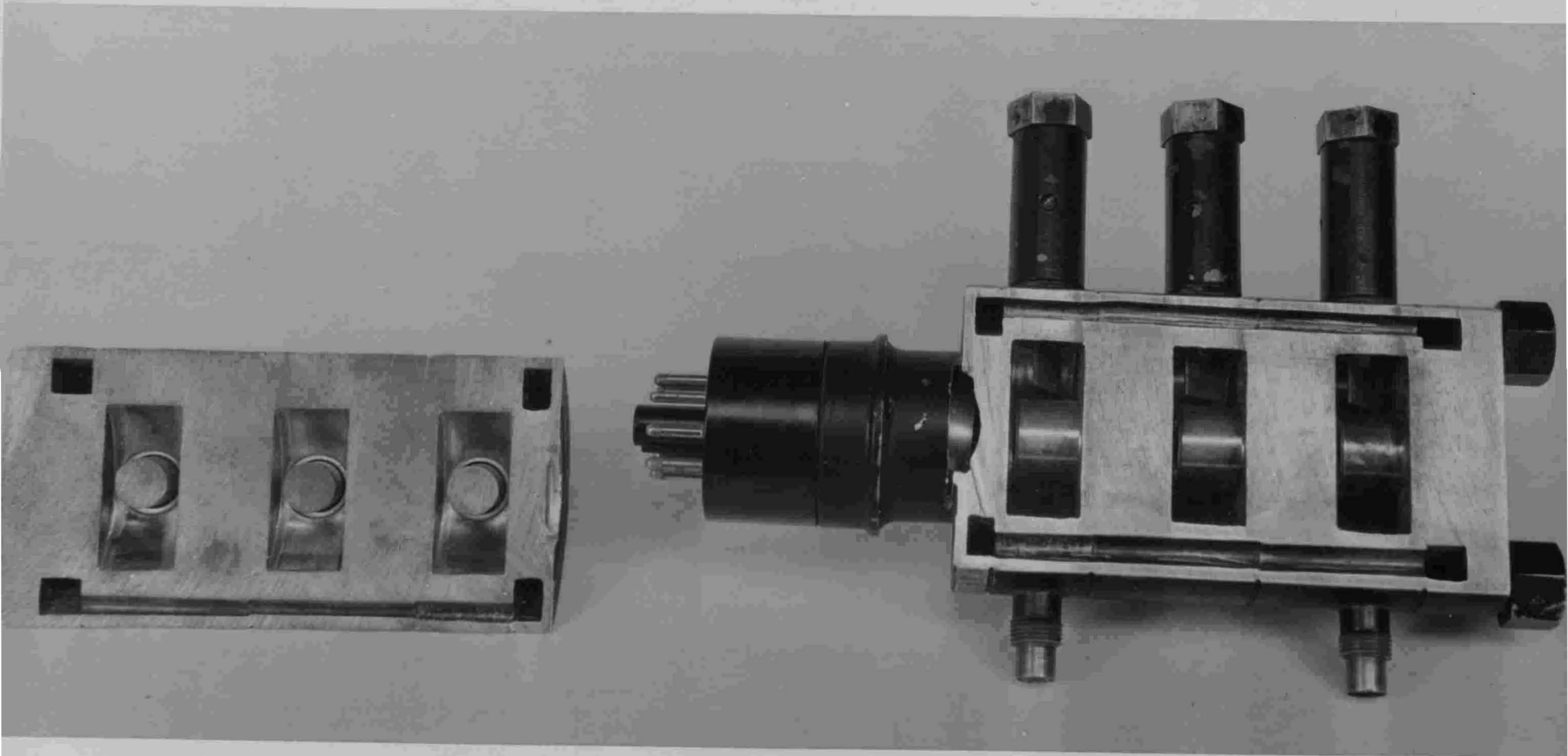
As a measure of safety the shells of the three klystrons are at ground potential. Thus the cathodes are at some negative value below ground. In the XAF 8529 (output klystron) the cathode is approximately 5000 volts below ground.

It should be noted here that the total frequency multiplication of the system is 540 times. The reason for the close tolerance on the quartz crystal in the basic oscillator becomes obvious. A one cycle drift of crystal results in a 540 cycle drift at the microwave frequency.

The output of the final klystron is coupled into a waveguide starting section which is in turn connected to the guide feeding the modulator and antennas. A thermo-couple probe in the starting section acts as a relative-power-out monitor and as a tuner for the final klystron.

The klystrons used in this transmitter are of the narrow band fixed grid type. Tuning is done by means of the paddles which project into the resonant chambers, page 31, and provide a tuning range of plus or minus 15 mc. When the paddle is turned so that it is parallel to the plane surface of the picture eddy currents in the vane neutralize a maximum number of magnetic lines and the resonator is tuned to its highest frequency. Conversely when the vane is turned perpendicular to the picture a minimum number of lines are neutralized and the resonator is tuned to its lowest frequency.

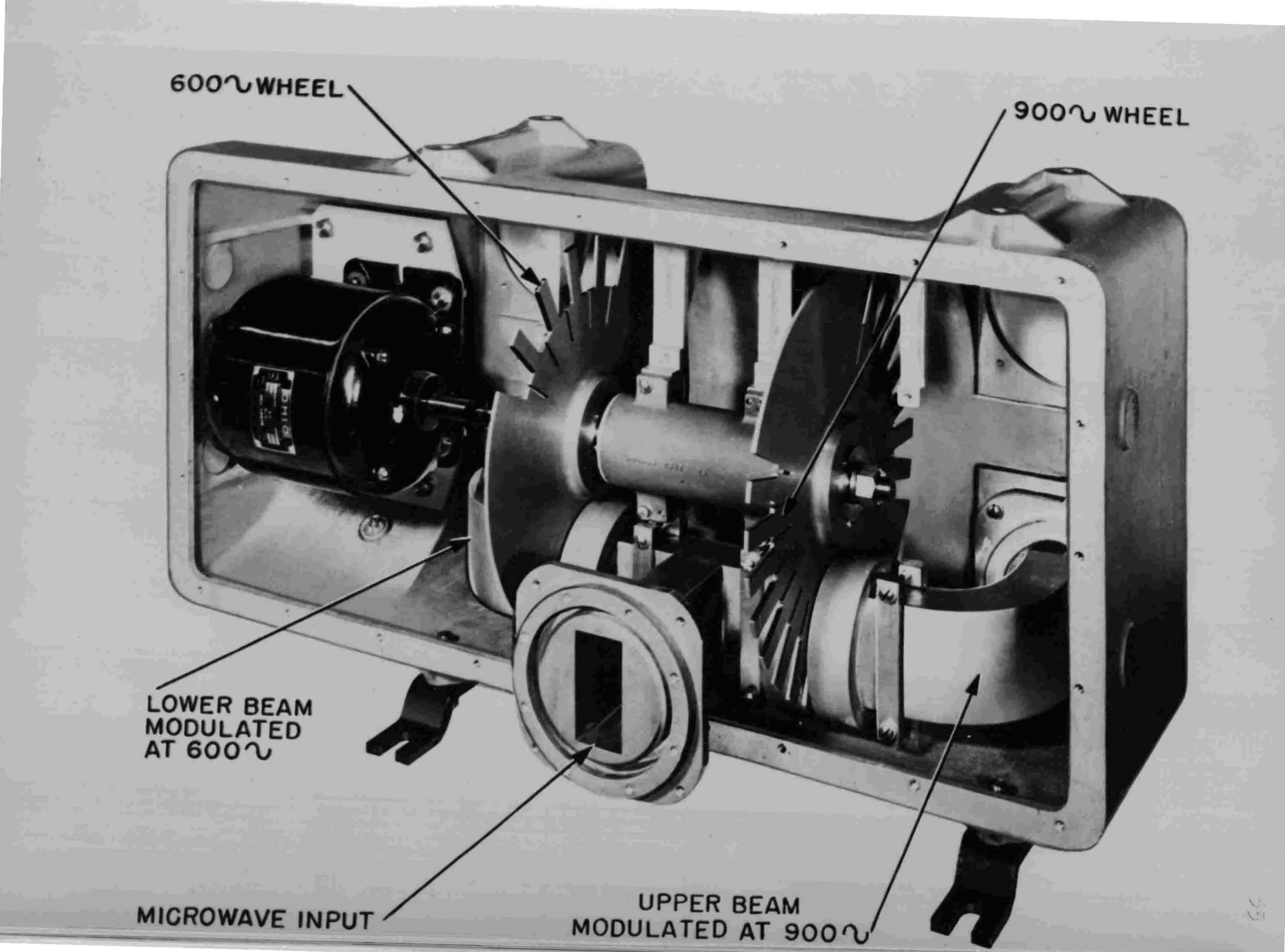
Since the resonant circuits used in these klystrons



are of comparable size to the wavelengths used the klystrons are temperature sensitive. Some means of maintaining the tube at a constant operating temperature must be resorted to. A complete thermostatically controlled cooling system using ethylene glycol solution as a coolant is employed.

Modulator

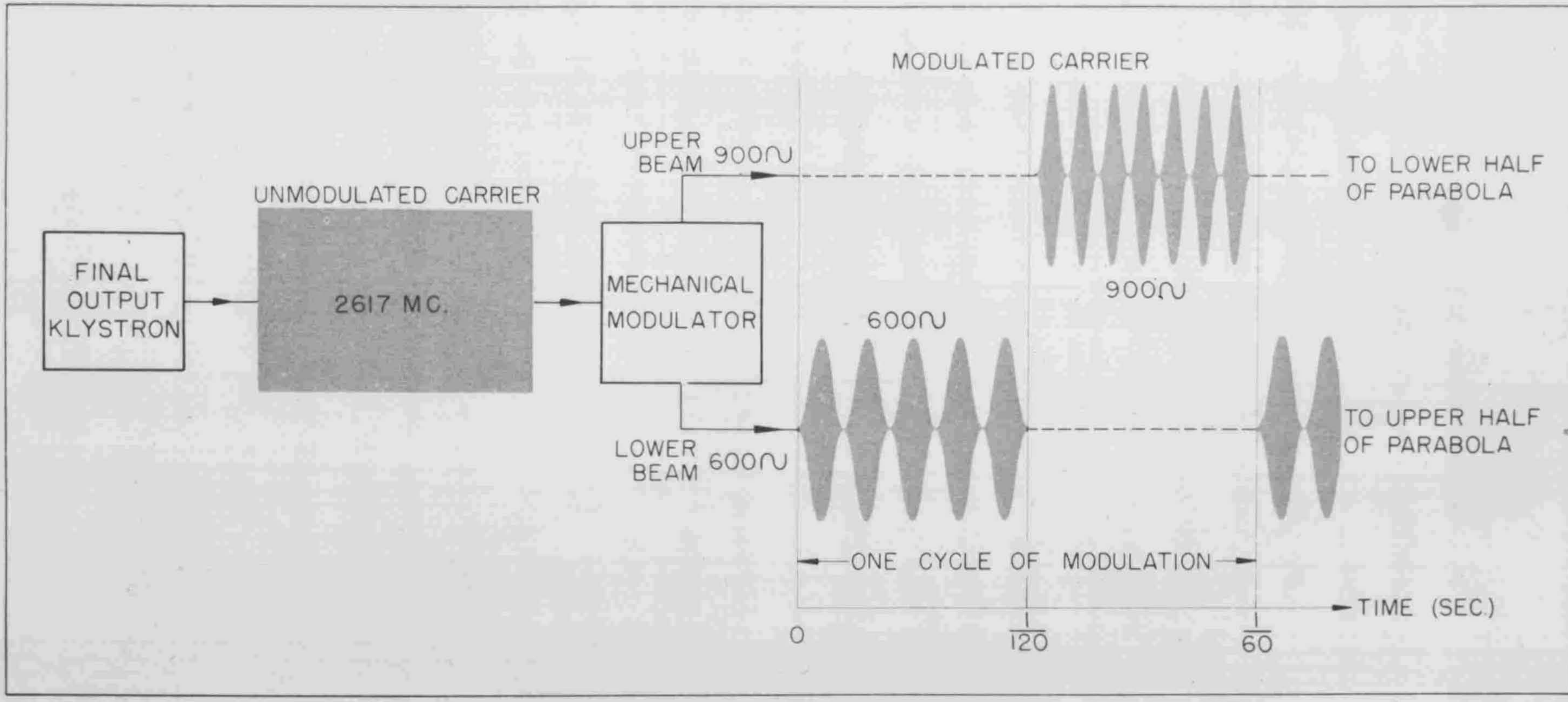
The output of the transmitter goes to the modulator. In order to match the modulator to the output klystron a phase shifter is inserted between the klystron and modulator. Adjustment of this phase shifter will control the shape of the transmitted wave. The modulator is a mechanical unit which varies the amplitude of the transmitted R.F. signal at an audio rate. This modulator, page 33, consists of two metal disks (for the glide path) mounted on a common shaft which is rotated at a constant speed by a synchronous motor. The teeth in the disks permit an alternate opening and closing of the waveguide. When a tooth is blocking the waveguide about 10% of the energy is passed resulting in about 90% modulation of carrier. By suitable shaping of teeth and allowing for fringing, approximate sine-wave modulation is obtained. The number of teeth and the RPM of the synchronous motor determine the audio modulation rate. Frequencies of 600


600∿ WHEEL
900∿ WHEEL
LOWER BEAM MODULATED AT 600∿
MICROWAVE INPUT
UPPER BEAM MODULATED AT 900∿

and 900 cycles per second are used in this system. With this type of modulation the problem of switching from one antenna to another becomes simplified. Referring again to Page 33, a portion of the disk has no teeth cut in it. When this section of the disk is in front of the wave guide slot, no energy is passed down the guide to the antenna. At this time the other disk is passing modulated energy. Thus, the problem of modulating and switching is combined into one (Page 35). Hence at anyone instant one modulated RF beam is being transmitted -- reducing the possibility of interference betwen two beams being transmitted simultaneously. The location of the modulator is such that the microwave energy from the output klystron can vary over a considerable range without effecting the position of the landing path, since all beams will be effected alike.

Antennas.

The glide path antenna, Page 14 consists of a 12 foot by 3 inch parabola fed by two waveguides one above and the other below the focal point. The result is two sharply defined overlapping beams 2.2 degrees wide at the half-power points. This equisignal intersection defines the glide path. The gain of this antenna is 324 or 25.1 decibels above an isotropic radiator.



Glide Path Modulation Patterns

Phase shifters are inserted between modulator and antenna. By properly adjusting these phase shifters feed back from one wave guide to the other is prevented. If feedback is present it will permit 600 cycles per second modulated energy to be radiated from the 900 cycle per second wave guide and vice versa.

The localizer antennas (Pages 18 and 19) as previously explained, radiate four patterns in space. The two main beams are 8 degrees wide at the half power points and have a gain of 890 or 29.5 decibels over an isotropic radiator. The cross-over point of the two main beams is set at $\sqrt{0.6}\ E_{max}$ to obtain correct course sensitivity.

The auxiliary antennas are set at 45 degrees to each side of the main antenna and radiate broad patterns 60 degrees wide measured at the $0.35\ E_{max}/1.414$ point where E_{max} is referred to the main beam. The design of these antennas is such that a gain of 159 or 22 decibels over an isotropic radiator is obtained.

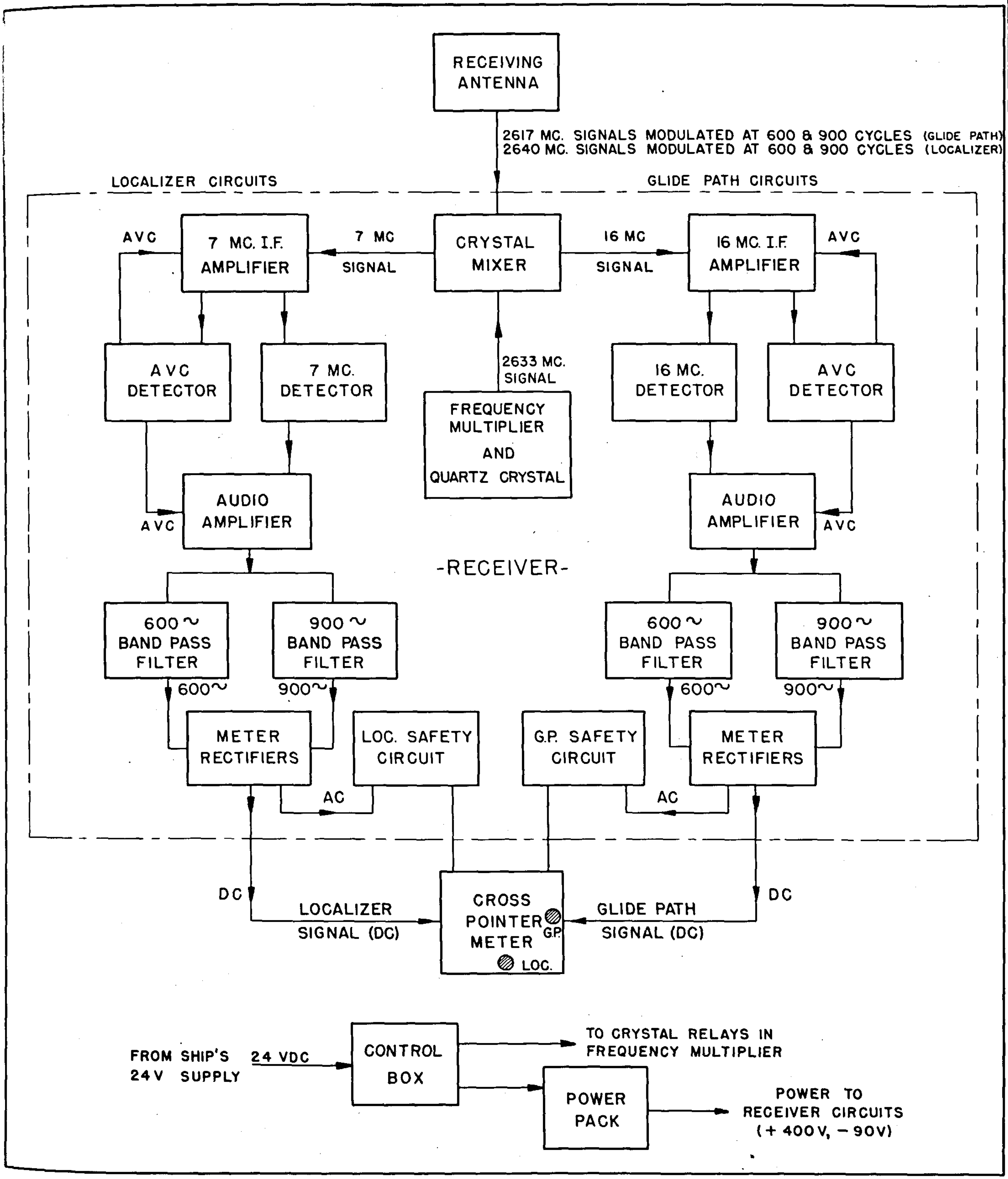
The use of phase shifters in the localizer antenna is not necessary since no two waveguides feed a single antenna and therefore no feedback is possible.

<u>Receiver.</u>

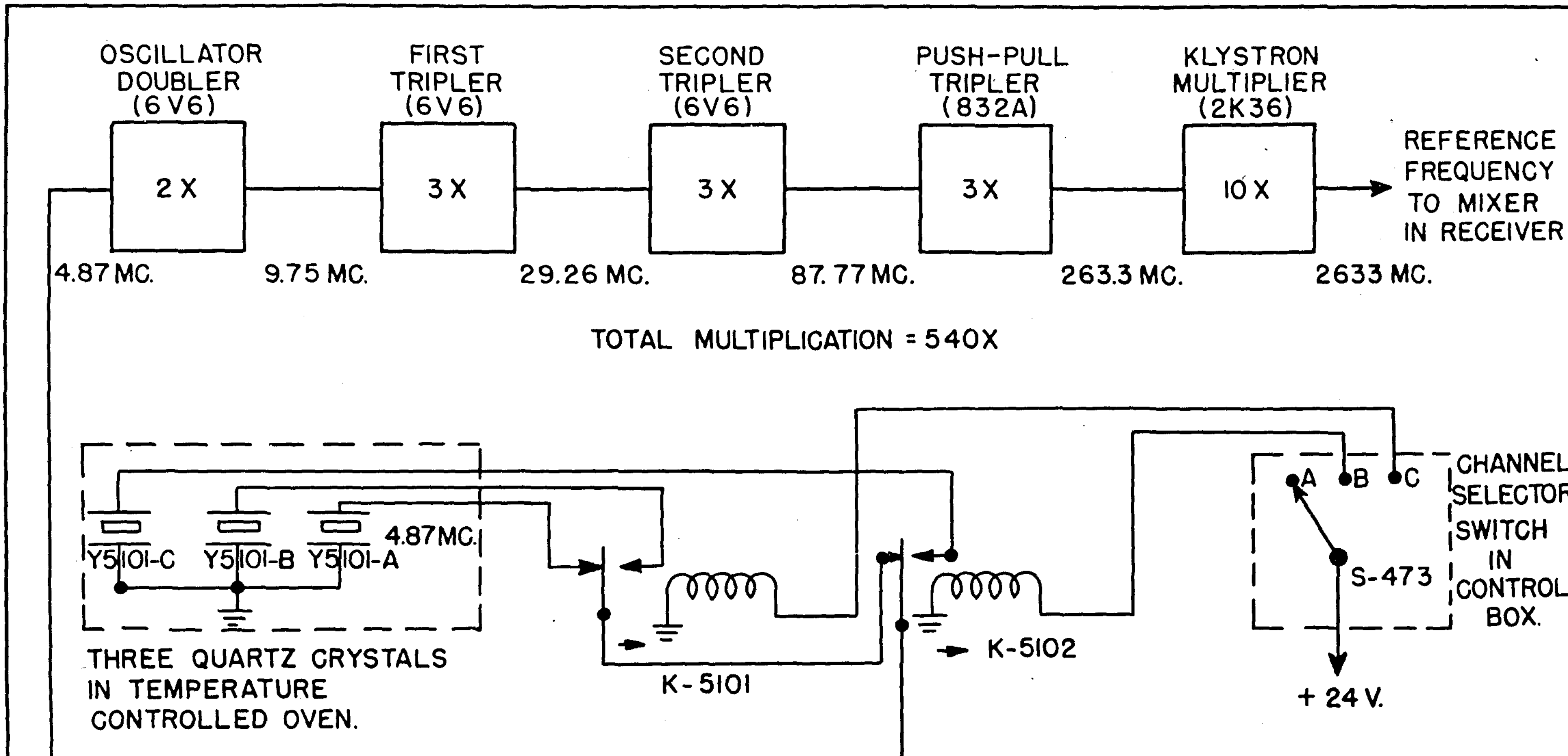
The receiving equipment in the aircraft detects the localizer and glide path signals and presents them to the pilot in the form of meter indications.

Referring to the block diagrams, Page 38, the received signals are coupled into the mixer chamber by a coaxial line which terminates in two probes. The local oscillator frequency is coupled into the cavity by means of a loop. The received signals are combined with the local oscillator signals and the resultant beat frequencies detected. Thus if the localizer and glide path frequencies are 2640 mc and 2617 mc respectfully, and the local oscillator frequency is 2633 mc the resultant beat frequencies of 7 mc and 16 mc will represent the localizer and glide path signals at the input to the IF amplifiers.

The local oscillator, Page 39, has five stages. Any one of three temperature-regulated quartz crystals can be selected depending upon the transmitter channel. These crystals in conjunction with trimmer condensers give a frequency accuracy of plus or minus 50 cycles. By energizing the correct relay the desired crystal is chosen. The first stage uses a 6V6 as an oscillator doubler in which the tank is permeability tuned to the second harmonic (9.75 mc) of the crystal. The second stage consists of a 6V6 tripler with the tank tuned inductively to the third harmonic of the input (29.26 md). The third stage similarly triples to 87.77 mc and its output is transformer-coupled to the third tripler. This stage consists of an 832A beam



BLOCK DIAGRAM OF AIRCRAFT RECEIVING EQUIPMENT


OSCILLATOR DOUBLER (6V6)
2X
FIRST TRIPLER (6V6)
3X
SECOND TRIPLER (6V6)
3X
PUSH-PULL TRIPLER (832A)
3X
KLYSTRON MULTIPLIER (2K36)
10X
REFERENCE FREQUENCY TO MIXER IN RECEIVER
4.87 MC.
9.75 MC.
29.26 MC.
87.77 MC.
263.3 MC.
2633 MC.
TOTAL MULTIPLICATION = 540X
Y5101-C
Y5101-B
Y5101-A
4.87MC.
THREE QUARTZ CRYSTALS IN TEMPERATURE CONTROLLED OVEN.
K-5101
K-5102
A
B
C
S-473
CHANNEL SELECTOR SWITCH IN CONTROL BOX.
+ 24 V.

power amplifier operating in push pull, whose plate circuits are terminated in a short-circuited two wire line tuned to 263.3 mc by a condenser across the line. A short loop couples the energy from the plate tank of the 832A to the input resonator of a 2K36 klystron multiplier. The output resonator of this klystron is tuned to the tenth harmonic of the input cavity (2633 mc). This output is the local oscillator frequency used as a reference in the mixer cavity.

The 7 mc and 16 mc IF signals are passed to two similar IF channels. These channels have three stages of amplification (6SG7S) the output of which is fed to audio and AVC detectors. The AVC detector (one-half of a 6SL7) produces a voltage for biasing the IF and first audio tubes. The audio components of the IF signals are detected by the audio detector (one-half of a 6SL7) and passed to the audio amplifier a 9003 tube followed by a 6V6 tube. The plate circuit of the last audio stage has two band pass filters in series with the plate supply. One filter is tuned to pass at 600 cycles and the other tuned at 900 cycles. The total variation of attenuation through the pass band (between 95% and 105% of center-frequency) does not exceed one decibel and the insertion loss does not exceed 6 decibels. After separation of the 600 and 900 cycle signals they are passed to two similar copper oxide rectifiers connected in opposition. The voltages developed across these rectifiers provide the signals to the cross-pointer meters.

In order to provide a means of knowing when the equipment is operating properly, each channel excites a neon lamp indicator on the cross-pointer meter. Rectified 600 and 800 cycle signals are fed to an amplifier tube which drives a cathode follower normally self-biased to approximately 45 volts betwen its cathode and ground. An audio voltage large enough to cause the cross-pointer meter to read causes the cathode follower to conduct and increase its cathode voltage to a sufficient value to light a neon lamp connected from cathode to ground.

The receiver bandwidth is 250 kc, that is, ± 125 kc. This determines the limit of the frequency variation allowable in the system.

This variation can be broken up as follows,

Transmitter:

Crystal plus or minus .0003 % = ± 15 kc

Safety factor = ± 25 kc

Receiver:

Crystal and local oscillator circuits accurate to ± .001% , = 30 kc

using safety factor of 1.65 = 50 kc

This leaves 50 kc for IF amplifier variation.

III. ANTENNA PROBLEM.

As indicated by the following specifications one of the most difficult problems of any instrument landing system is the design of suitable antennas which will produce the requisite patterns in space.

The specifications which the present system must meet are as follows:

Localizer

1. Any present localizer course shall be defined as a straight line with a minimum accuracy of ± 15 feet or ± 3 mils whichever is the larger.
2. The localizer shall be usable at all angles up to 5 degrees above the horizon.
3. There shall be no false courses within ± 85 degrees of the true course (within limits of paragraph 2).
4. The plane of the localizer on-course indication shall be perpendicular to the ground (within angular limits of paragraph 2)
5. The average localizer sensitivity shall be 5.5 microamperes per mil ± 1 microampere per mil. (A departure from course of ± 1.5 degrees in the horizontal plane will produce full scale fly-left or fly-right meter indication). The sensitivity shall be essen-

tially linear from full scale fly-left to full scale fly-right indications.

6. At all points outside of full scale to full scale course-width up to ± 85 degrees full scale fly-left or full scale fly-right indications shall be obtained.

7. The line of sight range of the localizer shall be 100 miles at azimuth angles up to ± 8 degrees to the course.

Glide Path

1. Any present glide path shall be defined as a straight line with a minimum of accuracy of 0.1 degree (1.78 mils).

2. There shall be no false course below the glide path.

3. Positive fly down indication shall be given by the system between the glide path plane and a plane 5 degrees above the glide path.

4. The average glide path sensitivity shall be 18.5 microamperes per mil ± 2 microamperes per mil (a departure from course of .45° shall produce full scale fly-up or fly-down meter reading). The sensitivity shall be essentially linear from full scale fly-up to full scale fly-down.

5. The range of the glide path when flying on course shall be a minimum of 50 miles.

Two antenna problems shall be considered:

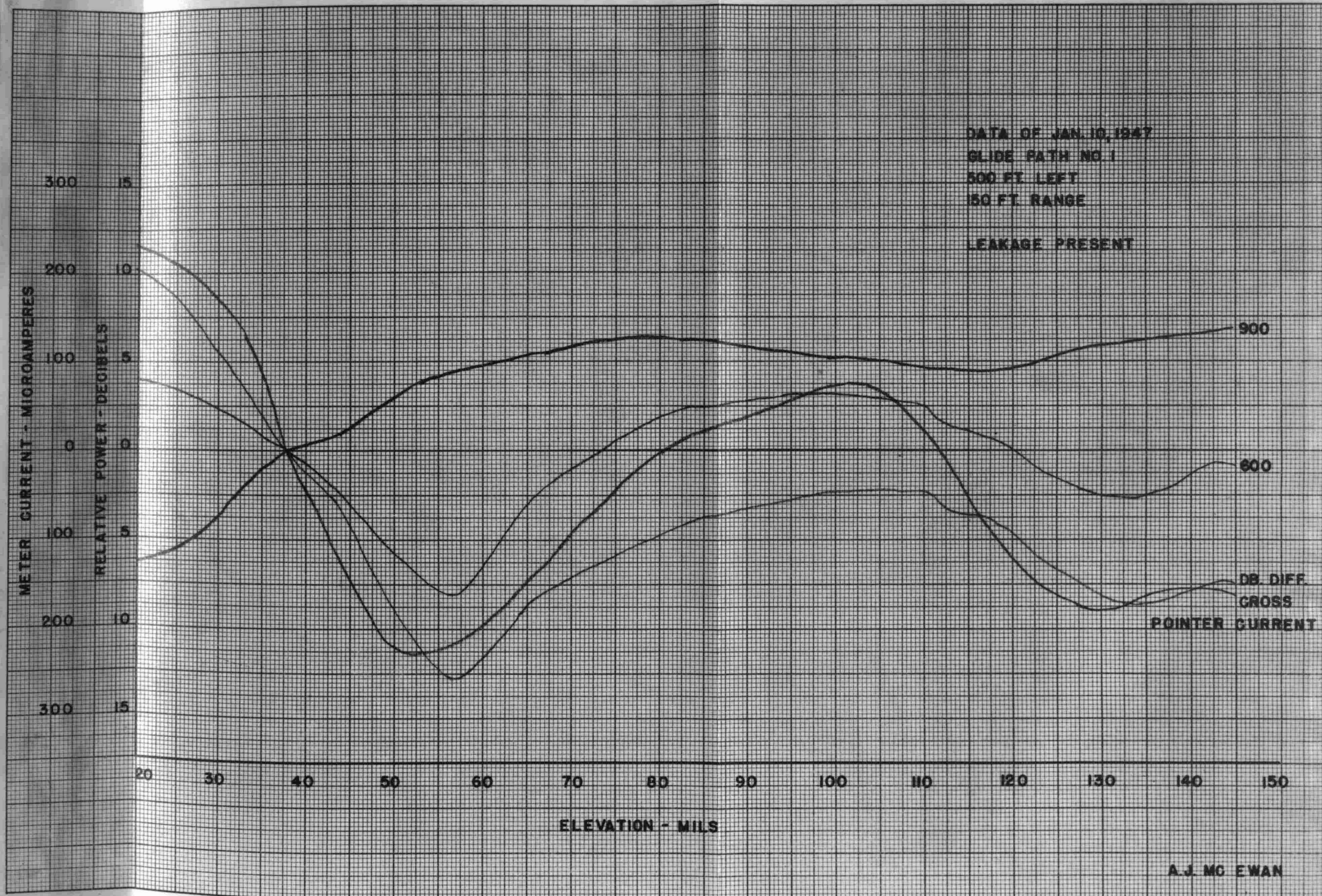
1. An analysis of the glide path patterns to determine if fly-ability of course can be improved and to determine if glide path lends itself to fully automatic landings.
2. Analysis of the localizer antenna patterns to ascertain why paragraphs 3 and 6 in the specifications are not fulfilled.

In order to analize the antenna patterns for the purpose of determing the answers to the preceding problems, field measurements were a requisite. This called for both static and dynamic measurements of the localizer and glide path. Static patterns were taken by measuring the R.F. field pattern using unmodulated CW transmitted from one beam at a time. The dynamic patterns were taken with the modulator running and two or more antennas transmitting.

A grid 500 feet ahead and 500 feet to each side of the glide path trailer was measured off and field strength measurements taken at 50 foot intervals. The measurement equipment consisted of a standard aircraft receiver installed in a mobile unit,(page 45), which towed a 35 foot tower on which was mounted the receiver antenna. This antenna could be moved up and down by means

of a motor drive, Page 47. An Esterline Angus recording unit, Page 48, was used to record both static and dynamic patterns. The recorder was inserted in the plate circuit of the last IF Stage in the receiver in such a manner as to present the same working load to the tube. The recorder measured IF plate current. As the receiver approaches the transmitter the signal strength increases - increasing AVC action and thereby reducing plate current. By suitably calibrating the receiver it is possible to measure relative field strength by intelligently interpreting the IF plate current readings.

Page 49 shows the results of an early glide path rung. Here it is at once apparent that an inconsistency exists. Since the pilots cross-pointer meter reading is a function of the decibel difference between the 600 and 900 cycle patterns the cross-pointer curve and the decibel difference curve should track rather closely and very definately cross the axis at the same point (within accumulated measurement error). Successive runs indicated that this error was alwyas present. By removing the receiver antenna it was found that indications were obtained on the cross-pointer meter as the receiver was moved about in the antenna field indicating direct leakage into the receiver. This would seem off hand as a design limitation of the receiver.



DATA OF JAN. 10, 1947
GLIDE PATH NO. 1
500 FT. LEFT
150 FT. RANGE
LEAKAGE PRESENT
METER CURRENT - MICROAMPERES
RELATIVE POWER - DECIBELS
300
200
100
0
100
200
300
15
10
5
0
5
10
15
900
600
DB. DIFF.
CROSS
POINTER CURRENT
20
30
40
50
60
70
80
90
100
110
120
130
140
150
ELEVATION - MILS
A.J. MC EWAN

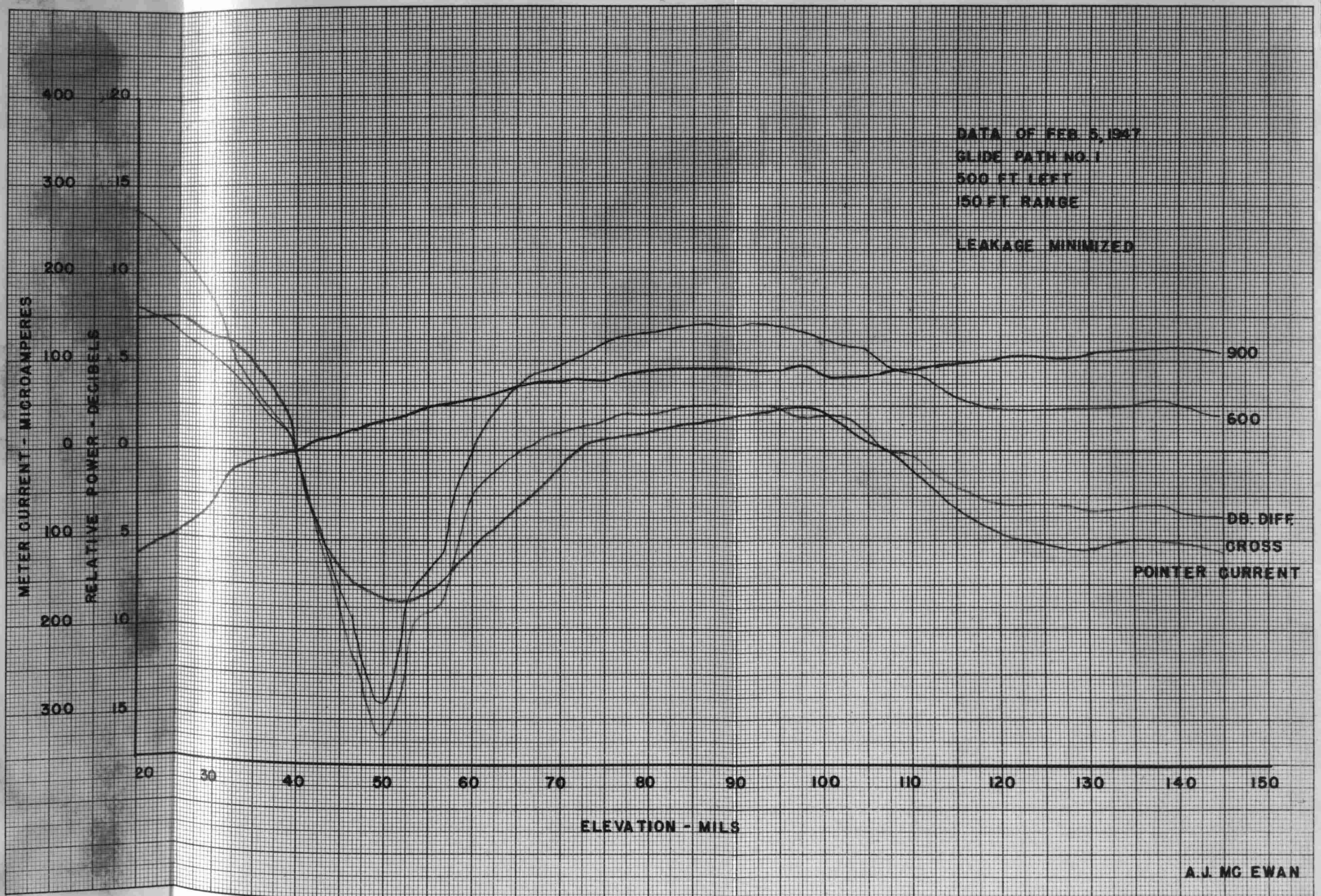
JAN-10

However the two operating conditions are quite different. In an aircraft the receiver is in approximately the same field intensity as the antenna and the receiver shield plus the shielding effect of the fuselage of the aircraft give at least a 70 decibel difference between antenna signal and leakage signal directly into the receiver mixer. In the field test set however, the test conditions were such that it was feasible for the antenna to be in a field 50 to 60 decibels below that in which the receiver was located. Thus the leakage signal can approach in magnitude the signal at the point being measured.

The problem of shielding at 2600 MC was quite interesting. A copper box completely enclosing the receiver and its power supply was not sufficient. The wire mesh used to permit air cooling of the local Oscillator klystron offered a low attenuation path to the leakage field. Because these ventilation holes were necessary, short pieces of circular waveguide were resorted to. Since a circular waveguide below cut-off has an attenuation of approximately 30 decibels per diameter of length, a bunch of guides below cut-off and long enough to give an attenuation of approximately 120 decibels and with an open area sufficient to permit adequate ventilation of the klystron were used, page 52. This effectively brought the leakage down to 90 decibels below signal.

Page 53 shows the results after leakage was minimized. The discrepancy between cross-pointer meter reading and decibel-difference crossover points is due to a number of possible reasons: outright errors in elevation mil-reading, error in metering circuits (Esterline Angus recorder is sluggish and does not follow rapid changes in signal - this is particularly true near the cross-over point), errors in receiver audio circuits (difference between the insertion losses of either the band pass filters or the copper oxide rectifiers will cause the cross-pointer meter to read other than zero when the decibel difference between the 600 and 900 cycle fields is zero).

The curves show that the first cross-over occurs at 40 mils or slightly less than 2.5 degrees. An inverse course (receive fly-up signal when proper correction would be fly-down and vice versa) appears at 72 mils and a false course (correct signals but glide path angle is not desired one) occurs at 107 mils elevation. The fact that the first inverse course is less than 5 degrees above the true glide path is due primarily to the short range (150 feet) at which the run



DATA OF FEB. 5, 1947
GLIDE PATH NO. I
500 FT. LEFT
150 FT. RANGE
LEAKAGE MINIMIZED
METER CURRENT - MICROAMPERES
RELATIVE POWER - DECIBELS
400
300
200
100
0
100
200
300
20
15
10
5
0
5
10
15
900
600
DB. DIFF.
CROSS
POINTER CURRENT
20
30
40
50
60
70
80
90
100
110
120
130
140
150
ELEVATION - MILS
A.J. MC EWAN

was made. At short ranges the beam patterns are not completely formed. Ground tests at increased ranges and flight tests bear out this statement.

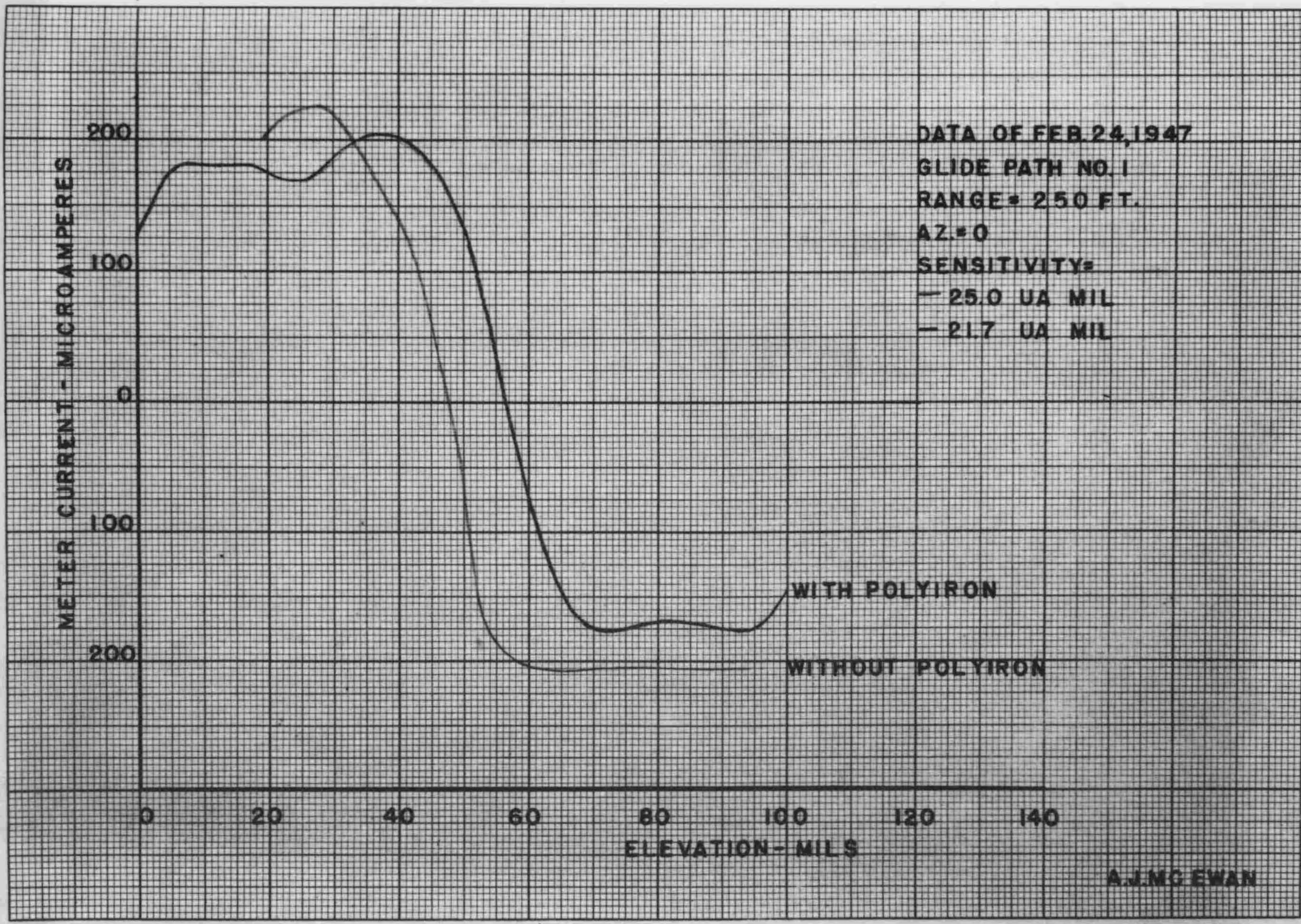
The course sensitivity at this particular point from page 53 is 25 microamperes per mil. This is a more sensitive course to fly than the 18.5 microamperes per mil the specifications call for. The fly ability of a system is a very important factor. It is conceivable to produce a flight path which is so precise that it would be impossible to fly. Thus the course sensitivity gives a direct indication of the fly-ability of the course.

Because it is not possible to match feeds on the glide path without sacrificing course sensitivity the angular course width (minimum off-course angle to produce full scale deflection of cross-pointer needle) cannot be increased beyond .9 degrees. The same antenna is used to form both glide path beams, page 14. Vertical displacement of the beams is obtained by moving the effective source of the 600 and 900 cycle energy, above the focus for the 600 cycle beam and below the focus for the 900 cycle beam. The result is two overlapping beams whose overlap is inversely proportional to the displacement. Considering the sources at the center of the waveguide openings it becomes obvious that the minimum off-set of the sources will be limited by the physical shape of the wave-guides since they are placed one on top of the other. When the guides are in contact with each other a method of further increasing the overlap is to close off part of the wave guide opening which is furthest from the focal point. This has the effect of moving the center of the operture closer to the focal point of the cylindrical parabola thus broadening the course. However this results in a high SWR in the guides feeding the antenna. Attempts to match the antenna to the wave-guide results in changes in course characteristics. With the feeds matched a course width of 6.3 mils was obtained as against 22 mils with unmatched feeds. A course width of perhaps 28 mils would be considered better for manual flight purposes. At the present time a SWR of 1000: 1 is tolerated in order to get the widest course. It should be noticed that there is a limit to widening the course by simple overlapping of the beams. As overlapping increases, the angle between the course and the first inverse course decreases, resulting in poor angular coverage of the system.

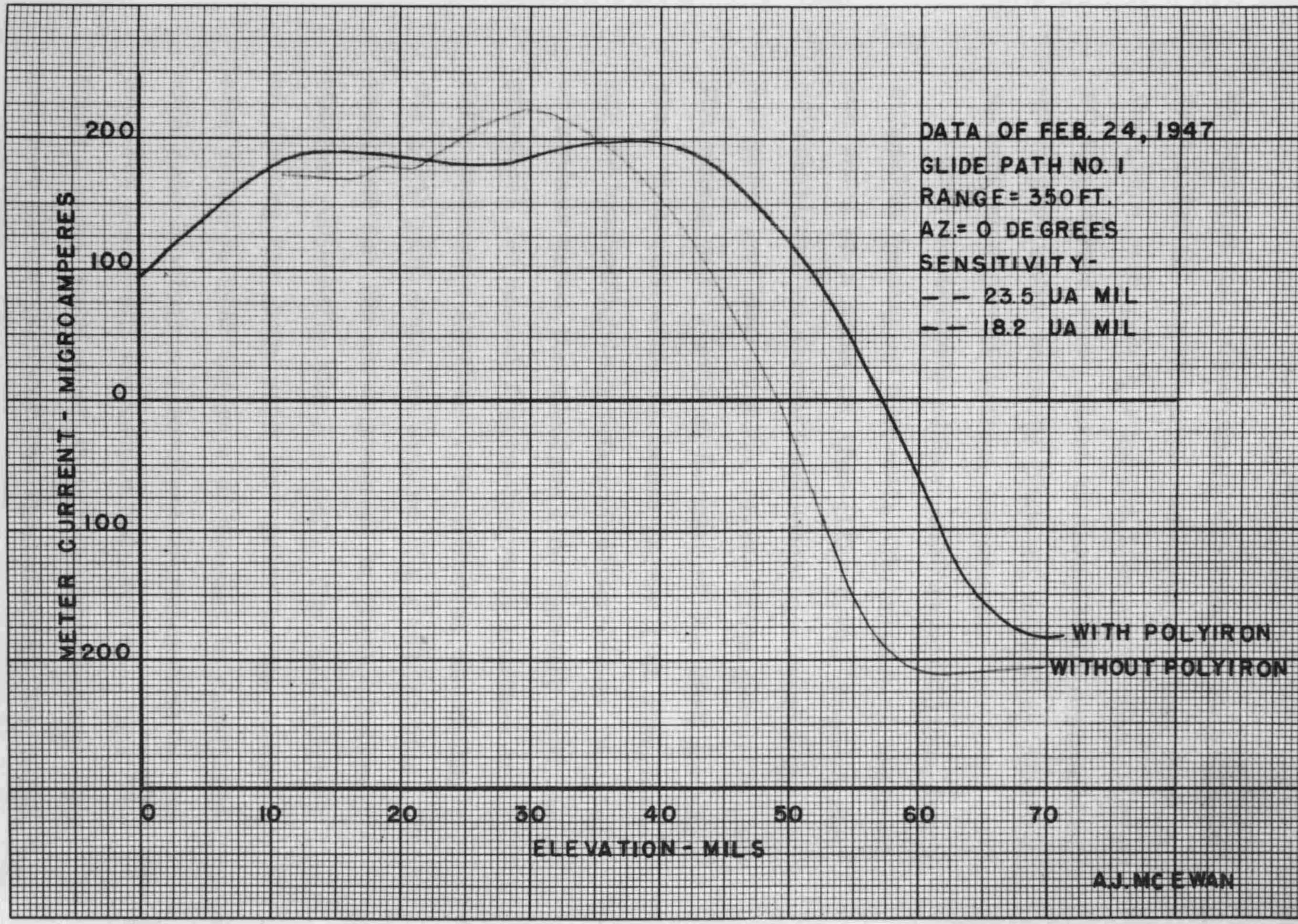
The question then arises converning the possible effects on the antenna patterns caused by currents flowing on the outside face of the waveguide window.

It is obvious that any currents flowing on the face will cause a different effective excitation across the aperture of the wave guide. Since it is very difficult to tie down the exact magnitude and direction of these currents, an empirical approach was considered. Runs were then taken with a polyiron slug on the outside surface of the waveguide window. The idea of the slug being to absorb any radiated energy caused by these supposed currents on the guide window. Pages 57 and 58 show the comparative results. It is noted that in both cases the course sensitivity decreased; in one case 3.3 microamperes per mil and in the other case 5.3 microamperes per mil. This seemingly small decrease is significant when the foregoing problem of waveguide spacing is considered. The change in course cross-over point indicates the decided effects of the polyiron slugs on the main beams. This decrease in course sensitivity indicates that the currents which flow on the face of the window are of such a magnitude and direction that they tend to increase the distance of the effective sources from the focal point of the parabola decreasing the overlap of the beams.

A comprehensive picture of the glide path formed as a result of all of the field measurements indicated that the glide path was not a plane surface

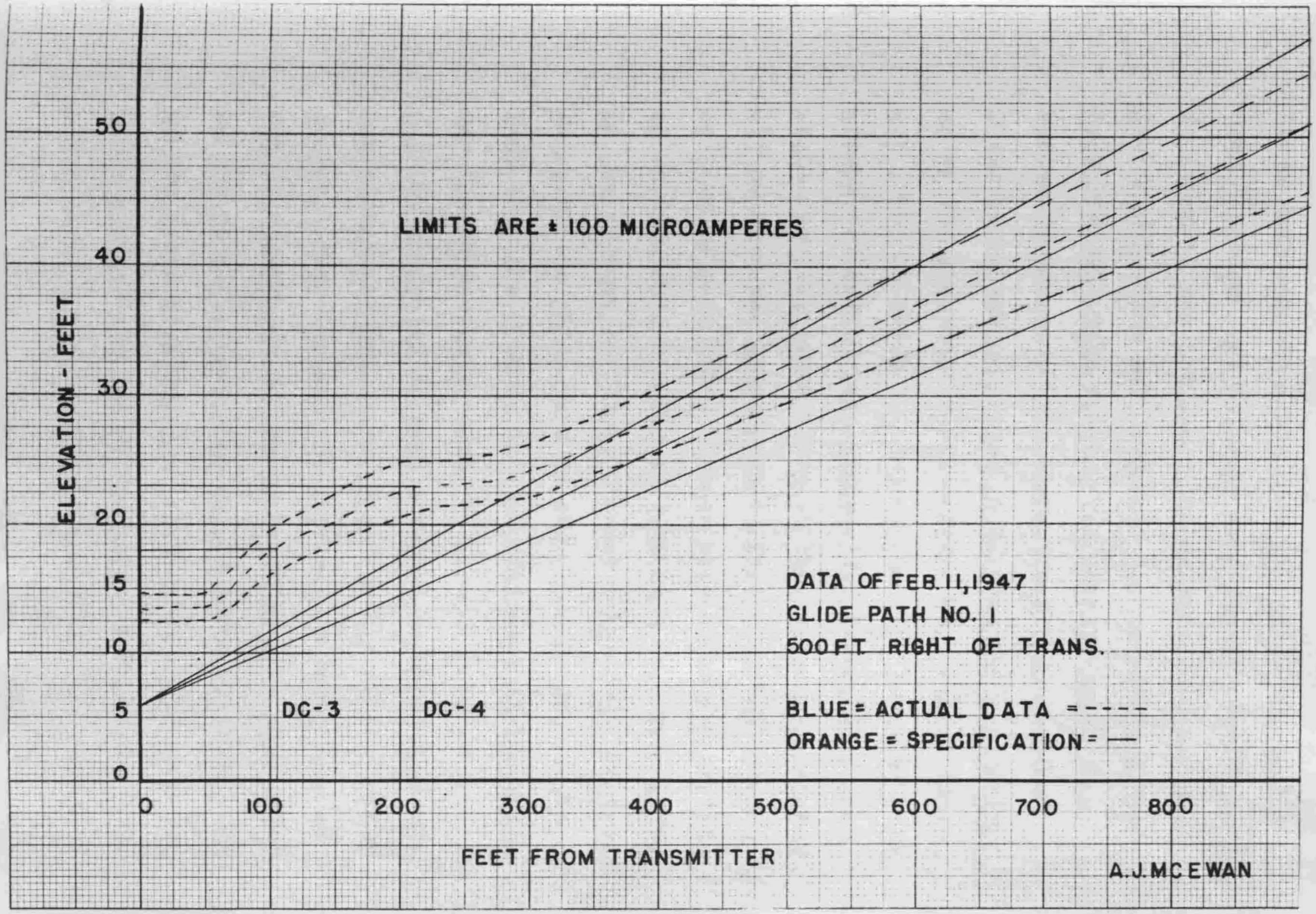


DATA OF FEB. 24, 1947
GLIDE PATH NO. 1
RANGE = 250 FT.
AZ. = 0
SENSITIVITY =
— 25.0 UA MIL
— 21.7 UA MIL
WITH POLYIRON
WITHOUT POLYIRON
METER CURRENT - MICROAMPERES
200
100
0
100
200
0
20
40
60
80
100
120
140
ELEVATION - MILS
A.J. MC EWAN


DATA OF FEB. 24, 1947
GLIDE PATH NO. 1
RANGE = 350 FT.
AZ. = 0 DEGREES
SENSITIVITY -
— — 23.5 UA MIL
— — 18.2 UA MIL
METER CURRENT - MICROAMPERES
200
100
0
100
200
0
10
20
30
40
50
60
70
ELEVATION - MILS
WITH POLYIRON
WITHOUT POLYIRON
A.J. MC EWAN

as supposed but turned up at the ends at the right and left sides of the antenna. Vertical sections through the glide path gave a straight line glide path in front of the antenna (very close to theoretical expectation) and a part which began to flare at the end as distance to left or right of antenna increased.

This immediately offers great possibilities for automatic landing of aircraft. The system as designed was based on a straight line glide path. From simple calculations, an aircraft approaching a runway at 110 miles per hour on a 2.5 degree glide path will hit the runway with a rate of descent of 420 feet per minute. This rate with the added factor that the pilot may be bracketing in a downward direction at the line of contact makes the straight line approach path impractical for manual fly-to-touchdown landings or fully automatic landings (the method of decreasing the glide path angle to utilize the straight line technique for the above purposes is limited by obstacles surrounding the airport). The possibility of flaring the glide path just prior to the touchdown point so that the rate of descent is compatible with safe landings has received consideration in the past but has never adequately been solved. Page 60 shows a cross section of the glide path at a position 500 feet to the right of the transmitter. The solid


LIMITS ARE ± 100 MICROAMPERES
ELEVATION - FEET
50
40
30
20
15
10
5
0
DC-3
DC-4
0
100
200
300
400
500
600
700
800
FEET FROM TRANSMITTER
DATA OF FEB. 11, 1947
GLIDE PATH NO. 1
500 FT. RIGHT OF TRANS.
BLUE = ACTUAL DATA = - - - -
ORANGE = SPECIFICATION = —
A. J. MC EWAN

lines indicate the glide path as called for in the specifications and which is very nearly true directly in front of the antenna. The dotted lines indicate the actual glide path 500 feet to the right of the transmitter. This flaring can be attributed to a number of reasons: the theoretical lines assume plane beams and no ground reflection while actually since the parabola is fed off-center, conical beams are produced which in conjunction with very definite ground reflection help produce the flare; when the angle from the center line of the antenna approaches 45° or more the glide path is formed by the intersection of side lobes - these side lobes are affected more by second order effects such as irregularity in the antenna or slight off-set of feeds. The broadening of the glide path in elevation is due to the fact that the antenna is less efficient at its edges for the elevation pattern.

As indicated on page 60 a DC-4 (4 engined aircraft) has an antenna height of approximately 23 feet above ground. This permits the aircraft to touch down at 225 feet in front of the transmitter at a time prior to the possible reception of a fly-down signal. This is the required case.

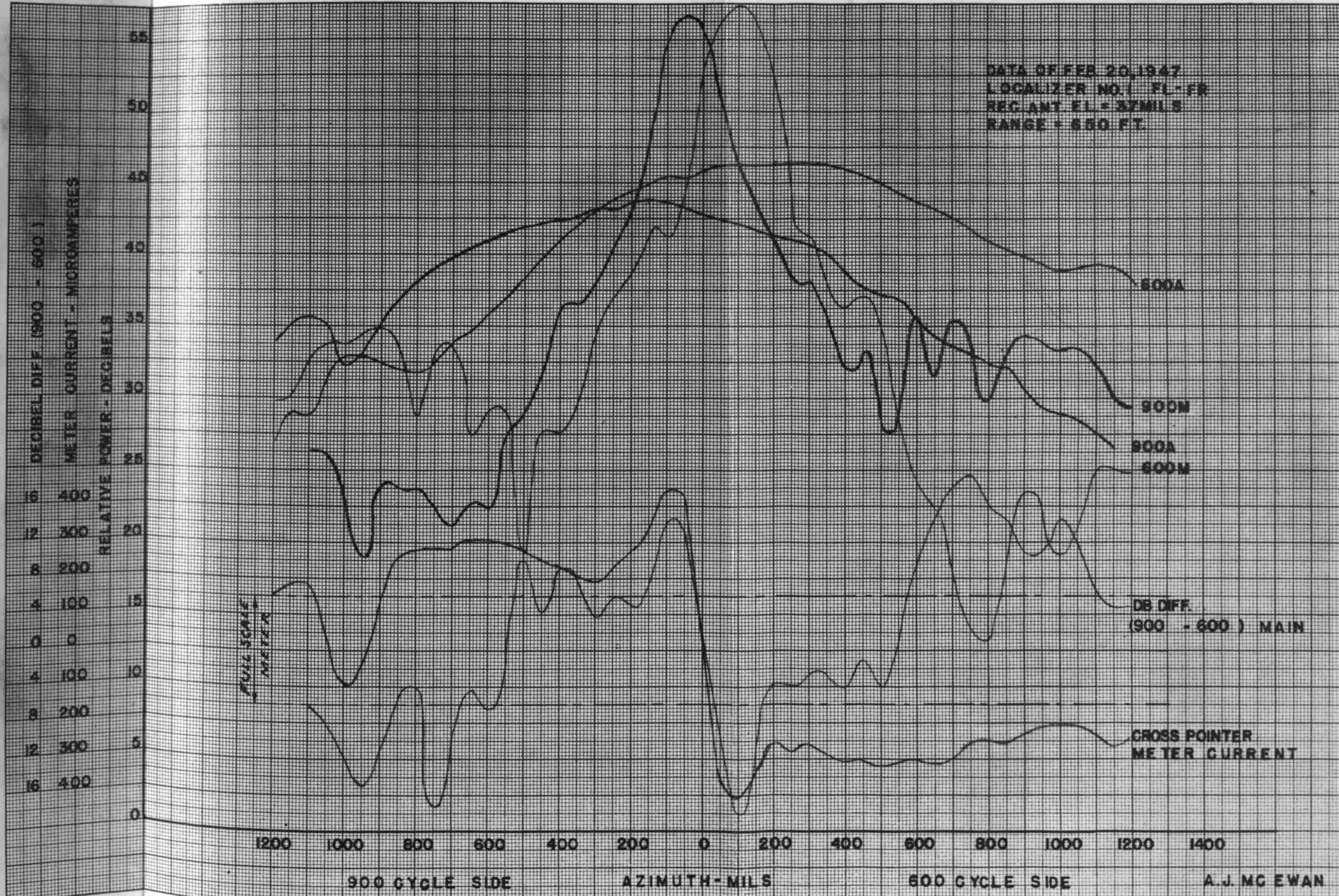
However, for a DC-3 (2 engined aircraft) the antenna height is only 18 feet and the point of touchdown is 115 feet in front of the transmitter. Here it is seen that after the aircraft has flared off and before it has touched the runway a very decided fly-down signal is received. This would tend to produce high stresses on the landing gear and is not conducive to smooth landings. A continuous fly-down signal is however essential for a certain tire after contact with the runway if automatic landing is desired. Since the application of fully automatic landing would most probably be applied to the larger aircrafts perhaps this would not be too great a problem to overcome. However, difficulty becomes evident when operating at great distances to the left or right of the transmitter in order to utilize this flare. As the angle from the center line of the antenna increases to the left or right the tilt of the beams approaches zero. Half of the energy is radiated into the ground and the beams are very much distorted. The result is two interweaving beams with sufficient intersections to cause rapid fluctuation of the cross-pointer meter. As the glide path angle increases the aircraft lands closer to the radiator and the azimuth angle of the point of contact approaches 90 degrees. Hence the duration of the fly-down indication becomes shorter and shorter.

The evidence of flare was observed only on three systems. The consistancy of such a flare and the possibility of reproducing it in successive equipments is questionable and only after many field tests with and without ground reflection effects could sufficient data be obtained to prove the feasibility of its use for completely automatic landings.

Localizer

The localizer field measurements were made by making runs perpendicular to the localizer course and recording 600 cycle auxiliary and main beams, 900 cycle auxiliary and main beams and cross-pointer meter current readings.

An ideal cross-pointer curve would be one that gave full scale readings to ± 85 degrees of the localizer course, no false or inverse course within this region and a linear change through zero as the localizer course was crossed. Page 64 shows the RF patterns of the four localizer antennas and the resulting cross-pointer meter readings. These patterns show that the first two main beam side lobes on each side are at least 12 to 15 decibels down from the main beams. Due to the partition in the main disk, Page 18 the beams are not symetrical, resulting in the minor

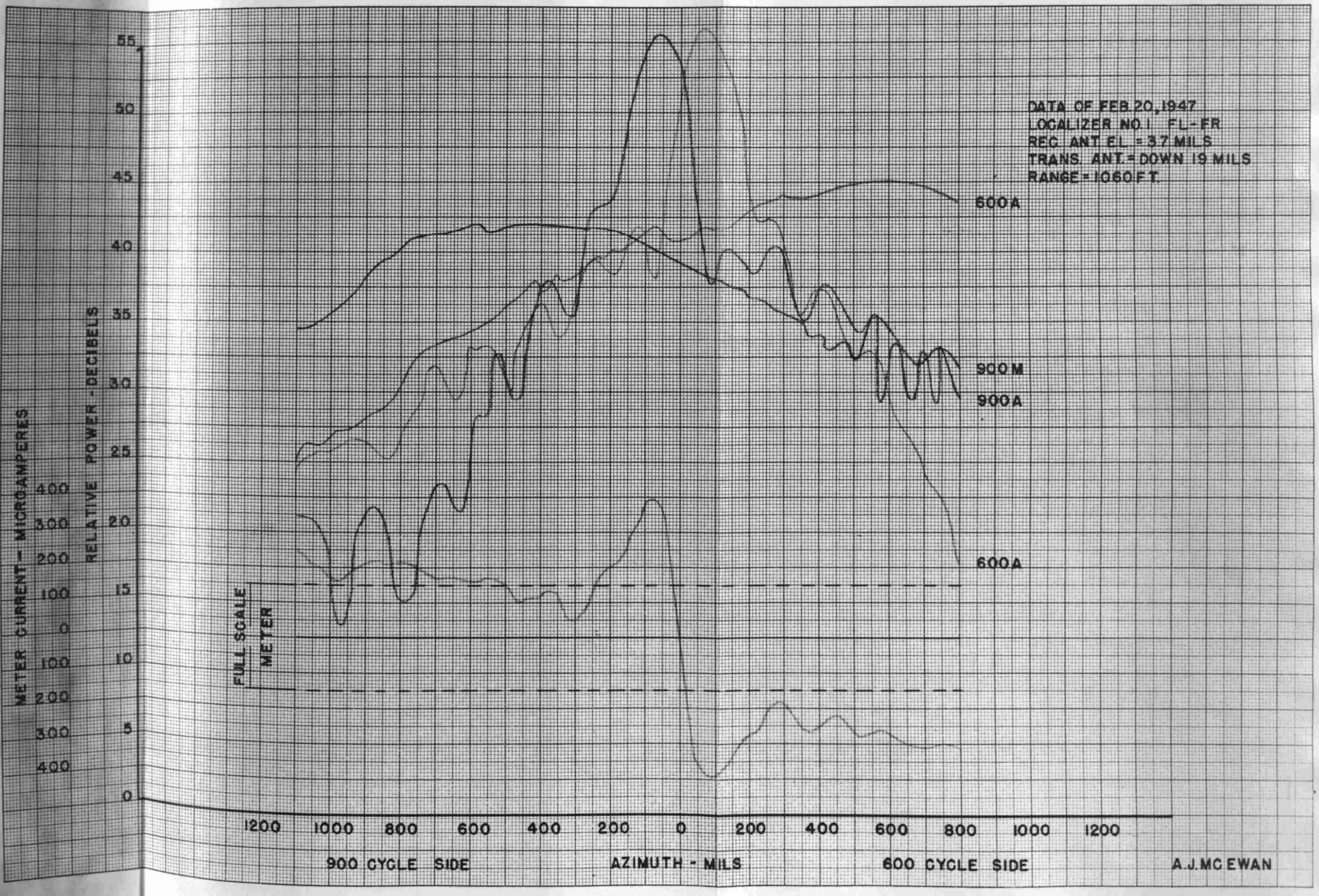

DATA OF FEB 20, 1947
LOCALIZER NO. (FL-FR
REC. ANT. EL. = 37 MILS
RANGE = 650 FT.
DECIBEL DIFF. (900 - 600)
METER CURRENT - MICROAMPERES
RELATIVE POWER - DECIBELS
FULL SCALE METER
600A
900M
900A
600M
DB DIFF. (900 - 600) MAIN
CROSS POINTER METER CURRENT
1200 1000 800 600 400 200 0 200 400 600 800 1000 1200 1400
900 CYCLE SIDE
AZIMUTH - MILS
600 CYCLE SIDE
A.J. MC EWAN

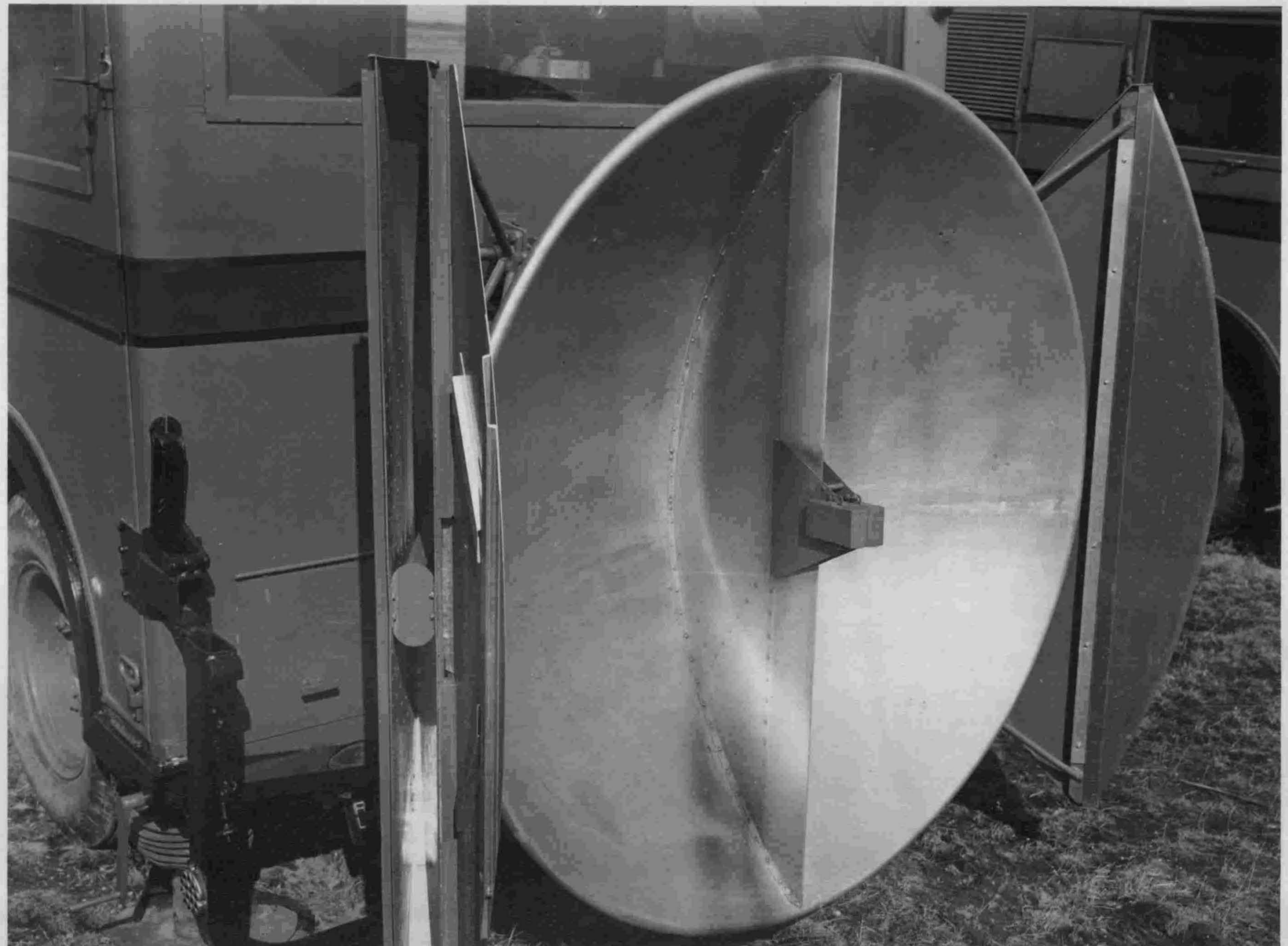
lobes on one side of the main beam being longer than on the other side. It is unfortunate that the larger minor lobes appear on the side of the course opposite to that of the main beam itself. The decibel curve indicates the decibel difference between the two main beams only. This indicates approximately what the cross-pointer meter would read if there were no auxiliary antennas. The cross-over is fine, however, the specification that there be full scale reading to ± 85 degrees of the localizer course and that there shall be no false or inverse courses within the region is flagrantly violated. The lack of full scale reading and presence of inverse coursesis due in part to the fact that minor lobes of the 900 cycle main beam are of a magnitude approaching or greater than the 600 cycle main beam on the 600 cycle side. A similar condition exists on the 900 cycle side. By adding auxiliary antennas it is possible to submerge the effects of these minor lobes without at the same time altering the course characteristics. The cross-pointer meter reading shows the dynamic effects of all of the antennas. It is evident here that at 1000 mils on the 900 cycle side there is a decided soft spot (point not on course where full scale meter deflection is not available) accompanied by a false course and an inverted courses are very confusing. The pilot sees on-course readings and rapid meter fluctuations in regions where the pointer should remain hard-over. If such courses were flown the results might be disastrous. Thus all anomalous courses must be eliminated within the specified region to insure consistantly safe landings. Flight checks indicated no soft spots in this particular region. An analysis of the curves indicates a consistant dip of the 900 and 900A beams at approximately 900 mils on the 900 cycle side. This leads to the conclusion as surmised earlier that even at 2640 mc and with a tilted-up beam system, ground reflections are significant. It should be remembered however, that the aircraft usually touches-down about 400 feet in front of the localizer and that this run was made at 650 feet giving rise to the possibility of incomplete beam forming.

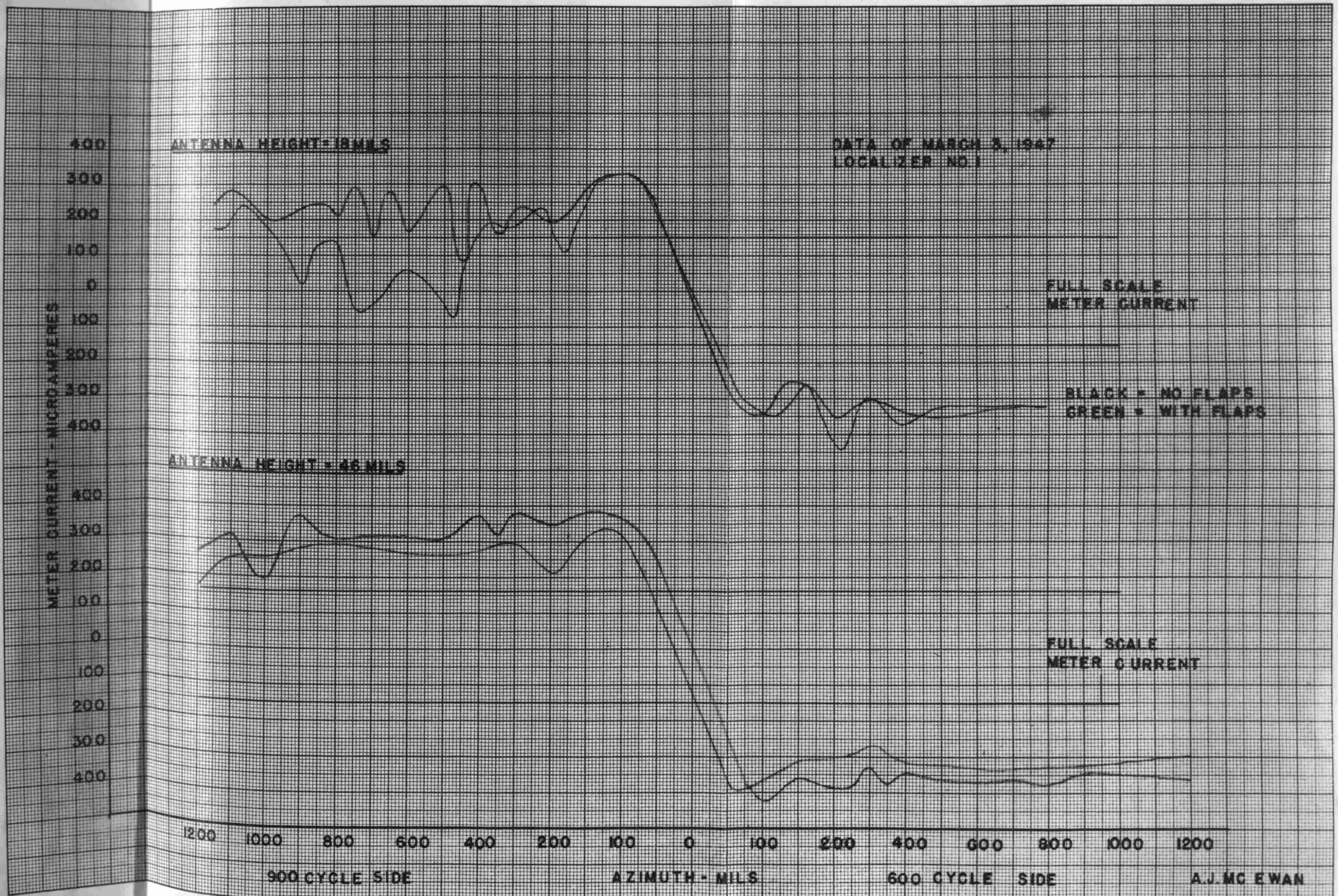
If the 900A beam were increased in power about 2.5 decibels to equal that of the 600A beam (this is the normal case, the drop here is not due to mismatch in the guide but is due to an irregularity in the waveguide slot in the modulator, later tests with a new modulator gave the same power out for both auxiliary antennas) and the auxiliary beam peaks moved out slightly the soft spot would be eliminated. In these runs corrections for the fact that the run was made perpendicular to the localizer course and not on a circular track around the transmitter (constant range) was taken into consideration.

However, a look at Page 68 shows that this attack will not quite solve the problem. The chart shows the patterns at a high point in the field. Here a soft spot between 225 and 500 mils on the 900 cycle side and a weak spot at 300 mils on the 600 side are evident. Any increase in the 900A power to satisfy the 900 cycle side will make the weak spot on the 600 cycle side a very definite soft spot. In any case an improvement of one side will be detrimental to the other side.

At this point the idea of using reflectors on the auxiliary antennas was proposed. This reflector was to be set at the proper angle to reflect energy in such a manner that the soft spot would be removed. The technique used was to attach the reflectors to the inboard side of the auxiliary antennas, Page 69, and orient them by noting the disappearance of the soft spot on the cross-pointer meter. The resulting tests showed a very decided improvement. Remembering that a soft spot occurs when the cross-pointer meter current drops below 150 microamperes (full-scale) when not on course we see that with the additional of flaps, Page 70, the very large soft spot between 410 and 900


DATA OF FEB. 20, 1947
LOCALIZER NO. 1 FL - FR
REC. ANT. EL. = 37 MILS
TRANS. ANT. = DOWN 19 MILS
RANGE = 1060 F.T.
600 A
900 M
900 A
600 A
RELATIVE POWER - DECIBELS
METER CURRENT - MICROAMPERES
FULL SCALE METER
55
50
45
40
35
30
25
20
15
10
5
0
400
300
200
100
0
100
200
300
400
1200
1000
800
600
400
200
0
200
400
600
800
1000
1200
900 CYCLE SIDE
AZIMUTH - MILS
600 CYCLE SIDE
A. J. MC EWAN




ANTENNA HEIGHT = 18 MILS
DATA OF MARCH 3, 1947
LOCALIZER NO. 1
FULL SCALE METER CURRENT
BLACK = NO FLAPS
GREEN = WITH FLAPS
ANTENNA HEIGHT = 46 MILS
FULL SCALE METER CURRENT
METER CURRENT - MICROAMPERES
400
300
200
100
0
100
200
300
400
1200 1000 800 600 400 200 100 0 100 200 400 600 800 1000 1200
900 CYCLE SIDE
AZIMUTH - MILS
600 CYCLE SIDE
A.J. MC EWAN

mils was almost completely eliminated. A run with the antenna slightly higher indicated a greater microampere reading at all points except at 1000 mils on the 900 cycle side. At 1000 mils the reading was more than adequate at 190 microamperes. Tests also showed that these flaps reflected energy from the minor lobes of the main antenna in such a way as to decrease the effects of the minor lobes.

From the localizer patterns the full significance of course sensitivity becomes evident. It is obviously desirable to get high angular sensitivity at long ranges to prevent wandering. However, if the same angular sensitivity were maintained near the landing point the course would be too sensitive to fly. Since the meter indicates the amount of flight error, it is desirable to have the meter remain on-scale during the final phases of the landing. By this means the pilot has an idea of where he is with respect to the course.

The reduction of course sensitivity is called course broadening. The breadth can be increased by raising the relative cross-over intensity of the main beams and reduced by lowering the cross-over point of the beams.

Consider again the angular sensitivity of the course with a constant angular sensitivity the flyability of the course apparently becomes more difficult as the range from the transmitter decreases. A fixed linear deviation from on course at a range of two miles will produce only one half the scale deflection as the same deviation at one mile. Thus as range decreases the mil deviation (and thus crosspointer reading) will increase for a fixed lateral deviation. If it were possible to broaden the course in such a manner that during the final phase of the approach the convergence would not be too great the flyability of the course would be improved.

So-called course-softening has been tried in which the audio tubes have been biased by AVC action in such a manner that the output drops off as range is decreased so that the apparent sensitivity of the course is reduced. This technique has not proven satisfactory since AVC voltage is not a precise means of measuring range and further the AVC action is different for various receivers. This would make the characteristics of the course a function of the receiver and each one would be different. If a precise means of measuring range were available (as in Distance Measuring Equipment - DME) then this information could be used to control the sensitivity of the receiver's output as a function of range. When DME equipment is adapted for use in the microwave system it seems at the present time to be a feasible solution to the problem.

IV. ANALYSIS OF SYSTEM

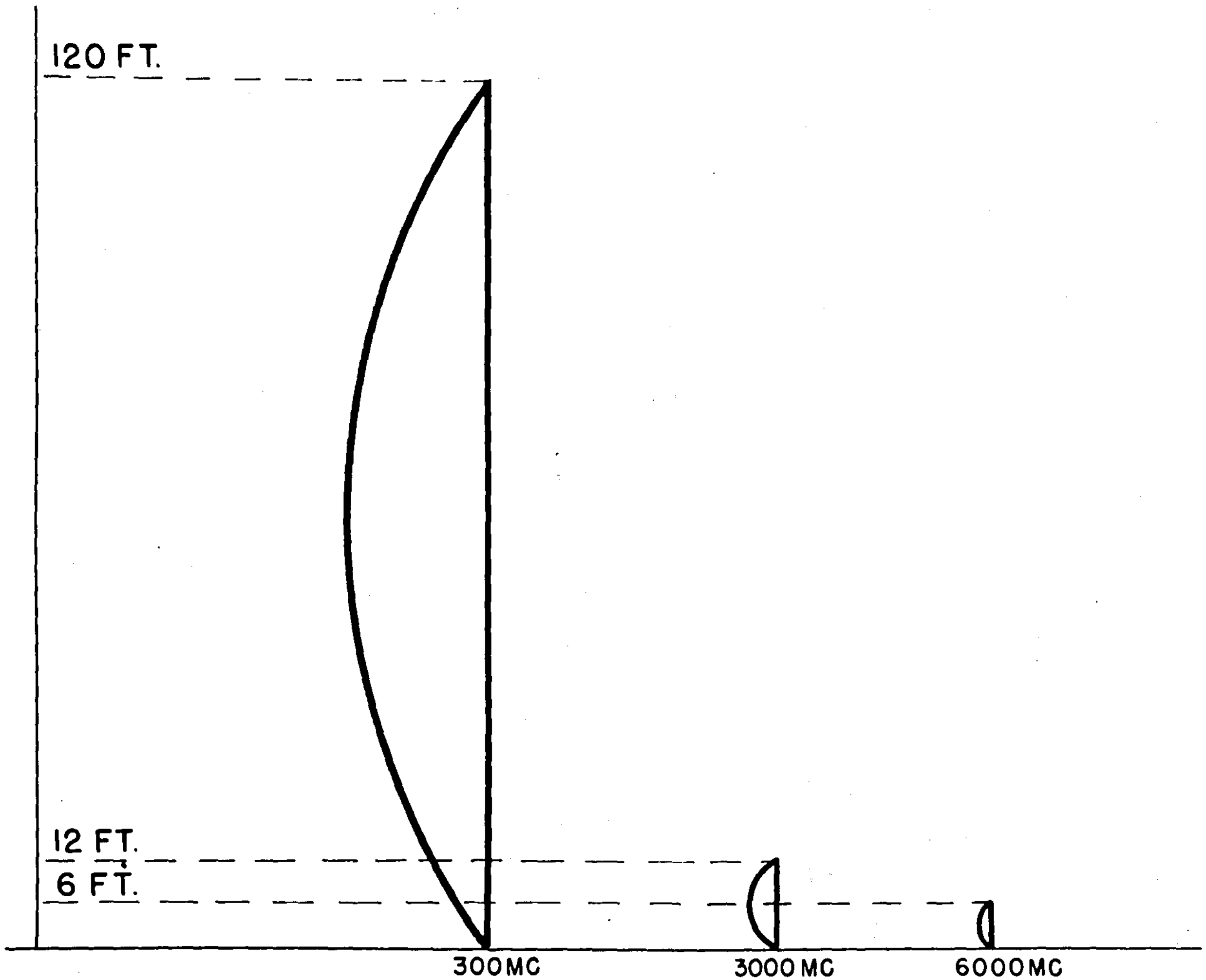
The results of the foregoing field tests indicate that ground measuring techniques will suffice to determine the actual antenna patterns and can be extrapolated to determine what takes place at much greater range in the flight approach path. Providing the beams have completely formed these ground measurements are sufficient to determine the operating characteristics of the system as a whole.

Considering the microwave landing system as an integrated system it becomes evident that there are many advantages peculiar to it.

1. Antenna size - It is of great advantage to have sharp narrow beams yet have small antennas. Page 74 shows the relative antenna heights to produce the same beam width (2 degrees) at different frequencies. Keeping in mind that large antennas present hazardous obstacles in a flight landing area and that the antenna pattern should be independent of variables such as the ground the advantages of a system operating in the microwave region becomes obvious.

2. Tilted-up antenna systems - Not only are the beams sharp and independent of the ground for pattern formation but the nature of their uptilt reduces to a minimum the amount of interference by reflection.

3. Mobility - The fact that the equipment can be set up optically leads to portability and ease of re-



RELATIVE HEIGHT OF GLIDE PATH ANTENNAS

locating on any one of a number of runways on the same airfield.

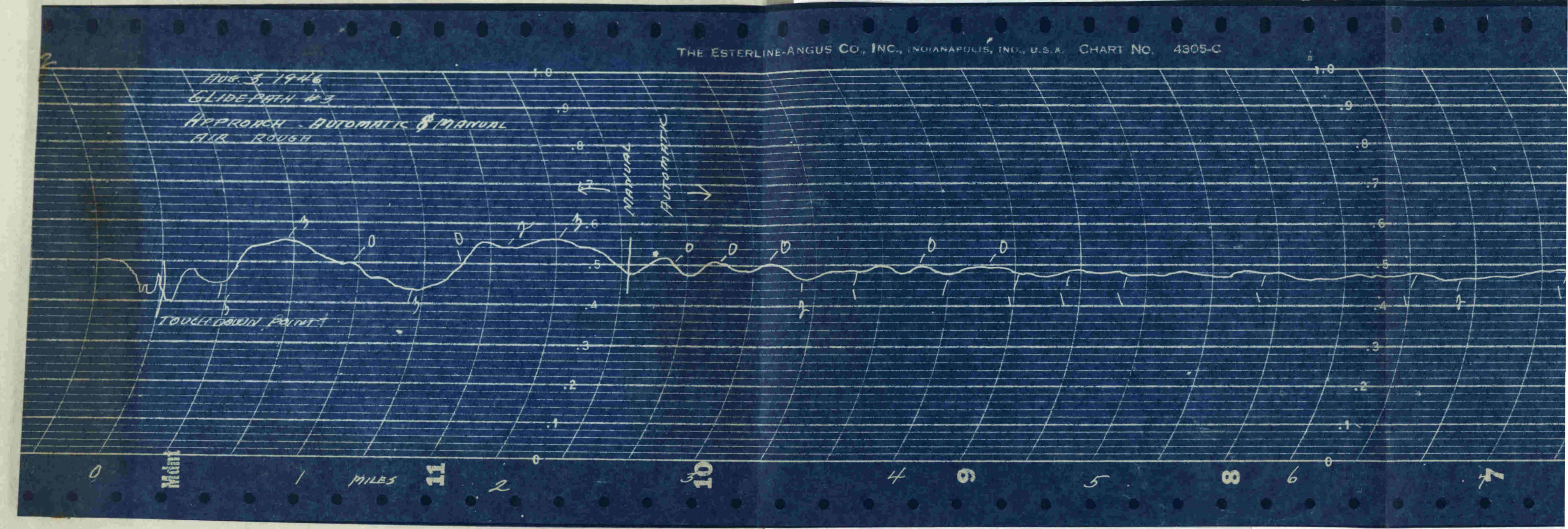
4. Spectrum Utilization - CW microwave techniques permit the fullest use of the RF spectrum. Since the frequency stability is of a high order and the intelligence required for instrument landing purposes is of a simple nature the transmission bandwidths are narrow.

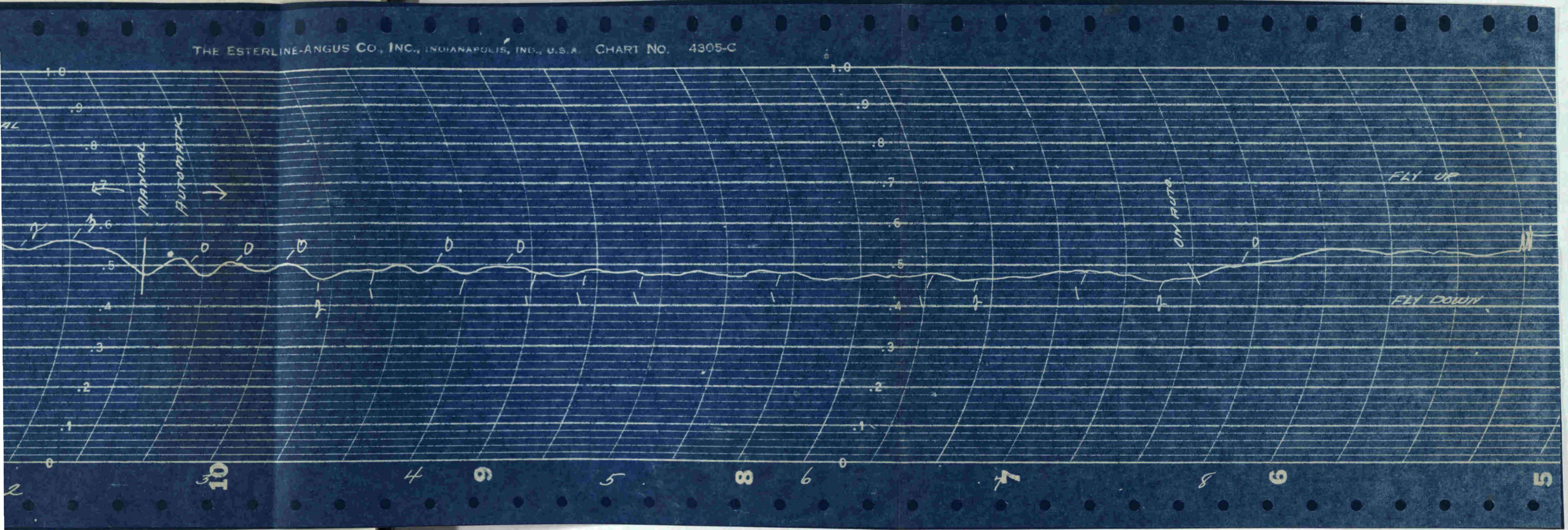
5. Future Utility - A very important consideration of any present day landing system is its possible adaptability to automatic approach techniques. When a great effort is expended on making a system provide a highly accurate flight path in space it is invariably found that the more accurate and precise the path the more difficult it is to fly. For automatic approach this does not offer a great problem however, it must always be remembered that at any point on the approach path, should the automatic equipment fail, the system must be capable of being flown manually with sufficient accuracy to permit a safe landing.

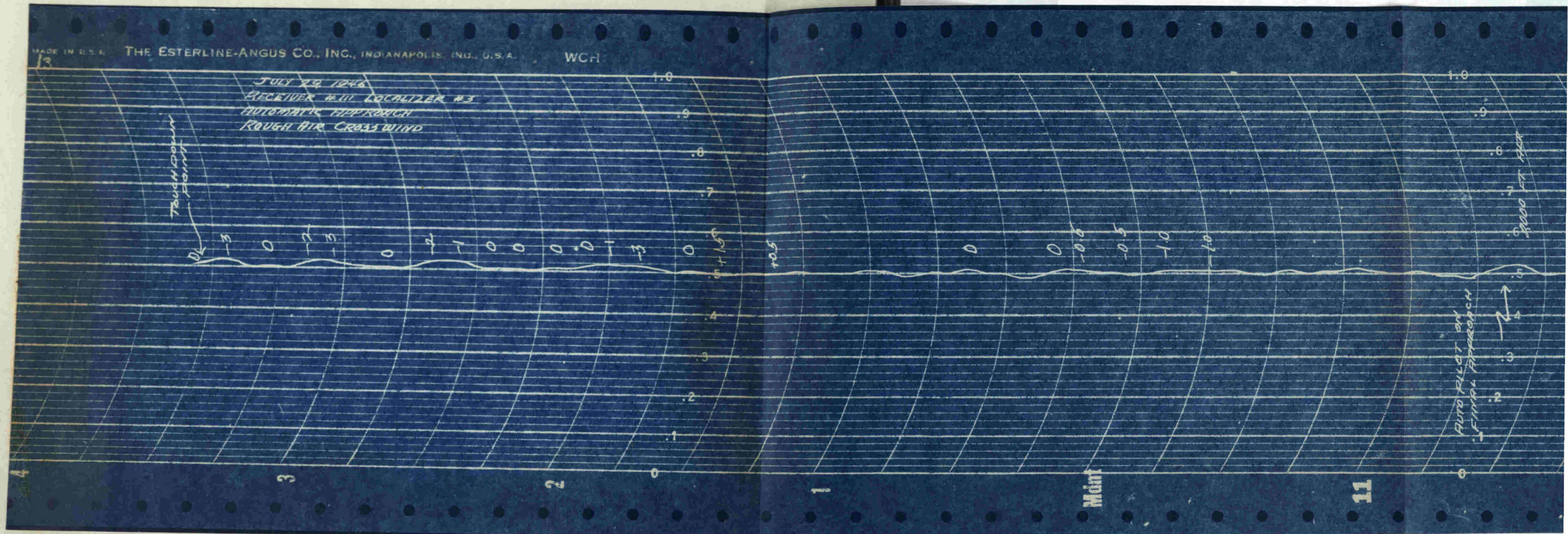
The Sperry Gyroscope Company has automatic approach equipment as an adjunct to their microwave landing system and which can also be used on the CAA or SCS-51 instrument landing systems. This equipment provides automatic bracketing of the localizer when the control switch is in "localizer" position. Upon interception of the glide path the switch is set on "approach" and combined bracketing of both localizer and glide path beams results. This operating in conjunction with the A-12 automatic pilot, which automatically sets the aircraft tab controls as flight attitude changes, and an automatic air-speed control provides a smooth approach to the runway with a minimum of hunting and bracketing.

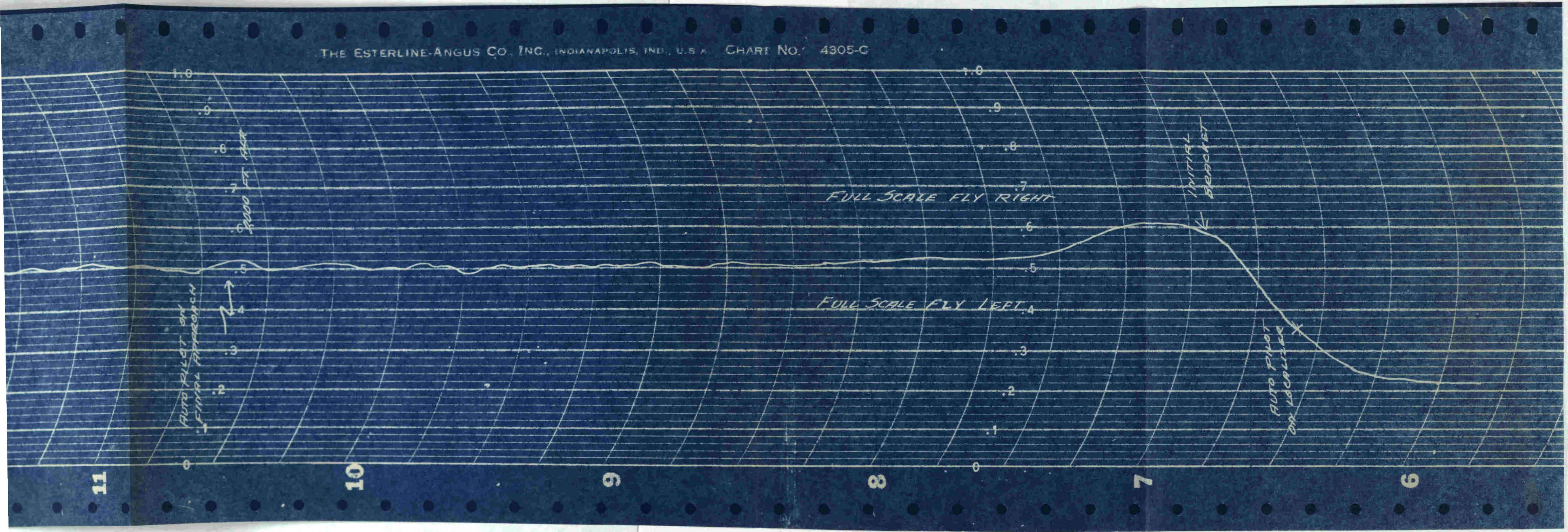
Flight tests show that automatic flight is three times more accurate than the best manual approach by a pilot familiar with instrument approach techniques. To illustrate this point consider the glide path shown in Page 77. Here the numbers on the curve indicate mil deviation from the true glide path and the numbers on the left side indicate range in miles. At approximately 8 miles the automatic approach equipment is engaged and a slight hunting and bracketing takes place. At a range of 2.5 miles the pilot takes over and flys manually. Note the increase in mil deviation from the true path. Note also that it is the last mile or so where deviation assumes a major importance. Flight bracketing corrections as the range decreases become comparable to the total height of the aircraft above the terrain. Manually this system can be flown safely down to 50 to 100 feet above the runway. Automatic approach techniques reduce this altitude to 5 to 25 feet.

Page 78 shows a localizer flight recording. Note the point of engagement of the automatic pilot on the


THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. CHART NO. 4305-C
AUG. 3, 1946
GLIDE PATH #3
APPROACH - AUTOMATIC & MANUAL
AIR ROUGH
MANUAL
AUTOMATIC
TOUCH DOWN POINT
MILES

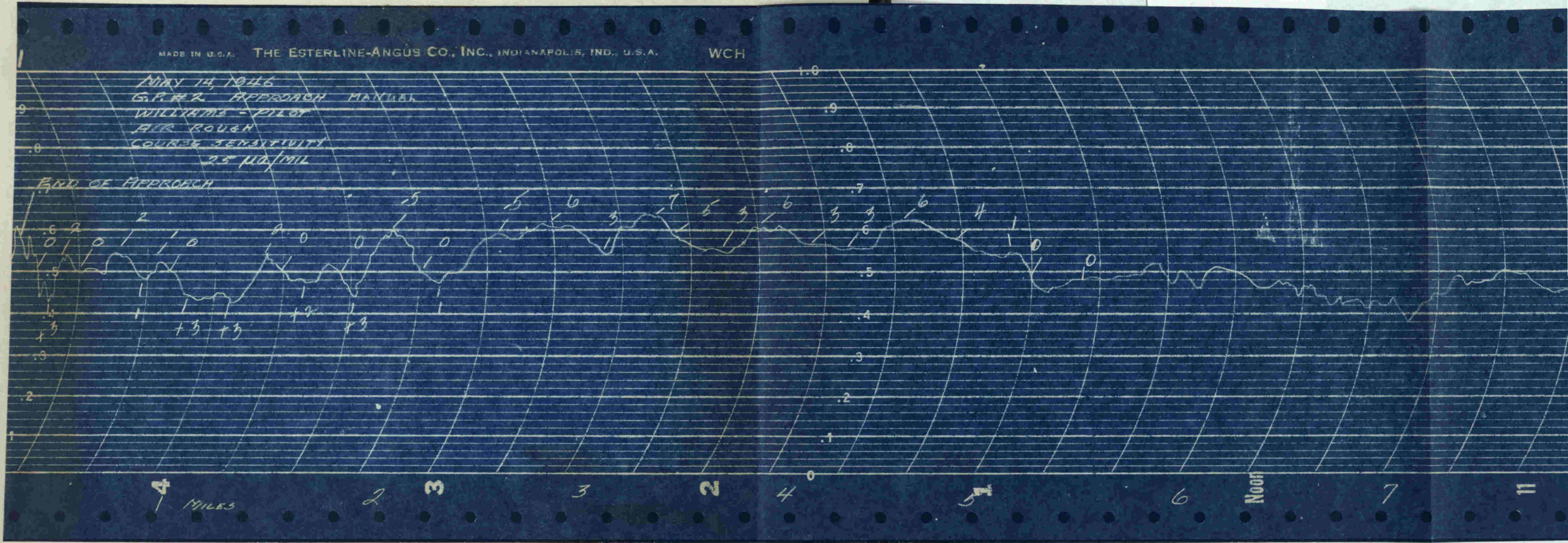

THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. CHART NO. 4305-C
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
MANUAL
AUTOMATIC
ON AUTO
FLY UP
FLY DOWN

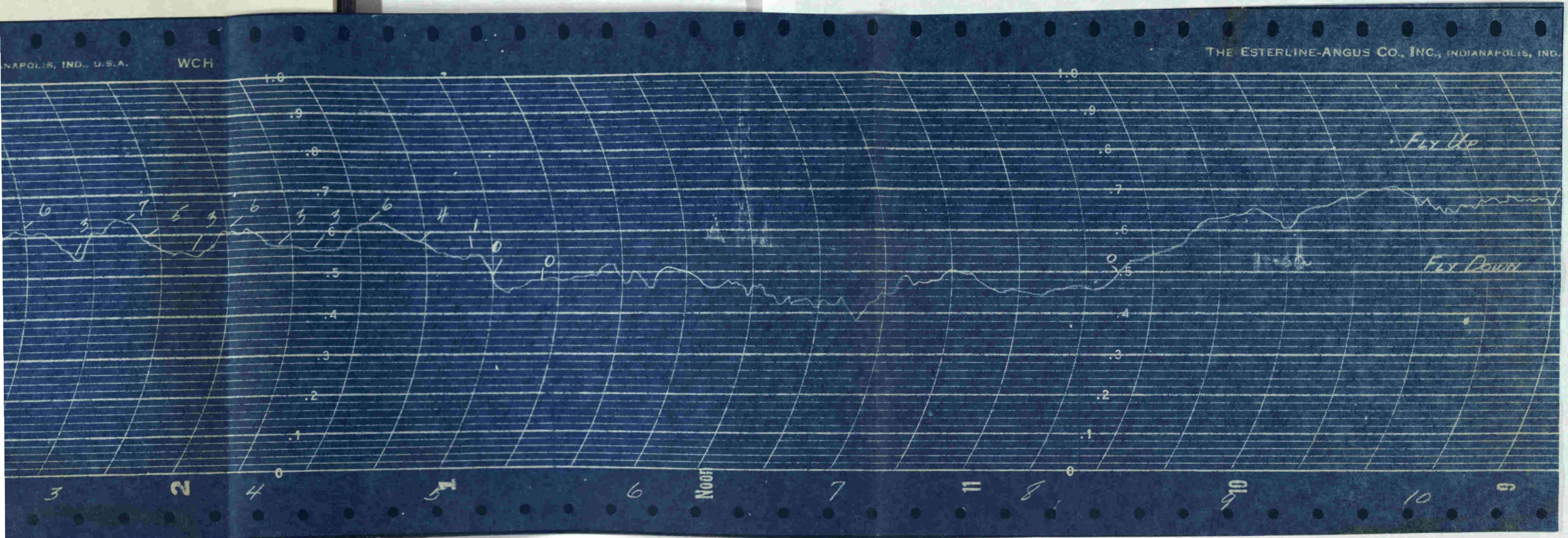

MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A.
WCH
JULY 29, 1946
RECEIVER #111 LOCALIZER #3
AUTOMATIC APPROACH
ROUGH AIR CROSSWIND
TOUCHDOWN POINT
AUTO PILOT ON FINAL APPROACH
2000 FT. ALT.


THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A. CHART NO. 4305-C
FULL SCALE FLY RIGHT
FULL SCALE FLY LEFT
INITIAL BRACKET
AUTO PILOT ON LOCALIZER
AUTO PILOT ON FINAL APPROACH
1000 FT. ALT
11
10
9
8
7
6

localizer and initial bracket. Although this flight took place in rough air and a considerable cross-wind the maximum deviation from the true course was only 3 mils and this taking place at about 1 mile amounts to a lateral deviation of approximately 15 feet. As indicated at 2000 feet altitude the glide path was intercepted and the automatic approach equipment switched to final approach position. From this point on, both beams were being bracketed simultaneously. The advantage of automatic approach is again very evident on Page 80. Here the glide path is flown manually and in very rough air. The maximum mil deviation from the correct glide path angle is 7 mils. Note the excessive bracketing and overshooting between 0 and 1 mile range. However maximum deviation in this range did not exceed 3 mils or 15 feet.

In conclusion it can be said that the employment of microwave techniques in a landing system which is adaptable to automatic approach and in the future to completely automatic landings indicate a great stride towards the ultimate in consistently safe and dependent aircraft landing systems.


MADE IN U.S.A. THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND., U.S.A.
WCH
MAY 14, 1946
G.P. #2 APPROACH MANUAL
WILLIAMS - PILOT
AIR ROUGH
COURSE SENSITIVITY
25 μa/MIL
END OF APPROACH
MILES
Noon



NAPOLIS, IND., U.S.A.
WCH
THE ESTERLINE-ANGUS CO., INC., INDIANAPOLIS, IND.
Fly Up
Fly Down
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0
Noon

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