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MICROWAVE SYSTEM OF DISTANCE MEASUREMENT

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FINAL TECHNICAL REPORT

SHORT RANGE ELECTRONIC POSITIONING EQUIPMENT

PERIOD COVERED BY REPORT: 23rd FEBRUARY, 1959 - 30th SEPTEMBER, 1961

CONTRACT NO: DA-44-009-ENG 3811

PROJECT NO: 8-35-10-500

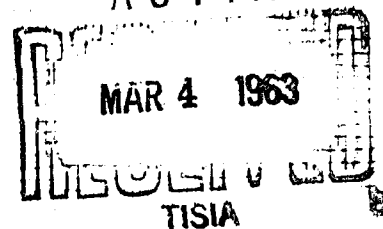
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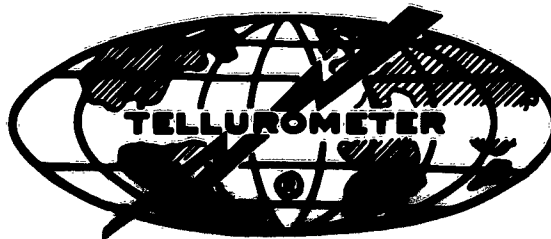
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AD..... ACCESSION NO..... Instrument Manufacturing Corporation of South Africa Limited SHORT RANGE ELECTRONIC POSITIONING EQUIPMENT - L.F. Houghton J.F. Ogle Final Technical Report 1st February, 1962. 54 pp 22 illus. 2 tables CONTRACT NO: DA-44-009-ENG 3811 PROJECT: 8-35-10-500. Unclassified Report This Report deals with the development, fabrication, and testing, of a Short Range Electronic Positioning Equipment for use in a highly mobile role. The prototype equipment and the modifications to it are discussed from both theoretical and practical aspects.	UNCLASSIFIED 1. Mapping, charting, and geodesy. Hyperbolic position fixing. 2. Project 8-35-10-500
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PREFACE

The U.S. Army Engineer Research and Development Laboratories were assigned the responsibility of developing methods and procedures for utilizing new equipments for position-measuring under all conditions. The assignment was under GIMRADA Project 8735-10-001-06 'Utilizing of Ground Surveying Electronic Equipment for Mapping'. In May, 1958, a requirement for a rapid means of determining positions over short ranges was placed by USCONARC on USAERDL for field-artillery use.

The early work on SREPE was initiated in April, 1958, by Dr. T. L. Wadley of the National Institute for Telecommunications Research (N.I.T.R.) of the South African Council for Scientific and Industrial Research at the request of the Union Defence Force. The task was to conduct a scientific investigation into the problem of determining the position of troops in mobile warfare by radio. The programme was controlled by the South African Defence Research Advisory Council on a contract basis.

Interest in this investigation was expressed by E.R.D.L. On 1st November, 1958, after considerable consultation and after the necessary approval from the South African authorities had been obtained, E.R.D.L. extended an invitation to the Contractor to submit a proposal for the procurement of SREPE on the basis of a purchase description dated 20th October, 1958.

On 13th November, 1958, the Contractor submitted a proposal for a fixed-price procurement on the basis of a slightly modified purchase description. This proposal was accepted by E.R.D.L. on 30th December, 1958, and on 23rd February, 1959, the contract was signed by the Contractor and returned to E.R.D.L.

The contract was carried out in three phases. Phase I comprised the scientific investigation and building of laboratory prototypes. A successful demonstration of this equipment was given to representatives of various military and civilian agencies at the Artillery Survey System Demonstration on 4th August, 1959, at Mount Clark, Virginia. After the demonstration, permission was given to the Contractor to proceed with Phase II, which comprised the fabrication of new equipment that was based on the design of the prototypes but involved certain modifications. Under Phase III (Demonstration, Modification, and Final Delivery) the equipment was demonstrated in Virginia during February and March, 1961, and returned to South Africa in April, 1961, for modification. It was returned to the U.S.A. for final delivery on 19th August, 1961. A final demonstration and evaluation took place in Virginia during September, 1961.

As stated above, the original development work was undertaken by Dr. T.L. Wadley, whose invaluable services were made available to the Contractor throughout the period of the contract. Assistance was also rendered by Dr. F.J. Hewitt, Director, and Mr. H.D. Holscher, both of the N.I.T.R. The latter was present at the trials in the U.S.A. and much of the modification of the equipment was guided by him.

The development and construction of the equipment was carried out by personnel of the Research Division of the Instrument Manufacturing Corporation of South Africa. During the trials in the United States, practical assistance was rendered by personnel from Tellurometer Inc. and GIMRADA.

Special mention must be made of Mr. D.R. Hendrikz, Geodetic Officer of the Department of Trigonometrical Survey (South Africa), for his advice on survey aspects.

In reading this Report, reference should be made to the Type II Interim Report for Phase II of this Contract.

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SUMMARY

This Report presents an account of the work carried out by the Contractor throughout the period of the Contract.

The Phase-I equipment, which was actually developed before the Contract was issued, is described and its limitations are listed. The modifications that were made in Phase II are dealt with in detail. As a result of pre-acceptance tests, further modifications were carried out in Phase III. These were followed by acceptance trials in the United States. These test results are given in detail, together with the relevant graphs, and are discussed later in the Report.

The Report concludes with recommendations regarding further development aimed at simplifying the equipment in certain respects and extending its capabilities.

CHAPTER 1

INTRODUCTION

Section 1. CONTRACT SPECIFICATION

Modern concepts in military tactics have made necessary the development of new methods of and equipment for making rapid and accurate measurements of position in all types of weather by day and by night. Systems operating in both the high-frequency and medium-frequency bands were already in existence, but a new system that avoided their shortcomings was required.

The special points to be brought out in the new system were: rapid and accurate positioning of any number of stations, operation under non-line-of-sight conditions, and light weight and small bulk of all units.

Based on an original investigation of such a system by the South African Council for Scientific and Industrial Research, the Contract called for the design, fabrication, development, and testing, of an electronic, hyperbolic, positioning system that used phase-comparison techniques and consisted of three base (transmitter) stations and any number of mobile (receiver) units. The system should require no calibration procedure, should give full position information by automatic, sequential, switching arrangements, and should not be dependent on lane identification for position information.

The accuracy of measurement should be 1 part in 1000 and no position should be in error by more than ± 25 feet; corrections for surface-wave propagation effects would be permissible. The system should be capable of positioning over a range of up to 20 miles from the most advanced base station. Within the limitations imposed by day-time and night-time propagation effects, positioning was required over an area of 40 miles square.

Lesser requirements of the Contract were as follows:-

a. Read-out

Read-out was to be direct, immediate, and in hyperbolic co-ordinates referred to the base stations. A formula and a quick method of calculation from hyperbolic to U.T.M. co-ordinates were to be provided.

b. Time Switching

Hyperbolic co-ordinates were required to be available at unknown points within 45 minutes of the setting-up of the base stations. The read-out was to be made within 1 minute and the co-ordinate conversion within a further 1 minute by converter or 15 minutes by formula and calculation.

c. Frequency

Transmission was to be in the band 1605-1800 kc/s.

Section II. THEORETICAL CONSIDERATIONS

a. Hyperbolic Positioning

The method of determining a position by means of hyperbolic co-ordinates is described briefly.

If two fixed stations transmit equiphase signals that can both be received by a mobile station, where the phases of the signals are compared, the loci of points of constant phase difference are confocal hyperbolae, whose foci are at the two transmitters. If, now, a third fixed station is introduced, and if it transmits signals that are in time phase with those from one of the other stations, a second set of hyperbolae, whose foci are the second and third stations, will be generated. If station pairs 1 - 2 and 2 - 3 transmit alternately, or if the mobile station can receive both sets of transmissions simultaneously, the position of the mobile station can be determined as the intersection of two hyperbolae.

Since two hyperbolae intersect in two points, the approximate position of the receiver needs to be known in order to resolve this ambiguity.

If two stations are transmitting signals of a particular frequency, with which is associated a particular wavelength, the hyperbolae can be considered to form lanes. The 'width' of the lanes depends on the wavelength of the transmitted signals. Within a lane, positioning on a hyperbola is unambiguous, in that a reading of phase difference is associated with only one hyperbola; but the lanes themselves are ambiguous in that any reading of phase difference is repeated in all the lanes. Consequently, when a 3-station system is used, a position determination is unambiguous within a lane but ambiguous in the whole field.

In order to resolve this ambiguity, existing systems employ methods of lane identification. However, the Contract specifically stated that the system should not depend on lane identification for position determination; an alternative method had been incorporated in the original equipment, and this, with slight modification, was adopted for the Contract equipment.

b. Patterns

Avoidance of lane ambiguities is made possible by the provision of three signals that differ in frequency. The fundamental signal is termed the ROUGH FINE pattern, which produces a lane width of approximately 84 metres along the base line. The other two patterns, MEDIUM and

COARSE DIFFERENCE, in effect produce lanes of approximately 840 metres and 8.4 kilometres along the base lines, respectively. These patterns are switched consecutively, a procedure that results in a consecutive read-out of the three patterns and consequent resolution of ambiguity up to lane widths of 8.4 kilometres. It is assumed that the position of the receiver is known to within that distance; so a fourth ambiguity pattern is not provided.

Section III. THE ORIGINAL EQUIPMENT

a. General

The original equipment, developed by the C.S.I.R., operated in accordance with the above principles. One transmitting station (the Control Station) was sited at the apex of two base lines, inclined at a specific angle to each other, and one different transmitter (the Outstation) was sited at the other end of each base line.

The Control Station transmitted continuously. On the other hand, the Outstations transmitted alternately for 30 seconds each; during this period the patterns were transmitted in one complete sequence. Thus, the mobile station (the Search Receiver) received signals continuously from the Control Station and alternately from the Outstations. During a 30-second period the Search Receiver compared the phases of each pattern as received from the Control Station and from one Outstation. Thus, in one minute a complete set of readings for position determination could be taken.

A subsidiary base station (the Synchronizing Receiver), whose function is described in the next Section, was sited about 100 yards from the Control Station and connected to it by cables.

Read-out on the Search Receiver was in the form of a diametral line on a cathode-ray tube, the rotation of the line from a fiducial line being a measure of the phase difference between the two received signals. This angle of rotation was measured by means of a cursor and fixed scale. The operating procedure was to wait for the beginning of a 30-second period, align the cursor with the c.r.t. trace, and read the scale. When the second pattern was transmitted, the position of the diametral trace changed; the cursor was again aligned with the trace and the scale read. This procedure was repeated for all the patterns, including those transmitted during the following 30-second period. Should the operator have been unable to take any reading, he needed only to wait for a minute in order to have the same measurement displayed again.

b. Generation of Patterns

The Control Station transmitted two c.w. signals, one on a 'lower channel' and the other on an 'upper channel', whose frequency was 10% higher than that of the lower channel. The Outstation transmitted two c.w. signals, also on lower and upper channels; however, these channels differed from those of the Control Station by an audio frequency (200 c/s).

The Synchronizing Receiver detected the two audio frequencies and fed them to the Control Station. There the phases of the two signals were compared and any resultant from their being out of phase was used to change the frequency of the upper-channel transmission of the Control Station till the two audio signals were in phase at the Synchronizing Receiver. At the Search Receiver the phase difference between the audio frequencies was measured; this phase difference was a measure of the hyperbolic position. It can thus be seen that, if a Search Receiver were situated at the Synchronizing Receiver, the measurement (i.e., the phase difference) would be zero. This point is considered in Section II d of Chapter 3.

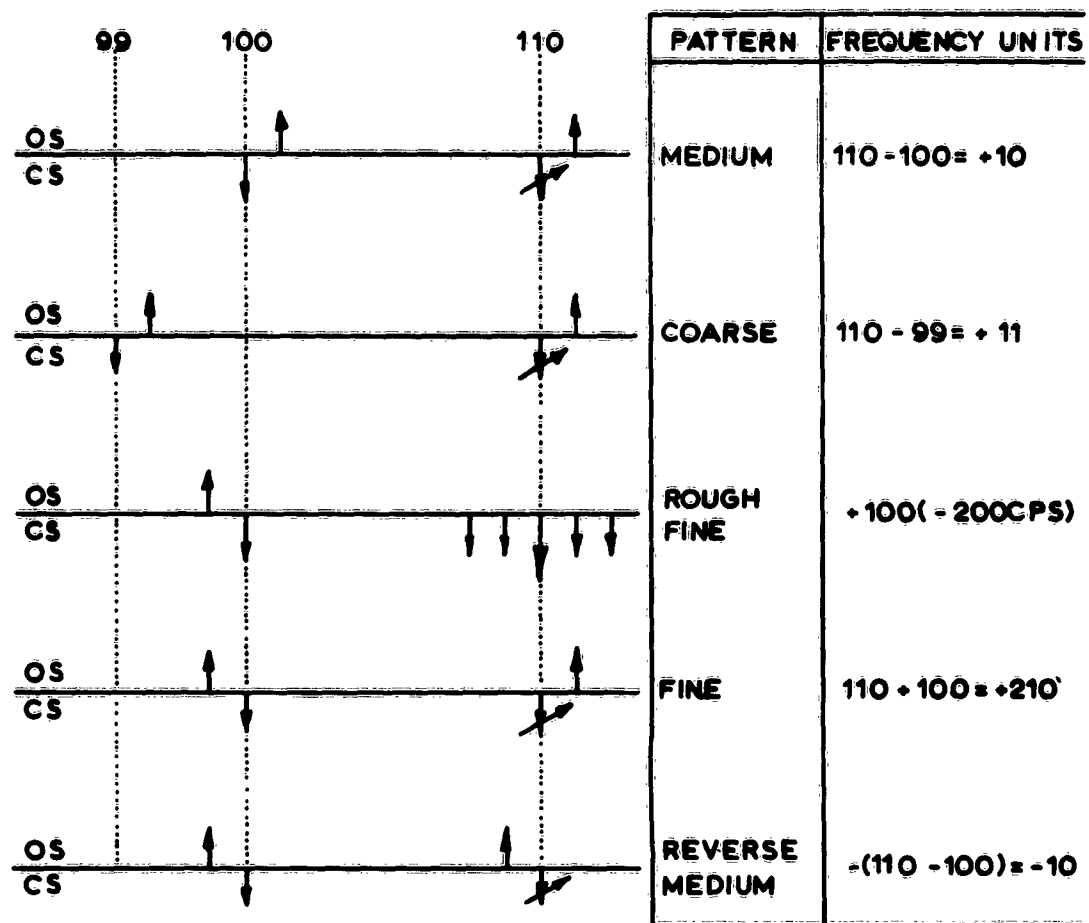
The COARSE and MEDIUM transmission patterns were derived in the above manner. In the case of the MEDIUM pattern, the frequencies of the upper and lower channels at the Control Station were in the ratio 110:100, and the Outstation frequencies were 200 c/s above these. In the case of the COARSE pattern, the frequencies at the Control Station were in the ratio 110:99, and again the Outstation frequencies were 200 c/s above them. At the Search Receiver the MEDIUM pattern was used as a reference, and the COARSE - MEDIUM difference was obtained to give a COARSE DIFFERENCE read-out pattern of frequency one tenth that of the MEDIUM pattern.

The ROUGH FINE pattern was produced in a different manner. The frequencies of the upper and lower channels of the Control Station were in the ratio 110:100; but the lower channel of the Outstation was 200 c/s below that of the Control Station, and there was no Outstation upper-channel transmission. The 200-c/s beat between the lower-channel transmissions was frequency-modulated onto the upper-channel frequency of the Control Station. At the Search Receiver the phases of the two 200-c/s signals were compared in the same manner as for the other patterns.

The COARSE DIFFERENCE pattern, being a difference reading, was free from internal instrumental errors. The MEDIUM and ROUGH FINE patterns were not free from these errors. Consequently, two further transmission patterns (REVERSE MEDIUM and FINE) were provided so that the differences between them and the MEDIUM pattern would give read-out patterns (DOUBLE MEDIUM and DOUBLE FINE) that were free from these errors.

The FINE pattern was produced in the same way as the MEDIUM except that the lower-channel frequency of the Outstation was below instead of above that of the Control Station. The REVERSE MEDIUM pattern was produced in the same way as the FINE except that the upper-channel frequency of the Outstation was below instead of above that of the Control Station.

The above system of pattern generation is shown in Figure 1.



PATTERN	COMPONENTS	FREQUENCY UNITS
COARSE DIFFERENCE	COARSE - MEDIUM	$+11 - (+10) = +1$
MEDIUM	MEDIUM	$+10$
DOUBLE MEDIUM	MEDIUM - REVERSE MEDIUM	$+10 - (-10) = +20$
ROUGH FINE	ROUGH FINE	$+100$
DOUBLE FINE	FINE - MEDIUM	$+210 - (+10) = +200$

Figure 1 Phase-I Pattern Arrangement

Section IV. DISADVANTAGES OF THE ORIGINAL EQUIPMENT

Before the equipment was made acceptable certain disadvantages inherent in the instruments, as originally developed, had to be eradicated.

a. Mains operation

Both the Control Station and the Outstation were operated from the mains supply. This was necessary for synchronous switching of the patterns and alternate switching of the Outstations. Operation from the mains imposed severe limitations on the deployment and portability of the system.

b. Utilization of vacuum tubes

The circuitry of the transmitters was designed round vacuum tubes.

As a result, the current consumption was rather heavy.

c. Patterns

The system of pattern generation, as detailed above, called for three crystals in the Control Station and five in each Outstation. As there were more Outstations than Control Stations, a large number of crystals was required. Furthermore, the frequency of one pattern (ROUGH FINE) was in error by 200 c/s, and two reference patterns (MEDIUM and REVERSE MEDIUM) were necessary; the latter fact meant that the DOUBLE MEDIUM pattern had to be read on a cursor that was displaced by 90° (180 electrical degrees) from normal.

d. Pattern sequence

The pattern sequence was inflexible because the MEDIUM pattern had to precede the COARSE pattern when measurement was made in motion, and the ROUGH FINE pattern had to follow the COARSE pattern to make use of a 5-second delay after the end of the COARSE pattern.

e. Pattern frequencies

The frequencies of the transmitted signals lay between 1648.350 kc/s and 1831.700 kc/s; this band was outside the allowable band of 1605 - 1800 kc/s.

f. Oven temperatures

The operating temperature of 50°C in the crystal ovens was too low for the ambient temperatures that were likely to be encountered.

g. Construction

The instruments were only laboratory prototype equipment, which did not conform to the military specifications of ruggedness, waterproofing, types of controls on the front panels, environmental operation, fungus and dust resistance, and facilities for testing.

Section V. BREAKDOWN OF THE PROBLEM

Resulting from a survey of the Contract specifications and the disadvantages of the existing equipment, the Contract requirements could be

broken down into two major categories: conceptual redesign, and practical redesign.

In the first place, not only had the method of pattern switching to be altered in order that the sequence of patterns might be given a degree of flexibility, but also the pattern frequencies had to be changed in three respects: the error in the ROUGH FINE pattern had to be eliminated, only one reference pattern was required, and the distribution of crystals between Control Station and Outstation had to be changed in order to reduce the number of crystals used.

In the second place, the equipment needed to be transistorized and powered by batteries instead of the mains supply. The latter requirement necessitated the replacement of the mains-driven synchronous timing motors by an alternative system. This practical redesign enabled all the military specifications to be met.

CHAPTER 2

INVESTIGATION

Section I. GENERAL

The first part of the investigation was concerned with the conceptual design. When the fundamental problems had been solved, practical re-design of the separate units was carried out. In this chapter each unit is treated separately except where it is necessary to deal with the system as a whole.

Section II. CONCEPTUAL DESIGN

a. Pattern Frequencies

In the new system the REVERSE MEDIUM pattern was made the reference pattern and the relative frequencies of the Outstation patterns were made 90, 99, 100. To utilize the allowed frequency band of 1605-1800 kc/s, the actual crystal frequencies became:

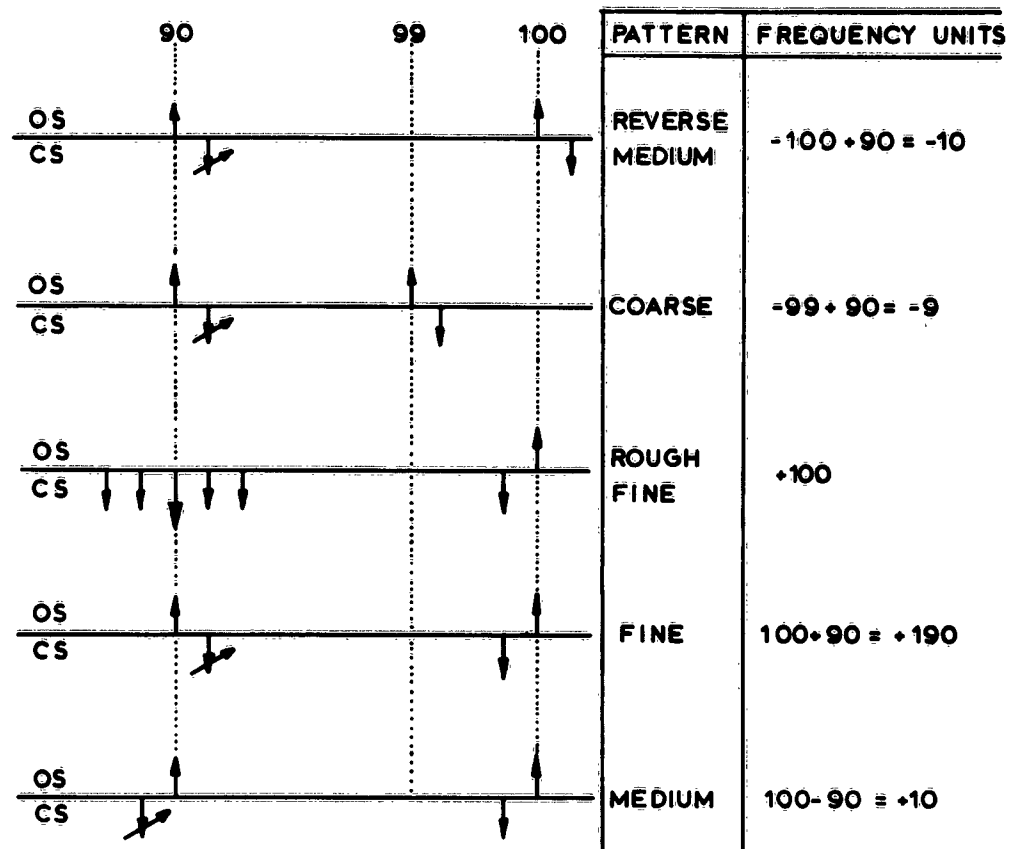
<u>Outstation</u>	<u>Control Station</u>
Lower channel 1611.000 kc/s	1610.800 kc/s
	1611.200 kc/s
Upper channel 1772.100 kc/s	1772.300 kc/s
1790.000 kc/s	1789.800 kc/s
	1790.200 kc/s

The switching sequence was changed to: REVERSE MEDIUM, COARSE, ROUGH FINE, FINE, MEDIUM. The sequence of read-out patterns then became: COARSE DIFFERENCE, ROUGH FINE, DOUBLE FINE, MEDIUM, DOUBLE MEDIUM.

This system is shown schematically in Figure 2, where it can be compared with the original system given in Figure 1.

b. Pattern Switching

The use of single-action cams was continued. Microswitches specially



PATTERN	COMPONENTS	FREQUENCY UNITS
COARSE DIFFERENCE	COARSE-REVERSE MEDIUM	$-9 - (-10) = +1$
MEDIUM	MEDIUM	$+10$
DOUBLE MEDIUM	MEDIUM-REVERSE MEDIUM	$+10 - (-10) = +20$
ROUGH FINE	ROUGH FINE	$+100$
DOUBLE FINE	FINE-REVERSE MEDIUM	$190 - (-10) = +200$

Figure 2. Phase-II Pattern Arrangement

chosen for micro-current operation were substituted for the relay contacts. The pattern durations were retained — 10 seconds for the reference pattern and 5 seconds for each of the other four patterns.

c. Power Source at the Base Stations

As the power transistors that were available were limited by their maximum collector currents rather than by their maximum collector-emitter voltages, a 24V and not a 12V battery supply was decided upon. Two 12V 95-Ah batteries are sufficient to provide power for 48 hours' operation.

Section III. PRACTICAL REDESIGN

a. The Outstation

(1) Crystal Clocks

The mains-driven synchronous motors were replaced by synchronous motors driven by a crystal clock. The components finally installed were a James Knights JKTO-26, 400-c/s, stable-frequency supply together with a 400-c/s power amplifier driving a 2-rev/min, 115V, synchronous motor. The 400-c/s supply is a transistorized, modular, plug-in unit comprising a 24V oven, a 40-kc/s crystal oscillator, buffer stages, divider stages, and a voltage regulator. The nominal working temperature of the oven is 75°C. The output is 1.5V into 5000Ω, and the stability of the output is better than ± 1 p.p.m. over ranges of battery voltage of 21.5V to 24.0V and ambient temperatures of -40°C to +50°C. This stability figure is equivalent to a possible 1-second misalignment over a period of 6 days. During tests, no trouble was experienced with this unit.

The 400-c/s amplifier consists of a single amplifier driving a class-B, push-pull, output stage that gives an output of 8W at 115V, which is sufficient to drive the timing motor. The output stage includes a negative-temperature-coefficient resistor in the bias chain to reduce the variation of bias with temperature. During trials at Fort Belvoir in March, 1961, it was found that the motor voltage fell at low temperatures to about 80V and rose at high temperatures to 130V. As a result, certain modifications were made.

First, a variable resistor was inserted in the input lead to the first stage of the amplifier, thus providing a control that covered the spread in the output of the supply.

Second, the biasing of the first stage was altered, feedback from the output stage being provided in order to stabilize the gain.

Third, a capacitor was inserted across the primary winding of the output transformer in order to tune out the inductive reactance of the motor load.

The timing motor, a 6.2W 2-rev/min unit manufactured by Haydon, gave no trouble during tests.

(2) Ovens and Crystals

In view of the overheating that was experienced during the August, 1959, demonstration, the operating temperature of the oven was increased from 50°C to 75°C. Crystals and 24V ovens were obtained from James Knights Co., who recommended that, for a stability of ± 2 to ± 3 p.p.m., ovens of type JK095, housing two crystals, should be used. The crystals were AT cut and were housed in HC6/U plug-in holders. The ovens were also of the plug-in type and had snap-action thermostats. The crystals were required to have a stability of better than ± 5 c/s over the temperature range -40°C to +50°C, but their frequencies drifted out of this range at the lower temperatures. The ovens were sent back to the manufacturers to have their heater power increased; later tests showed them to be still unsatisfactory. During the final tests in Virginia in September, 1961, the ovens were replaced by similar types manufactured by Federated Electronics Incorporated, and completely satisfactory results were obtained.

During the local field tests after the Phase-III modifications it was found necessary to take the -24V supply for the oven to ground through a capacitor to prevent r.f. pickup on the supply lead when the heater thermostat was open.

(3) Oscillators

The oscillators were of the conventional emitter-coupled Colpitts type. Overdriving of a buffer amplifier ensured a more-or-less uniform level of output signals from crystals of different activities, and a tunable output stage produced satisfactory wave shape. The oscillators, which were identical for both channels, were housed in Alden, type II, plug-in packages.

It was found necessary to use a coaxial cable for the oscillator feed to the first buffer stage and to shield the coil of that stage in order to prevent regeneration.

The supply to the collectors of the transistors in the oscillator and the buffer stage was stabilized to -6.3V by means of a zener diode. During Phase III the biasing of the oscillator was changed and transistors were selected for high common-emitter current gain (β) and low leakage current. As variation of supply voltage affected amplitude but not frequency, the supply to only the buffer stage was stabilized. Both the buffer and driver stages were simple class-A amplifiers. The driver stage used conventional potentiometer and emitter-resistor biasing on the base. A variable resistor was included in the input lead in order to control the drive. To reduce the current and increase the stability, the supply to the collector was reduced during Phase-III modifications.

(4) Output stage

For convenience, a Signal Corps Antenna Mast (AB-86/GRA-4) and whip antennae (MS116A, MS117A, and MS118A), with a total height of 55 feet, were used. Measurements by the Q-meter method showed that there was a capacitance to ground of about 160pF and an equivalent series

resistance that varied from about 30Ω in ground of good conductivity to about 200Ω in ground of poor conductivity.

Calculations gave a value of 6.6W (say, 10W) for the required power input per channel to the antenna. Two germanium transistors (2N1046) in class-B push-pull, mounted on aluminium heat-sinks, provided an output of 12W at ambient temperatures of up to $+45^{\circ}\text{C}$. It was found later that the use of a ground mat, consisting of 12 radials 50 feet long, increased the radiation efficiency of the antenna from 7% to 19%, with consequent increase in radiated power.

The heat-sinks were mounted on rails to enable their positions, and hence the coupling of the tank coils, to be adjusted for matching to the antenna under a variety of ground conductivities.

Separate biasing of the transistors was carried out by means of emitter-resistor and potential-divider circuits, and neutralization was obtained by links from each collector to the other base. During local trials the stage was found to be unstable. By detuning the antenna circuit the whole transmitter could be made unstable so that it oscillated without a crystal in circuit; when the crystal was inserted in the circuit the frequency was 'pulled'. Furthermore, when the antenna matching was poor, it was possible, because of poor load-sharing, to burn out one of the 2N1046 transistors. These faults were cured by paying attention to routing of leads and to biasing. During later modifications one neutralizing link was removed, thus increasing the stability. The biasing was further temperature-stabilized by the use of a diode in series with the resistor between each base and emitter.

A procedure for coupling both channels into the antenna was developed. By observation of the voltage across the tank coil, approximate positions for the heat-sinks could be determined. The final positions were found by observing the antenna current (as indicated by the brightness of a lamp) for different positions of the tuning capacitors and heat-sinks. A later modification was that of mounting the lamp on the front panel.

(5) Front panel

In accordance with military specifications, all controls were mounted on the front panel and knobs that were suitable for gloved-hand operation were used. Illumination was provided by edge lighting of a plastic panel.

Back and front covers were secured to the case by means of screws. This method of securing the front cover, being unacceptable to the Contracting Officer, was changed for snap-action fasteners.

Protection against reverse-polarity battery connection was provided by means of series-connected diodes, and all critical circuits were fused. The heat-sink assemblies, too, were fused, but, as it was necessary to remove the back covers in order to replace a fuse, the fuses were later mounted on the front panel.

A 1-inch, axial-flow fan, together with its filter, was mounted on the front panel, and louvres were punched in the back cover for air exits;

this arrangement provided cooling of the 400-c/s amplifier and the heat sinks. However, the cooling was insufficient; so a 3-inch fan was mounted in the base of the unit with a filter underneath it. To accommodate this fan, the heat-sink of the 400-c/s amplifier was modified slightly.

(6) Station selection

To provide for alternate switching of Outstations every 30 seconds, it was necessary to use a station selector, which consisted of a Ledex selector that stepped the rotor of a 12-position wafer switch one position every time the selector was pulsed, i.e., once every thirty seconds. Alternate contacts on the switch were strapped together and power to the buffer, driver, and output stages of the transmitter was applied through the rotor and the strapped contacts of the switch. During the February-March, 1961, demonstrations in Virginia, the alternate switching broke down periodically, with the result that there was simultaneous transmission from the Outstations. The cause was eventually traced to deterioration of the microswitch used for breaking the selector current (1 amp inductive). This fault was cured by replacing the microswitch by one with a larger gap (0.032") and shunting it by a large electrolytic capacitor. During the Phase-III modifications it was shunted instead by a 50 Ω 5W resistor to increase reliability.

b. The Control Station Transmitter

The circuitry and the construction of the Control Station transmitter were similar to those of the Outstation transmitter. Points of dissimilarity were: an extra oven to contain the extra crystals, altered switching arrangements, crystals of different frequencies, connections to the Control unit, two, separate, battery-supply connections, and the inclusion of suitable frequency-adjusting parameters, an f.m. oscillator, and harmonic filters in the output tank circuits.

(1) Pattern switching

The sequence of pattern switching of both the Outstation and Control Station transmitters is shown in Figure 3.

(2) Control circuitry

To counteract the feedback between circuits, it was necessary to house the control section in a separate case, thus forming the Control Unit. The transmitter was, therefore, connected to the Control Unit by means of two cables that carried the power and the controlling signals.

(3) F.M. oscillator

A frequency-modulated oscillator was necessary for the generation of the ROUGH FINE pattern on the lower channel. In order to maintain simplicity of circuitry, a square-wave modulation was used. (This point is treated further in Section III b of Chapter 3.)

The first circuit was a conventional emitter-coupled Colpitts oscillator with a Varicap across the L-C section. As the circuit had poor temperature stability, the L-C combination was replaced by a 1611-ke/s crystal, which had its parallel capacitance tuned out by another L-C circuit. Because of drifting of the crystal frequency, the oscillator was re-designed

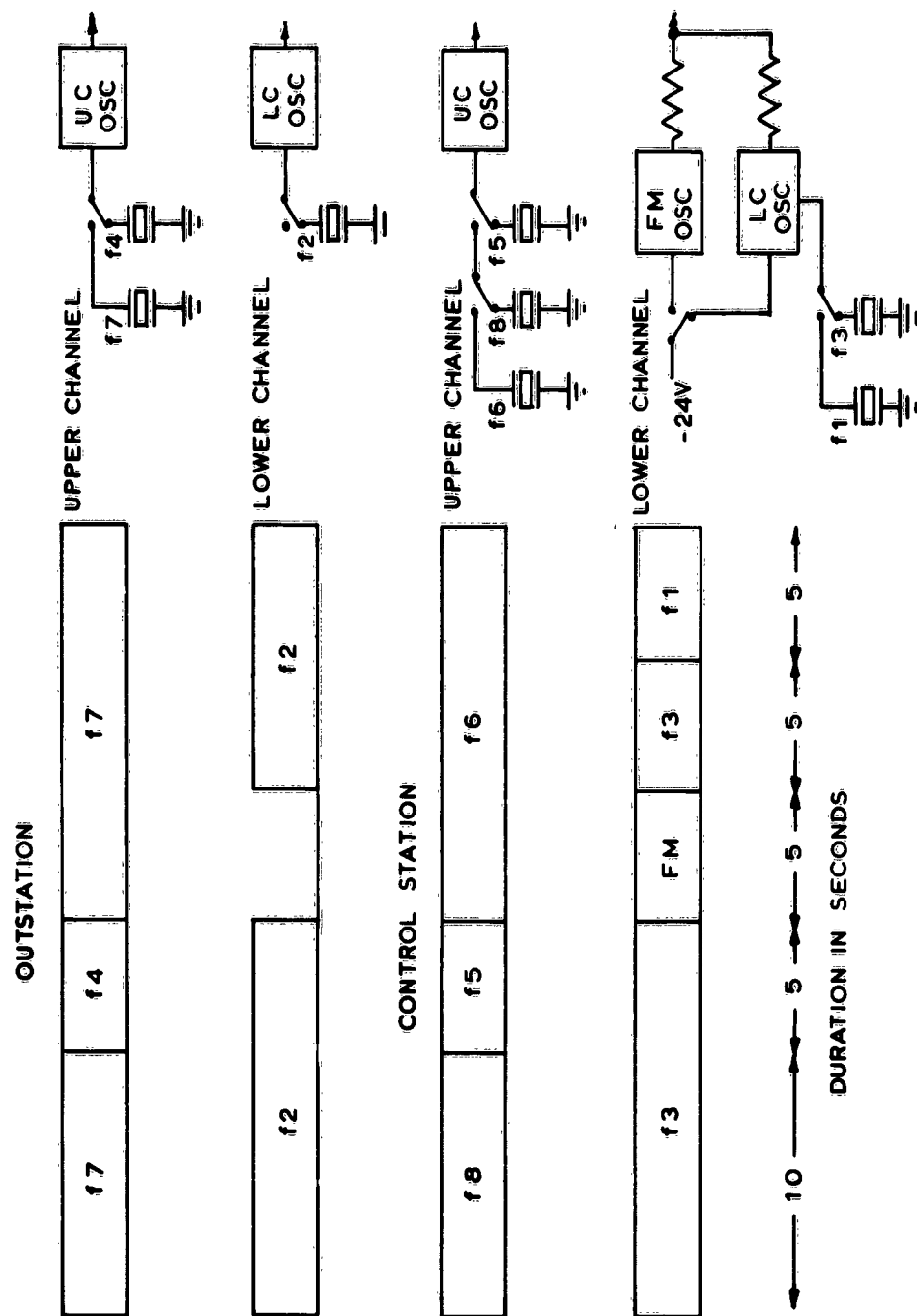


Figure 3. Pattern Time-sharing System

so as to switch between two crystals, of frequencies 1611 and 1616 kc/s. Transistors that were triggered by the f.m. signal were used as switches. This arrangement proved to be highly satisfactory.

(4) Harmonic filters

Various anomalies in the patterns were found to be caused by comparison-frequency beats between the tenth harmonic of the lower channel and the ninth harmonic of the upper channel. To counteract these anomalies, filters that were series tuned to each channel were inserted in the tank circuit of the other channel. Detuning effects at the operating frequencies had to be tuned out by suitable reactances, which also afforded a means of fine tuning of the filters.

(5) Battery supplies

A 400-c/s ripple that was injected into the power line by the 400-c/s supply produced a deleterious modulation on the transmitter output. In consequence, a separate lead was taken direct from the battery to the 400-c/s supply and a number of non-critical circuits, the original lead being kept for the rest of the circuitry. It was necessary to by-pass the supplies to ground at the oscillators in order to prevent regeneration.

c. The Control Unit

(1) Channel amplifiers

The main problem in the redesign of the channel amplifiers concerned the a.g.c. system, where the control obtainable with transistors is less than with vacuum tubes. The most satisfactory method of obtaining a.g.c. was found to be in the use of the logarithmic properties of a diode that shunted one of the tuned circuits. Considerable decoupling was necessary, and an additional, preset gain control was included in each stage to adjust for the extremely low signals likely to be encountered over long base lines.

To prevent coupling between amplifiers it was necessary to decouple each amplifier.

(2) Phase-sensitive rectifier

The design of the phase-sensitive rectifier, which was used as a discriminator, was conventional. Transistors that were connected in the inverse mode as synchronized series and shunt switches were used; they gave an output voltage proportional to the degree of coincidence of two signals = one squared and the other shifted 90° in phase and then squared. Several types of squarers were tried out, the most satisfactory being that in which the wave is clipped by feedback applied from collector to base by means of matched diodes.

(3) Filters and d.c. amplifiers

The low-pass filter, which followed the phase-sensitive rectifier, was designed to remove the 200-c/s signals and yet to have, at a frequency of 10 c/s, sufficiently low attenuation to provide the output that the servo loop required for correcting, within a fraction of a second, a frequency drift of 10 c/s.

The filter consisted of three sections, each having an attenuation of 20dB per decade (i.e., per frequency change of 10 times), and one section with an attenuation of 40 dB per decade. Of the first three sections, two had stepped characteristics, and one of those had a variable-base characteristic for adjusting the stability of the servo loop.

In the d.c. amplifiers, a virtual-ground input stage presented a low impedance to the phase-sensitive rectifier. Silicon transistors were used because of their low leakage currents and small variation of leakage current with temperature. Residual variations were taken care of by various balancing and biasing adjustments.

(4) Stabilized power supply

It was necessary to design a stabilized power supply for the phase-sensitive rectifier and d.c. amplifiers. A conventional regulator was used to supply a potential of -18V.

(5) Monitor circuit

A cathode-ray-tube, with its own high-voltage supply, was included in the unit for monitoring purposes. The circuit was similar to that used in the Search Receiver.

During the Phase-III modifications, the high-voltage supply and the c.r.t.-heater supply were derived from separate dropping resistors. This modification was designed to prevent damage to the high-voltage supply, which could be caused by overloading if the c.r.t. filament should become open-circuited.

(6) Controls

In the earlier equipment, some controls could be adjusted only by a screwdriver. The fault was remedied by bringing all controls out to the front panel and fitting knobs to the shafts. The controls were rearranged to increase ease of operation, and the wording of the engraving was made more descriptive from the operational aspect.

(7) Test oscillator

In order to set the crystal frequencies or trace faults in the earlier equipment, it was necessary to use an external 200-c/s oscillator. During Phase III of the Contract a variable-frequency (185-215 c/s) test oscillator was built into the Control Unit.

d. The Synchronizing Receiver

The original Synchronizing Receiver consisted of two filters, feeding two detectors, and a suitable whip antenna. During transistorization of the equipment, an amplifier for increasing the sensitivity of the circuit was included in each channel.

An amplifier consisted of two stages, which obtained voltage supplies for their collectors via the synchronizing cables from the Control Unit. The first stage was a low-noise amplifier.

Monitoring, for purposes of tuning, was provided by a switched meter (25 μ A) suitably damped to prevent its acting as a noise generator when the antenna was swaying in the wind.

The circuitry was built into a waterproof, ruggedized case. The antenna insulator was fastened directly onto the mounting post so that the vibration of the antenna should not be transmitted to the case.

e. The Filter Unit

The design of the original Filter Unit was not altered except that the unit was encapsulated. However, operation showed that encapsulation was a disadvantage, in that failure of one component necessitated replacement of the complete unit. As a result, the components were later mounted inside a cast box.

f. The Search Receiver

As the original Search Receiver proved to be satisfactory, it was decided to alter the circuitry as little as possible. Modifications were carried out only in respect of frequencies, selection of components, and mechanical construction.

(1) Frequencies

In the original equipment the frequency of the local oscillator was 1931.500 kc/s, which, in conjunction with the Outstation frequencies of 1648.350 kc/s, 1665.000 kc/s, and 1831.500 kc/s, produced intermediate frequencies of 100 kc/s in the upper channel and 266.500 kc/s and 283.150 kc/s in the lower channel.

Because of the change of Outstation frequencies to 1611.000 kc/s, 1772.100 kc/s, and 1790.000 kc/s, the frequency of the local oscillator was changed to 1509 kc/s, which produced intermediate frequencies of 263.1 kc/s and 281.0 kc/s in the upper channel and 102.0 kc/s in the lower channel.

(2) Batteries

In the original receiver a single 7 1/2V battery, tapped at 1 1/2V, supplied the power for the heater and the electron beam of the c.r.t. and for the transistor circuits. However, since the performance of the transistor circuits deteriorates more rapidly with falling battery voltage than does that of the cathode-ray tube, it was decided to use a separate, smaller battery (7 1/2V) for the transistor circuits in order that the battery for the cathode-ray tube might be discharged to a voltage lower than was acceptable for transistor operation. The 6V battery gave 8 hours and the 7 1/2V gave 24 hours of continuous operation. As receivers are normally used intermittently, it was considered that these battery capacities would suit the requirements of the system in field operation.

(3) Cathode-ray tube

The CV2175 cathode-ray tube was replaced by a Philips DG7-32, which type had been extensively used by the Contractor and had the advantage of having a conductive coating, which eliminates screen-charge effects. Zener diodes were included to stabilize trace positioning voltages, which previously had varied with the setting of the trace-brightness control. It was later found necessary to decouple the zener diodes from other parts of the circuit in order to reduce the propagation of the noise generated in the diodes.

(4) I.F. amplifiers

The original coils were designed for use with 0C44 transistors; these were replaced by 0C170 transistors, which do not require neutralization. Because of the different input and output impedances it was necessary to re-design all the coils. It was also necessary to increase the emitter currents of the 0C170 transistors in the upper channel amplifier to provide more gain. The limiting diodes in each of the original i.f. amplifiers were removed when the a.g.c. arrangements were changed.

(5) A.G.C. system

Owing to saturation of the i.f. amplifiers and consequent lack of signal for the system that generated a.g.c. from the comparison-frequency signals, it was difficult to operate the first modified receiver near a transmitter. A diode limiter after the second stage of each i.f. amplifier was found to be unsatisfactory as a remedy. Examination of the a.g.c. system showed that the control of the gain of the r.f. amplifier, by the d.c. outputs from the detector, was incapable of preventing strong signals from overloading the detector. The gain of the i.f. amplifier was therefore controlled by the d.c. output from the detector and by the voltage from the detector in the comparison-frequency amplifier, whereas the gain of the r.f. amplifier was controlled by the output from a special detector that was fed by an a.g.c. amplifier following the r.f. amplifier. This arrangement enabled the receiver to function, without amplifier saturation, at distances of a few hundred yards from a transmitter.

(6) Mechanical construction

During the Phase-III tests in February-March, 1961, it was found that, owing to its freezing, the cursor-drum assembly became inoperable at low temperatures. In consequence, the mechanical clearances were increased and a special low-temperature grease was used. Because of the difficulty of reading the red line of the cursor at night, the length of the line was increased. A machined, cast front panel was used in place of the fabricated front panel of the earlier model, and a new type of case, with improved water-proofing, and a canvas bag with a strap were provided.

All controls were brought out onto the front panel, and knobs that permitted operation with gloved hands were fitted. The panel was provided with edgewise illumination for night-time operation. Because of the unitized construction, the lid, the waterproofing, and the greater size of the batteries and c.r.t., the volume of the modified Search Receiver was about 80% greater than the volume of the original instrument.

g. The Co-ordinate Converter

(1) General

Various methods of converting hyperbolic co-ordinates to U.T.M. co-ordinates were investigated.

The requirement was for a light-weight computer (weighing not more than 10 lb), powered only by internal batteries (if batteries are necessary),

capable of being set up for various base-line configurations, and of sufficient accuracy not to degrade the accuracy of the information that is fed into it. Further, it had to be rugged enough for field use and operable by non-specialist military personnel. Among the devices were:

Concentric-circle Plotter
Digital Computer
Electronic Analogue Computer
Mechanical Analogue Computer

(2) Concentric-circle plotter

This method, which was described in Section III.2.2 of the Phase-II Report, was regarded as being accurate but unsuited to operation in the field by unskilled personnel.

(3) Digital computer at the receiver

An investigation into the possibility of designing a light-weight, transistorized, fixed-programme computer, having an error of less than 1 part in 10 000, showed that the price and size would be several times those of the Search Receiver; so the investigation was discontinued.

(4) Electronic analogue computer

No detailed investigation was undertaken, because it appeared to be unlikely that a computer that was more accurate, less costly, and smaller in size and weight, than a mechanical analogue computer, could be developed.

(5) Mechanical analogue computer

(a) Type A After considerable work and the carrying out of field trials, the investigation of this computer was discontinued because it was felt that the computer was a laboratory instrument rather than a field instrument: the high precision and accuracy that was involved in its manufacture detracted from the required ruggedness of the equipment.

(b) Type B This computer is described in Section III.2.6 of the Phase-II Report. Only two modifications were made during Phase III: one was to replace the jockeys of the three common-range arms by racks and pinions, and the other was to replace the millimetre scale and vernier by a Mercer dial.

Section IV. DERIVATION OF FORMULAE

a. Phase Velocity of Ground Waves

The phase of a signal at any point is a function not only of the separation of that point from the transmitter but also of the interference between the induction field and the radiation field and of the electrical constants of the ground.

The formula involving the radiation, magnetic induction, and electrostatic induction fields was discussed in Section III.3.2 of the

Phase-II Report. The effect of attenuation on the phase of the received signal was discussed in Section III.3.3 of that Report. A graphical method of correcting for the phase lag was derived.

b. Accuracy Contours

In Appendix I of the Phase-II Report the formulae pertaining to coverage area were discussed in respect of different base-line configurations. In Appendix II of that Report was given the derivation of the equations connecting the error of position with the position of the point relative to the base lines. Error contours were plotted for a variety of base-line configurations.

c. Conversion from Hyperbolic to Rectangular Co-ordinates

In Appendix III of the Phase-II Report the formulae for converting hyperbolic into rectangular co-ordinates were derived.

d. Power Output from the Outstation Transmitter

For design purposes the equivalent series resistance and the capacitance to ground of the antenna were taken as 50Ω and 160pF , respectively. At a mid-band frequency of 1700 kc/s , the wavelength $= 580$ feet and $h/\lambda = 0.095$, where h is the physical height of the antenna ($= 55$ feet).

Then the radiation resistance is ⁽¹⁾

$$R = 400h^2/\lambda^2 = 3.6\Omega$$

and the radiation efficiency is 7%.

For average ground the conductivity and permittivity can be taken as ⁽²⁾

$$k = 3 \times 10^{-4} \text{ e.m.u. and } e = 4$$

Then the phase constant b is given by ⁽³⁾

$$\tan b = (e + 1) \frac{f}{1.8 \times 10^{18}}$$

$$= 0.16$$

where f is the frequency in kc/s .

Then $b = 9^\circ$.

For a range $d = 64\text{ km}$ (40 miles), the numerical distance p is

$$p = \frac{\pi d}{\lambda} \cos b \left(\frac{f}{1.8 \times 10^{18}} \right)$$

$$= 35.3.$$

From graphs ⁽³⁾, the reduction factor A is then found to be 0.015.

Under normal noise conditions, the ultimate sensitivity of the Search Receiver can be taken to be $1\frac{1}{2}\text{ }\mu\text{V/metre}$. Hence, putting the field strength E equal to this figure, the required radiated power is

$$P = \frac{(E d)^2 \times 10^{-3}}{186.4 A \times 10^3} = 0.46\text{W}$$

Since the efficiency of the antenna is 7%, the power input per channel must be

$$\frac{0.46}{0.07} = 6.6W$$

$$= 10W, \text{ say.}$$

e. Outstation Antenna Coupling

The output stage of the Outstation comprises two 2N1046 transistors in class-B push-pull, which for a 15V swing, have a load per transistor of 22.5Ω and a collector-to-collector load of 90Ω . Since a loaded Q of 30 is necessary for the suppression of harmonic radiation and the elimination of intermodulation effects, the equivalent series load resistance is

$$R_s = R_p / Q^2$$

$$= 90 / 900$$

$$= 0.1\Omega$$

For an antenna series resistance of $R_o = 50\Omega$, the coupling required between the output stage and the antenna is

$$M = (R_o R_s) / 2\pi f$$

$$= 0.2 \mu H$$

Section V. TEST RESULTS

a. General

Initial trials (see Section IV .1 .1 of the Phase-II Report) were carried out in South Africa. No definite measurements were made, but the trials enabled certain design faults to be eradicated.

Two sets of trials were undertaken at the Warrenton, Va, test site, the first in February-March, 1961, and the second in September, 1961.

The configuration of the base and receiving stations is shown in Figure 4.

b. Tests in February-March, 1961

Position measurements were carried out, using two base-line systems: Woodbourne - Greenview - Lee (8.4 km) and Tapp - Greenview - Williams (16 km). The detailed results of the tests are shown in Tables 1 and 2.

A summary of the results of the first set of tests is as follows:-

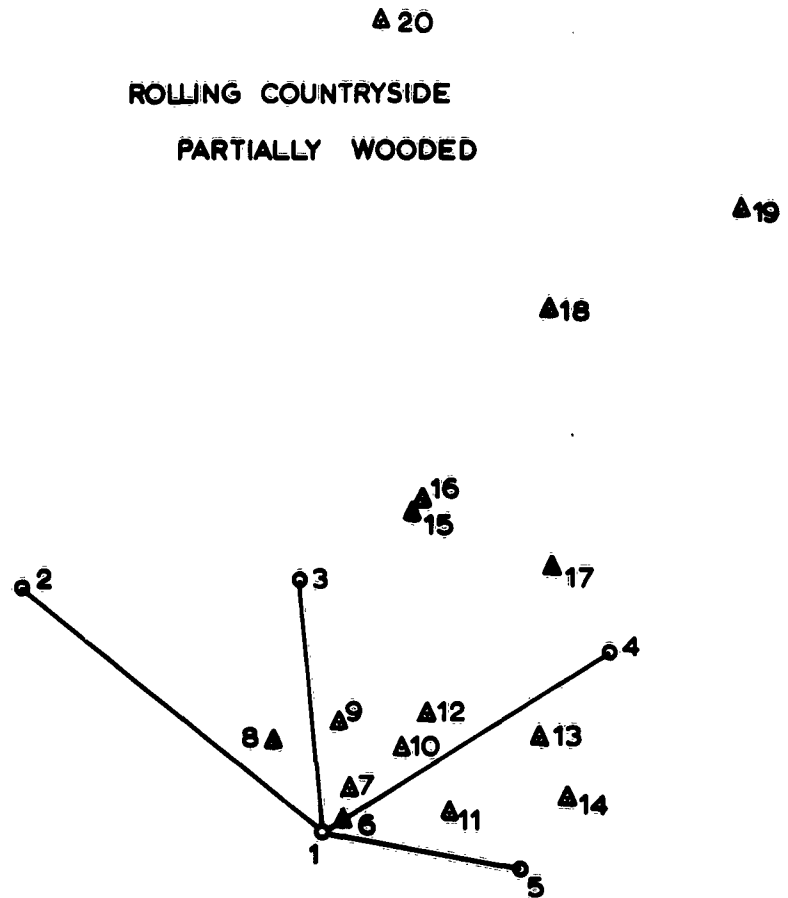
Woodbourne - Greenview - Lee

<u>Woodbourne - GV base line</u>		<u>Lee - GV base line</u>	
Zero correction	+ 70.9 b.u.	Zero correction	-8.1 b.u.
Mean error	4.9 b.u.	Mean error	2.7 b.u.
R.M.S. error	3.8 b.u.	R.M.S. error	2.3 b.u.
Peak error	7.6 b.u.	Peak error	5.6 b.u.

- 1 GREENVIEW
- 2 TAPP
- 3 WOODBOURNE
- 4 WILLIAMS
- 5 LEE
- 6 ROUTS HILL
- 7 TVS-A1
- 8 STEINER
- 9 PARADISE
- 10 TVS-B1
- 11 OPAL
- 12 SAND
- 13 HURLEY
- 14 MEADOW
- 15 WARRENTON
- 16 DAKOTA
- 17 MEETZ
- 18 BALTIMORE
- 19 STANTON
- 20 RAMEY

1-2 16,720m
 1-3 8,697m
 1-4 12,447m
 1-5 7,418m

$\angle 315 = 105^\circ$
 $\angle 214 = 126^\circ$



TEST AREA TERRAFIX TRIALS
WARRENTON, VA. FEB-MAR 1961

Figure 4. Configuration of Test Stations

The actual errors are shown plotted against actual readings in Figures 5 and 6.

The fact that the Woodbourne - Greenview base line gives considerably worse results than the Lee - Greenview base line can possibly be ascribed to the relatively poor siting of the Woodbourne position.

A summary of the results of the second set of tests is as follows:-

Tapp - Greenview - Williams

<u>Tapp - GV base line</u>		<u>Williams - GV base line</u>	
Zero correction	+ 130.8 b.u.	Zero correction	+32.1 b.u.
Mean error	2.4 b.u.	Mean error	2.96 b.u.
R.M.S. error	2.1 b.u.	R.M.S. error	2.46 b.u.
Peak error	3.8 b.u.	Peak error	5.1 b.u.

The actual errors are shown plotted against actual readings in Figures 7 and 8.

Table 1

8-km base line with 105° base angle

Station No.	Station	R	DN	DE	DR	DR/R	
4	Williams	12446.64	+0.32	+12.11	12.1	1:1028	1 ft from wire fence
6	Routs Hill	950.53	-37.54	-63.94	74.1	1:12	
7	TVS-A1	1774.49	-1.98	+7.80	8.0	1:222	
8	Steiner	3621.06	+2.99	+9.04	9.5	1:381	
9	Paradise	3950.28	-0.14	+7.83	7.8	1:506	
10	TVS-B1	4049.15	-5.87	+4.15	7.2	1:562	
11	Opal	4676.38	-10.98	-2.89	11.4	1:410	
12	Sand	5485.97	-6.47	-0.11	6.5	1:844	
13	Hurley	7911.10	-10.04	-4.10	10.8	1:733	
14	Meadow	8421.50	-14.36	-24.21	28.2	1:299	
15	Warrenton	11241.79	-498.52	-272.50	568.1	1:20	6 ft from fence and under power lines
16	Dakota	11287.21	+12.84	+9.12	15.8	1:714	
17	Meetz	12277.28	+31.36	+29.63	43.1	1:285	

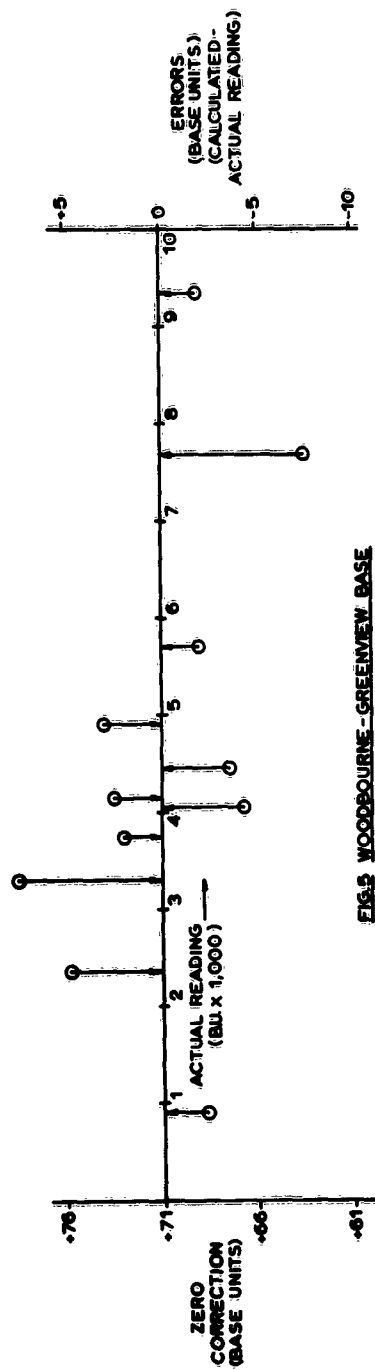


FIG. 5 WOODBOURNE-GREENVIEW BASE

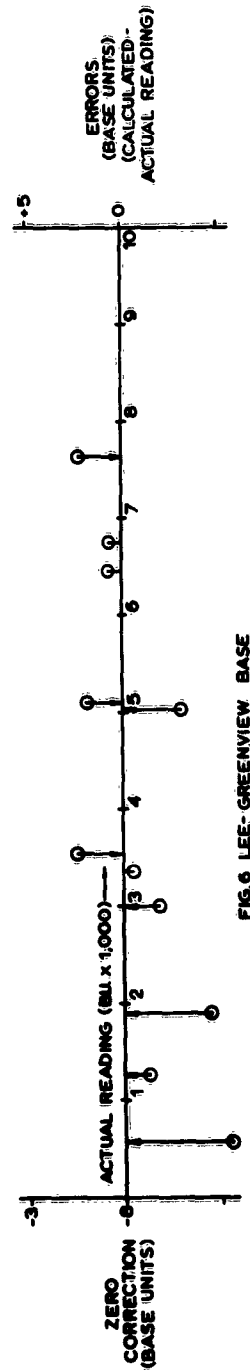
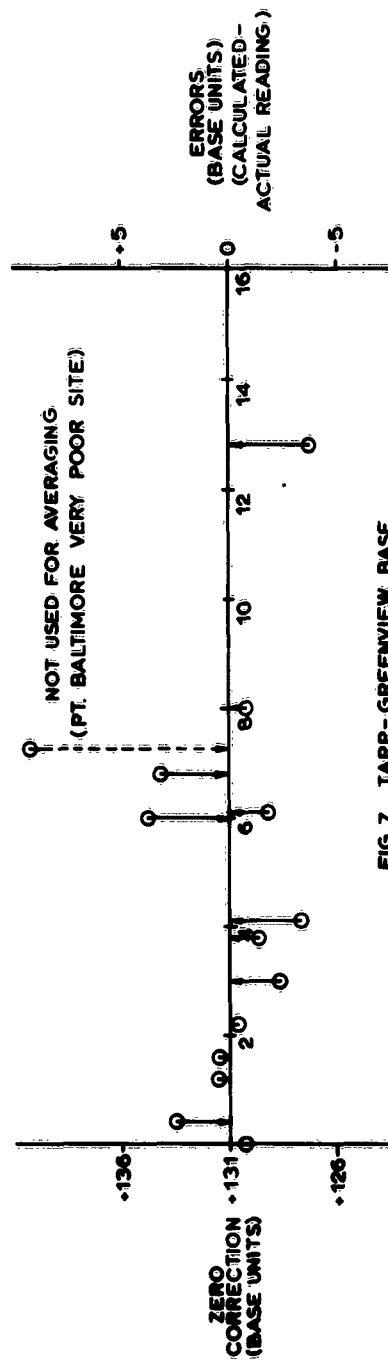
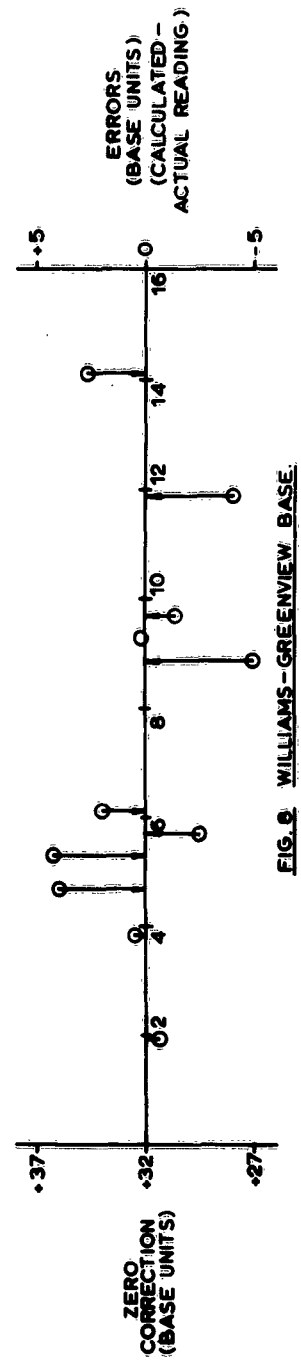


FIG. 6 LEE-GREENVIEW BASE

Figures 5 and 6. Errors for Woodbourne-Greenview-Lee Base Line, March, 1961



ACTUAL READING (B.U. x 1,000) →



Figures 7 and 8. Errors for Tapp-Greenview-Williams Base Line, March, 1961

Table 2

16-km base line with 126° base angle

Station No.	Station	R	DN	DE	DR	DR/R	Remarks
3	Woodbourne	8697.22	+5.01	+1.06	5.12	1:1699	
8	Steiner	3621.06	+4.86	+4.70	6.76	1:536	
9	Paradise	3950.28	-0.70	-6.36	6.57	1:602	
10	TVS-B1	4049.15	+4.88	+5.93	7.88	1:514	
11	Opal	4676.38	-3.50	+2.11	3.83	1:1200	
12	Sand	5485.97	-5.27	-3.17	6.15	1:892	
16	Dakota	11287.21	-3.50	+2.79	4.48	1:2519	
18	Baltimore	20613.11	-21.87	+6.97	22.95	1:898	4 ft from wire fence
19	Stanton	29558.40	-17.19	-40.56	44.05	1:671	
20	Ramey	32375.54	-2.28	-10.42	10.67	1:3034	

In the above Tables, R = Range, DR = Range error, DN = Mean northing error, and DE = Mean easting error.

c. Tests in September, 1961

The results of the first set of tests are shown graphically in Figures 9 and 10. A summary of these results is as follows:-

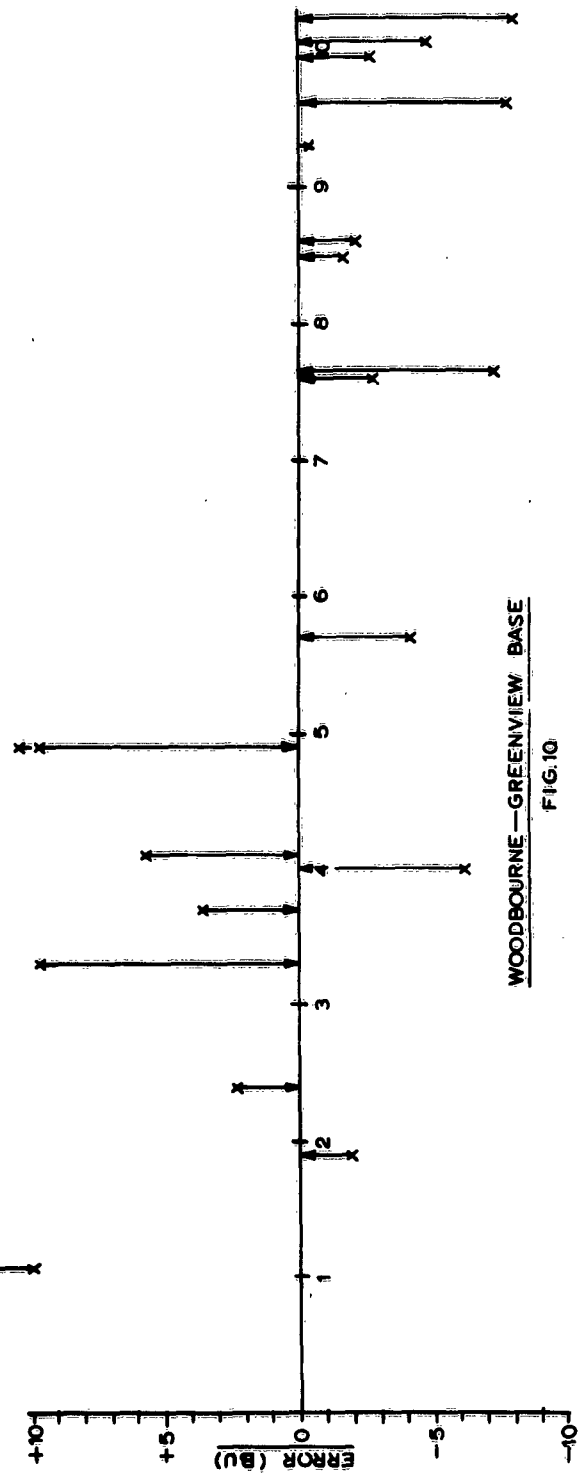
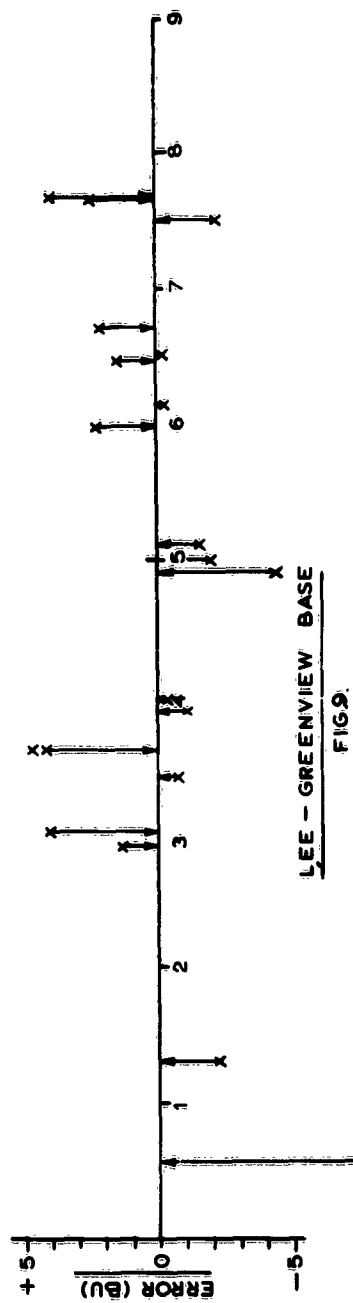
Woodbourne - Greenview - Lee

<u>Woodbourne-GV base line</u>		<u>Lee-GV base line</u>	
Zero correction	+87.4 b.u.	Zero correction	+26 b.u.
Mean error	6.2 b.u.	Mean error	2.7 b.u.
R.M.S. error	6.1 b.u.	R.M.S. error	3.6 b.u.
Peak error	10.6 b.u.	Peak error (Steiner)	10.8 b.u.

If the point Steiner is not used, the error for Lee-Greenview would be as follows:-

<u>Lee - GV Base Line</u>	
Zero correction	+26 b.u.
R.M.S. error	2.7 b.u.
Mean error	2.3 b.u.
Peak error	4.7 b.u.

The above results are very similar to those obtained during February, 1961, and again cast doubt on the Woodbourne transmitting site. A second test in the Warrenton area was undertaken during the period 26th - 29th



Figures 9 and 10. Errors for Lee-Greenview-Woodbourne Base Line, September, 1961

September, this time using Riverland instead of Woodbourne as one Out-station site. A similar procedure was carried out and the results obtained are as follows:-

Riverland - Greenview - Lee

Scale velocity: 299.800 km/s. Factor: 1.67487

<u>Riverland - GV base line</u>		<u>Lee - GV base line</u>	
Zero correction	+78.5 b.u.	Zero correction	+26 b.u.
Mean error	2.5 b.u.	Mean error	2.8 b.u.
R.M.S. error	2.9 b.u.	R.M.S. error	3.4 b.u.
Peak error	5.4 b.u.	Peak error	6.3 b.u.

The error distribution curves are shown in Figures 11 and 12. The curve for Lee - GV shows a bias of 2 divisions. Hence, the adjusted zero correction would be +28 b.u., giving the following results (see also Fig.13):-

<u>Lee - GV base line</u>	
Zero correction	+28 b.u.
Mean error	2.5 b.u.
R.M.S. error	2.7 b.u.
Peak error	4.7 b.u.

The GV - Lee base-line calibration was the first to be undertaken by inexperienced operators. Hence, the value of +26 b.u. could well be suspect.

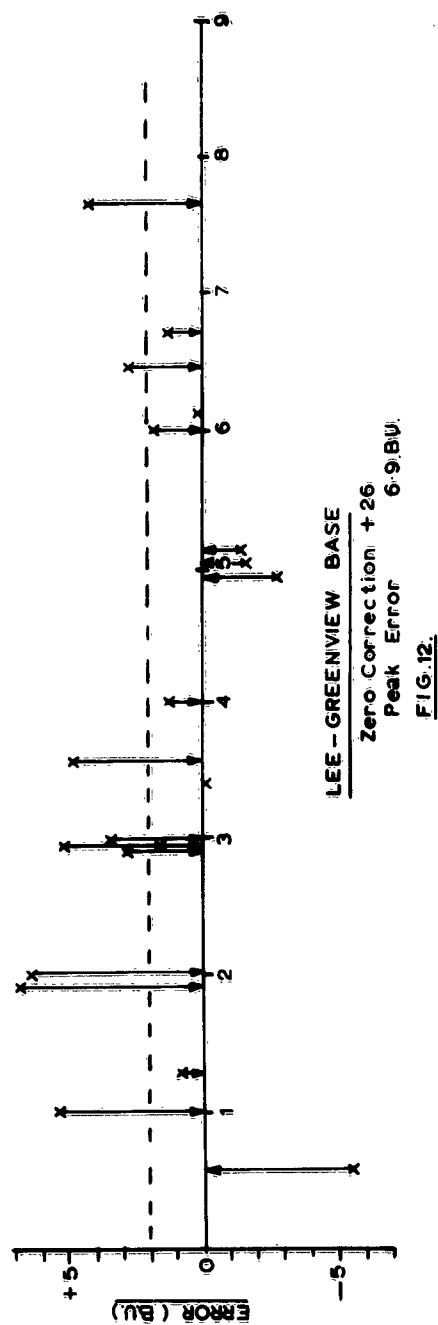
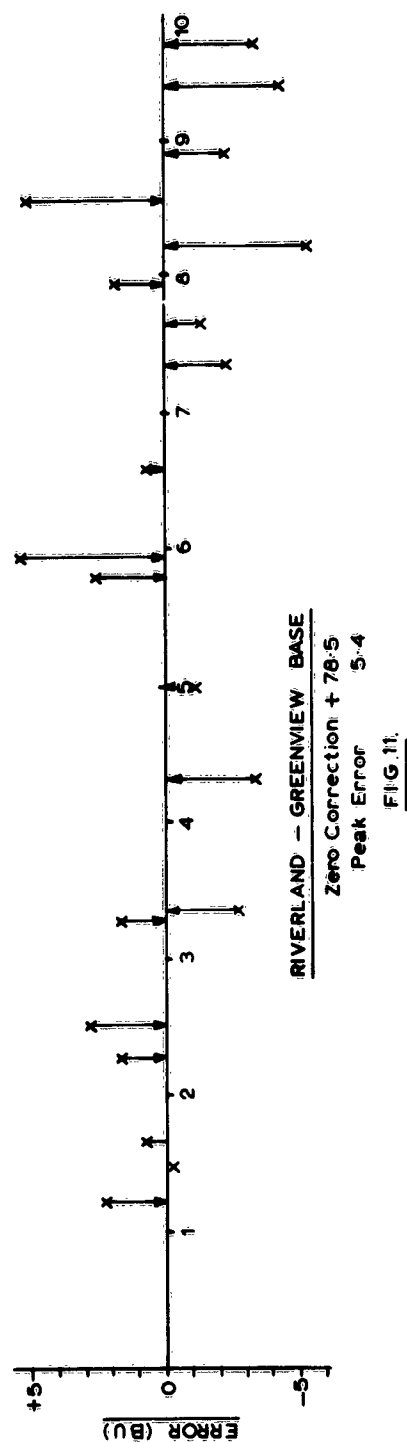
The calibration curve is shown in Figure 14 and the range correction curve in Figure 15.

The following positional errors are available at this time. Complete results from the GIMRADA computer have not yet been received by the Contractor.

Point	Northing error (metres)	Easting error (metres)
Sand	3.1	6.5
Hurley	5.4	4.4
Meadow	0.8	9.3
Dakota	3.2	2.7
TVS-B1	3.8	4.4
Meetz	8.0	7.4
Williams	11.2	6.5

Section VI. SPECIFICATIONS

A complete set of engineering drawings has been supplied by the Contractor. These drawings are fully explanatory and enable any mechanical part of the equipment to be fabricated.



Figures 11 and 12. Errors for Riverland-Greenview-Lee Base Line, September, 1961

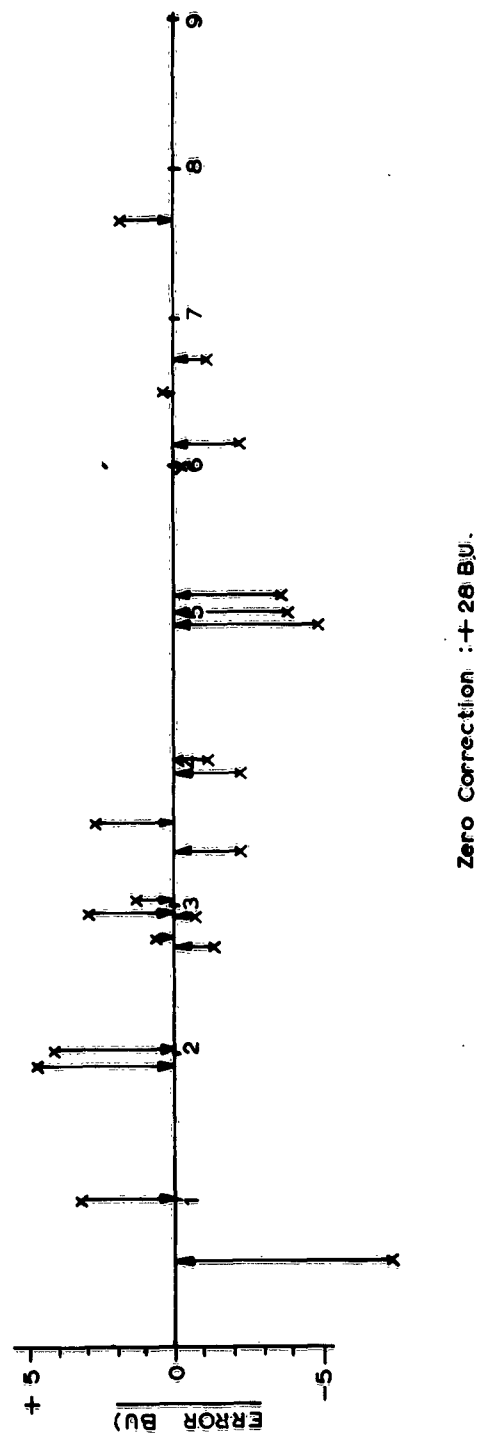


Figure 13. Errors for Lee - Greenview Base Line, September, 1961

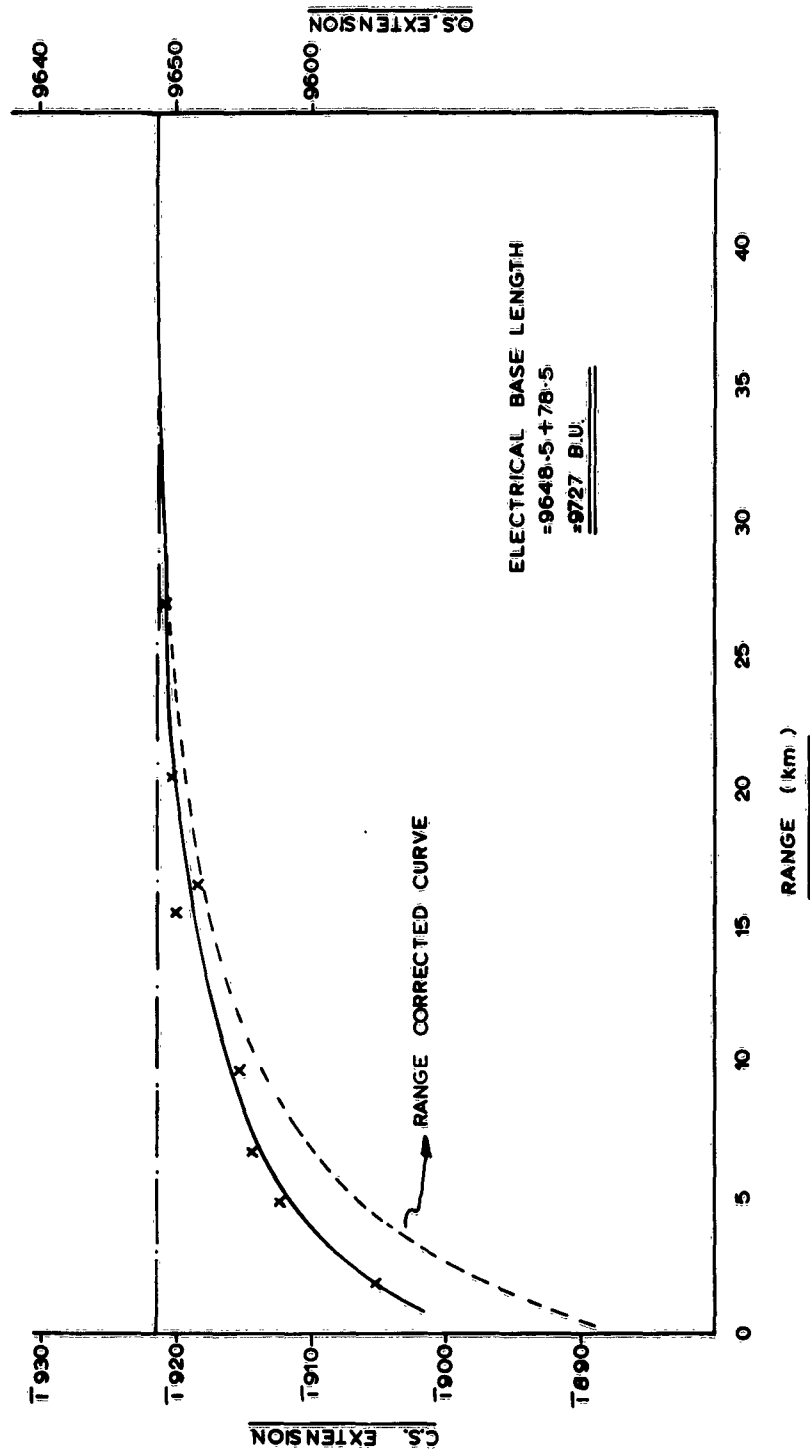


Figure 14. Calibration Curve for Riverland - Greenview Base Line

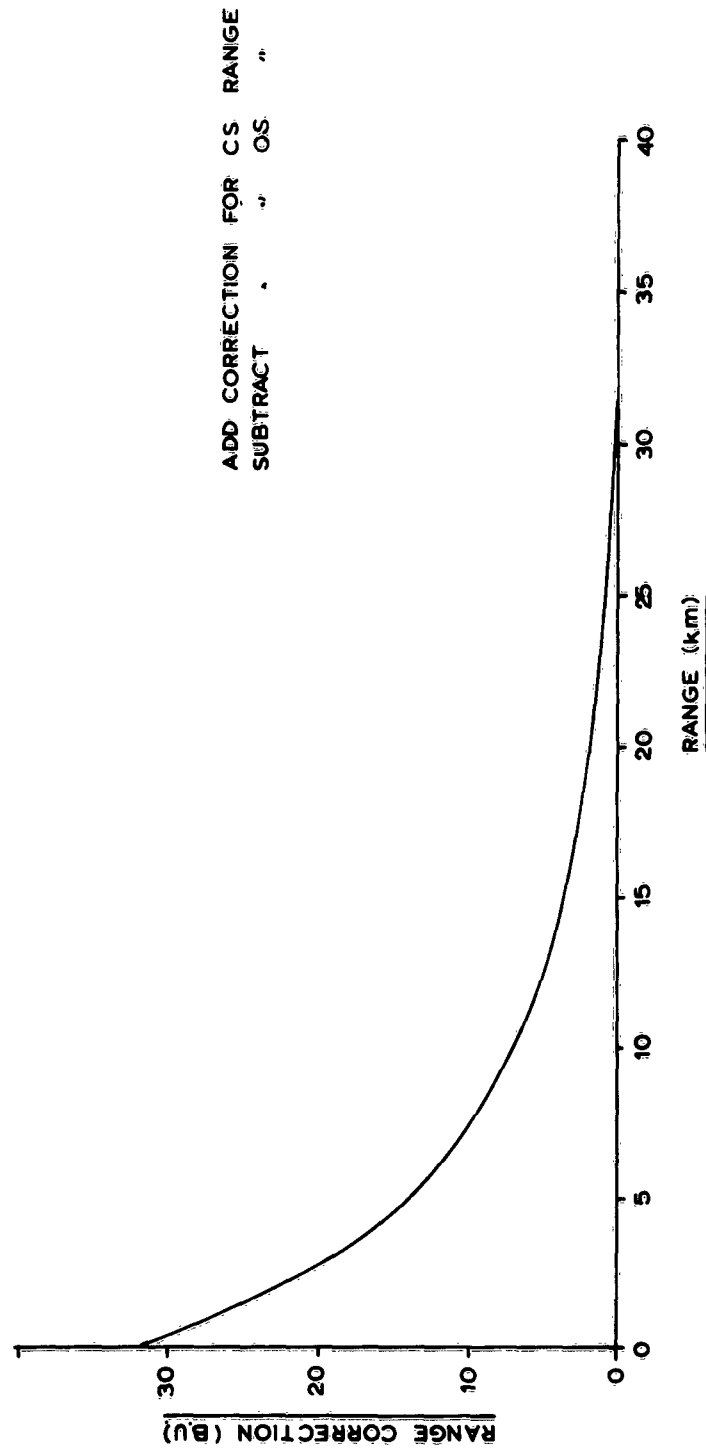


Figure 15. Range Correction Curve for Riverland - Greenview - Lee Base

Circuit schematics and all electrical specifications are contained in the Instruction Manual for the Part II Maintenance of the equipment.

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CHAPTER 3

DISCUSSION

Section I. FREQUENCIES

a. Pattern Frequencies

In order to correct the error associated with the ROUGH FINE pattern, it is necessary for one of the Outstation patterns to have a relative frequency of exactly 100 units. If all the difference patterns are to be read in the same sense relative to one reference pattern, that pattern has to be the REVERSE MEDIUM pattern with a relative frequency of -10 units.

For a DOUBLE FINE pattern (FINE-REVERSE MEDIUM) of +200 units, the FINE pattern frequency has to be +190 units. This means that the other channel has to be on a frequency of +90 instead of, as previously, +110 units.

The ROUGH FINE modulation must be on the lower channel, as, too, must the synchronizing control. Therefore, the sidestep to COARSE (i.e., the reduction, on switching from the reference pattern to the COARSE pattern, of both the Outstation and the Control Station frequencies on one channel) has to be on the upper channel, with a relative frequency of +99 units. This gives a pattern frequency of -9 units and a COARSE DIFFERENCE pattern frequency of +1 unit.

The pattern frequencies (given in Section IIa of Chapter 2) were selected to be in the band 1605-1800 kc/s as a compromise. On one hand, the lower the frequency is, the greater is the range over which measurements can be made, all else being equal; but at low frequencies, for a given maximum height of antenna (determined by considerations of portability), the antenna efficiencies are low and hence, for a given range, the power fed into the antenna has to be high. On the other hand, the higher the frequency is, the greater is the antenna efficiency (for a given maximum height of antenna) and hence the less is the power required; but at high frequencies the surface wave is greatly attenuated and, consequently, the maximum range is reduced. Furthermore, atmospheric noise is greater at lower than at higher frequencies.

The compromise is, therefore, between maximum range, maximum

antenna efficiency, and minimum noise. That is, the frequency that gives maximum signal strength at the required range must be selected.

For these reasons the band 1605-1800 kc/s was chosen.

b. The Intermediate Frequency

Once the pattern frequencies had been selected, the requirements for the intermediate frequency were that it should not be within 40 kc/s of a beat between harmonics of the pattern frequencies, and yet it should not be high because, in order to reduce the effect of noise, a small bandwidth was desired.

The values that were chosen for the intermediate frequency were 102 kc/s for the lower channel and 263.1 kc/s and 281 kc/s for the upper channel.

c. The Comparison Frequency

The comparison frequency (i.e., the difference in frequency between Outstation and Control Station patterns on either the lower or the upper channel) should be as low as possible in order to keep the two frequencies on each channel close together. At the same time, a lower limit is set by the size of the components.

At 200 c/s the components are not too large and the difference between Outstation and Control Station pattern frequencies is sufficiently small.

d. Continuous-wave and Pulse Systems

Although the Contract specified that a c.w. system should be used, prior investigation had shown that such a system had advantages that could not be equalled by a pulse system.

In a pulse system, the time of travel of short pulses over the distance is measured. Although the methods of measuring time are accurate, a small error in the measurement leads to a relatively large error in the equivalent distance, owing to the velocity of the pulse train. On the other hand, in a c.w. system the phase difference between two waves is measured. Even a large error in the measurement of phase leads to only a relatively small error in the equivalent distance, since a complete phase change on the finest pattern is equivalent to a distance of only 84 metres along the base line (at the frequencies in use).

The advantage of the c.w. system, then, is its accuracy, which is many orders higher than that of a pulse system. This advantage outweighs the advantages that a pulse system has over a c.w. system in respect of greater range, for the same average power output, and discrimination against the sky wave.

Section II. OPERATIONAL CONSIDERATIONS

a. Base Lengths

For a pattern frequency of 1790 kc/s, a change of one complete cycle of phase is equivalent to a distance change of 83.7 metres along the base line. For the coarsest of the read-out patterns, the equivalent value is

8.37 km. A base line that is 8.37 km long is then equal to 10 000 base units.

Base lengths should not be reduced much below about 6 km as positional error at a given range increases with decrease in base length. Base lengths greater than 8.37 km produce receiver readings that are ambiguous to 10 000 base units. Base lengths of 16 km should be workable over good-conductivity ground in low-noise conditions by day.

b. Base-line Configurations

For the two-base-line system of this Report the base lines can either be separated, using two Control Stations and two Outstations, or intersect in a common apex (the Control Station) and can be inclined at any angle to each other. The governing factor in the choice of configuration is the errors to be expected over the coverage area.

A study of three, typical, intersecting configurations produced accuracy diagrams as shown in Figures 16-18. The areas enclosed by these contours are plotted against base angle in Figure 19, where it can be seen that the maxima of the curves occur at greater base angles for curves of larger errors. That is to say, for a small error, a greater coverage is obtainable with a small base angle than with a large; for a large error, a greater coverage is obtainable with a large base angle than with a small.

In practice, a compromise of 120° is recommended for the base angle.

It must be noted that large errors can be expected in a zone of approximately $\pm 10^\circ$ on each side of the extension of a base line. As each base line has two extensions, for a configuration of two intersecting base lines there are four such areas. This fact is illustrated in Figure 20.

A study was made of the configuration known as the 'two-base cross'. The accuracy diagram is given in Figure 21. It can be seen, by comparison with the previous diagrams, that this configuration gives better accuracy coverage. However, it has the disadvantage of having a much lower signal/noise ratio for the same area of operation on account of the greater separation between either Control Station and its Outstation.

The study showed further that the use of separated base lines leads to small errors in the vicinity of the perpendicular bisectors of the base lines. Such a configuration has an application when, for military or topographical reasons, the centre point (the common Control Station) cannot be occupied.

c. Extension of Control

An obvious use for the system of this Report, apart from the positioning of the points within the prescribed area, is that for the extension of control from one area to another. Three points in the first area are positioned with reference to three known base stations, the configuration of the points being as specified in the previous Section. The base stations are then moved to these three points, with the result that the operational area has now advanced.

It must be noted that the accuracy of measurement will fall off every

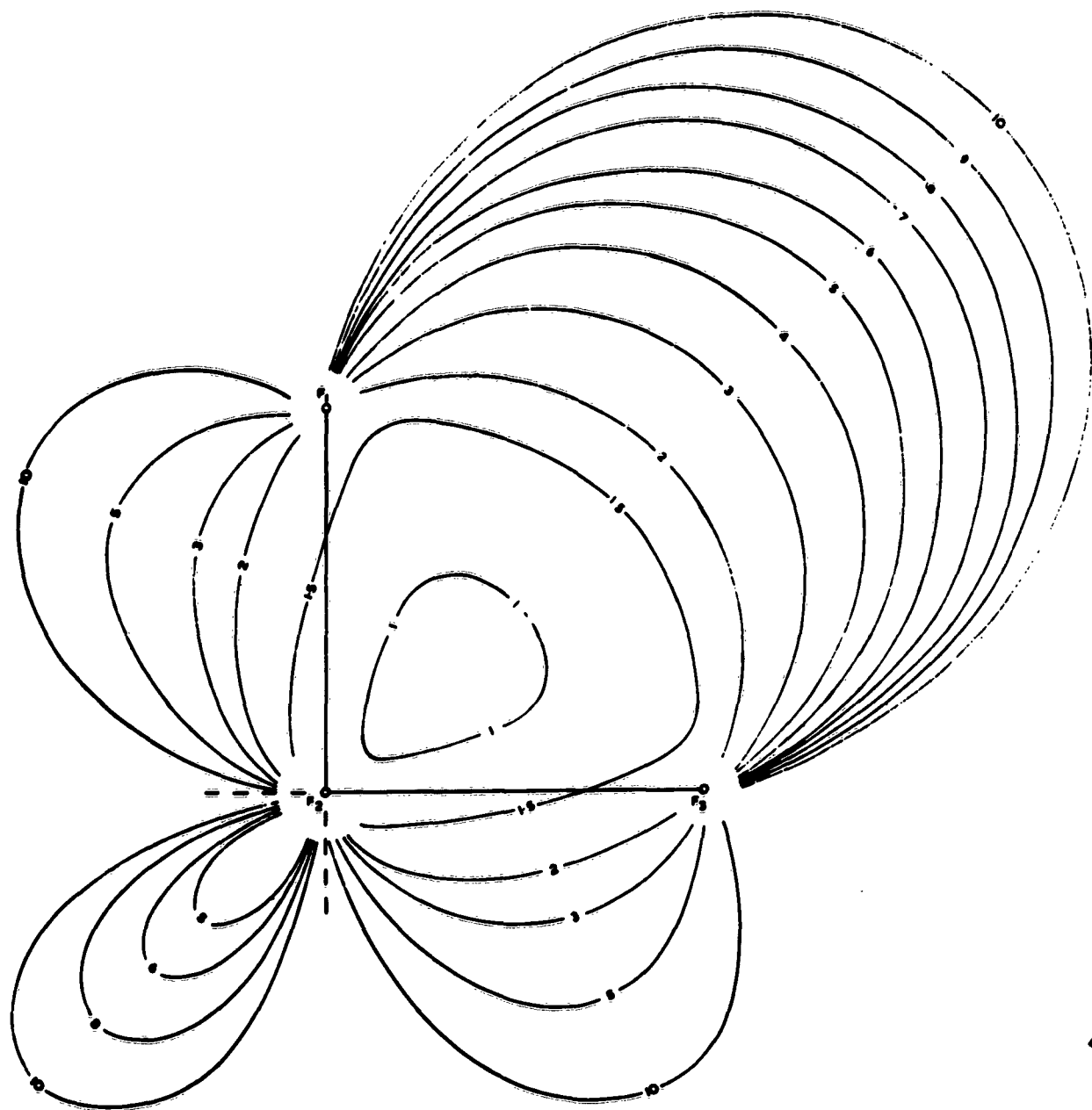


Figure 16. Accuracy Contours, 90° Base Angle

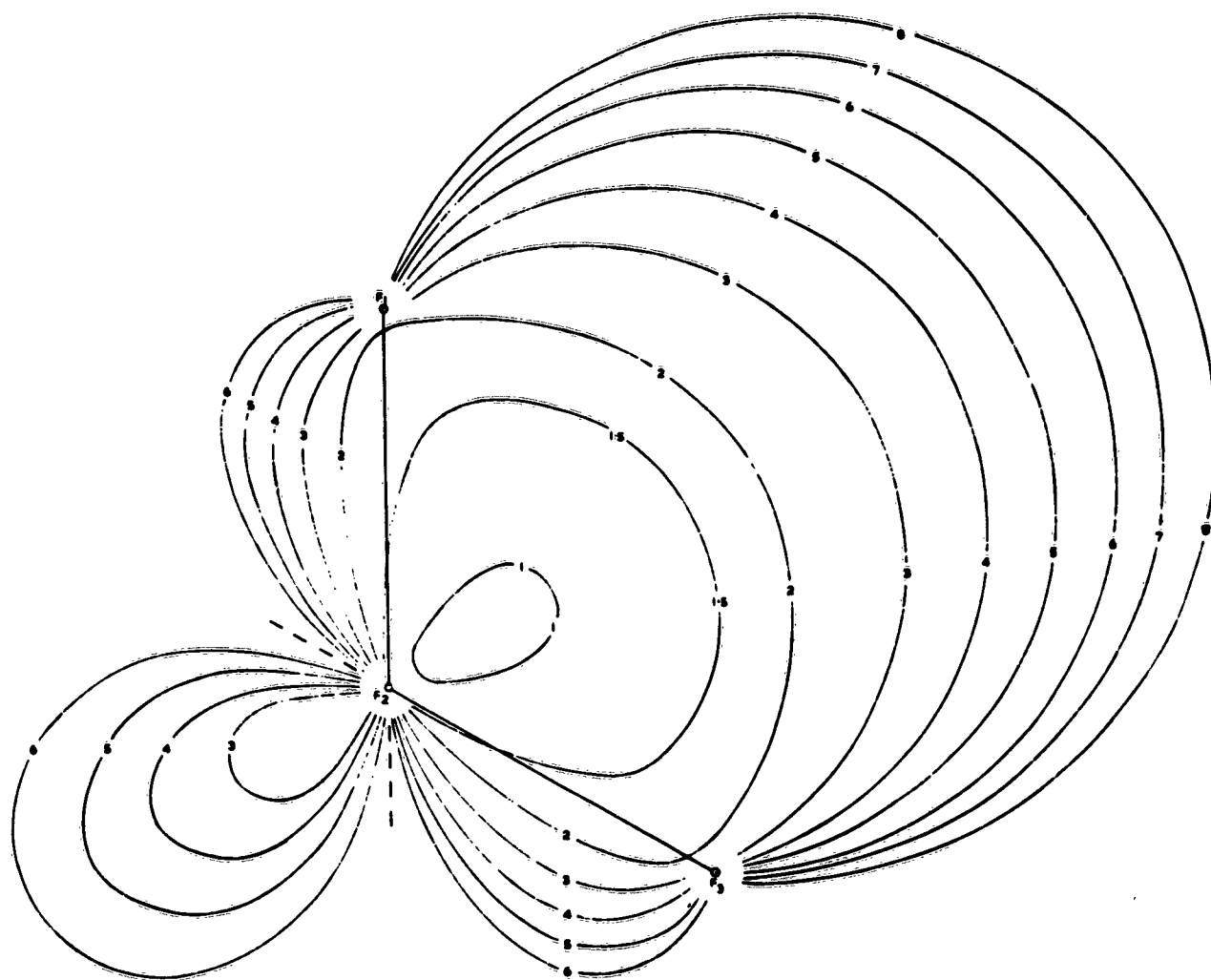


Figure 17. Accuracy Contours, 120° Base Angle

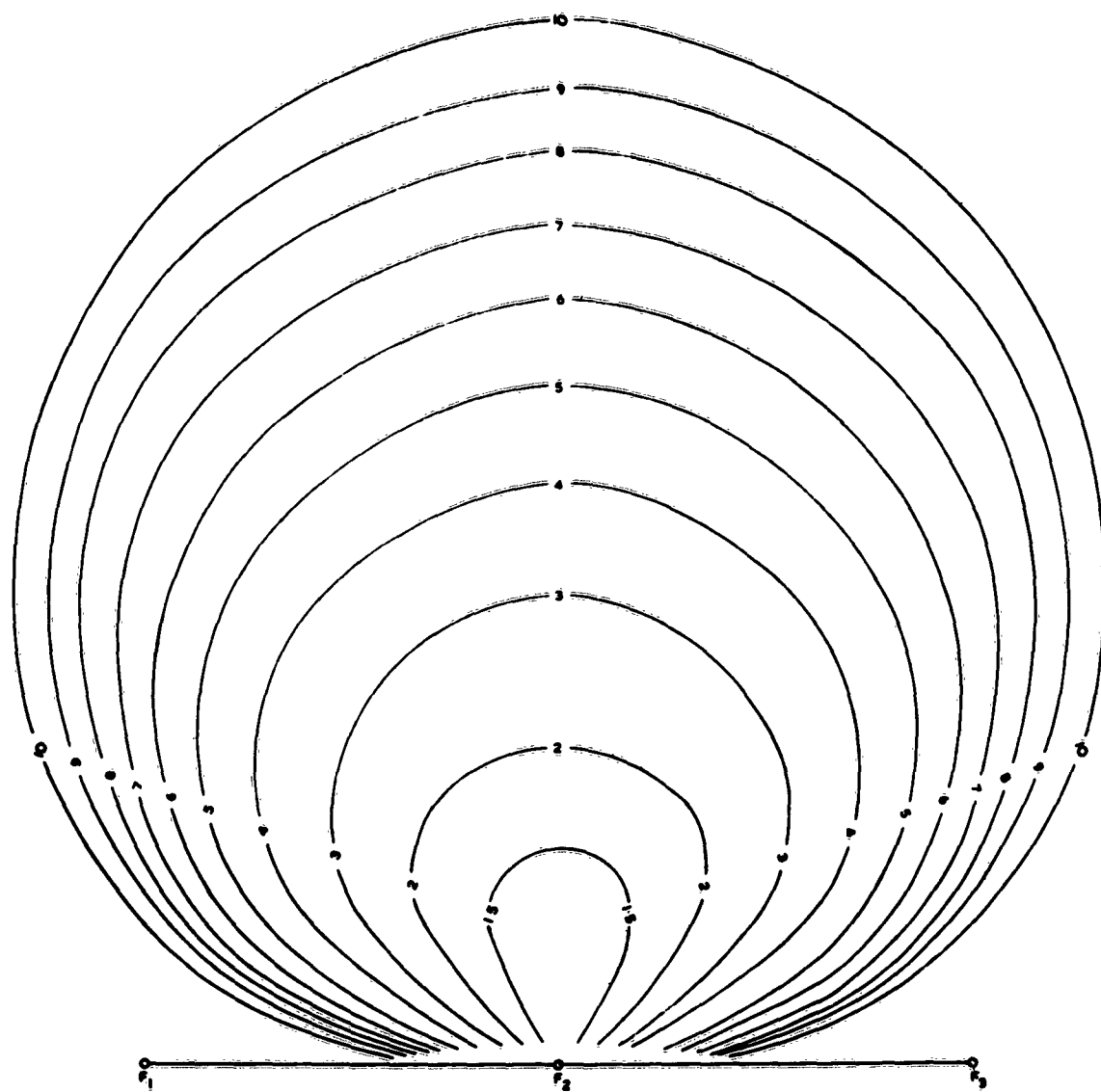


Figure 18. Accuracy Contours, 180° Base Angle

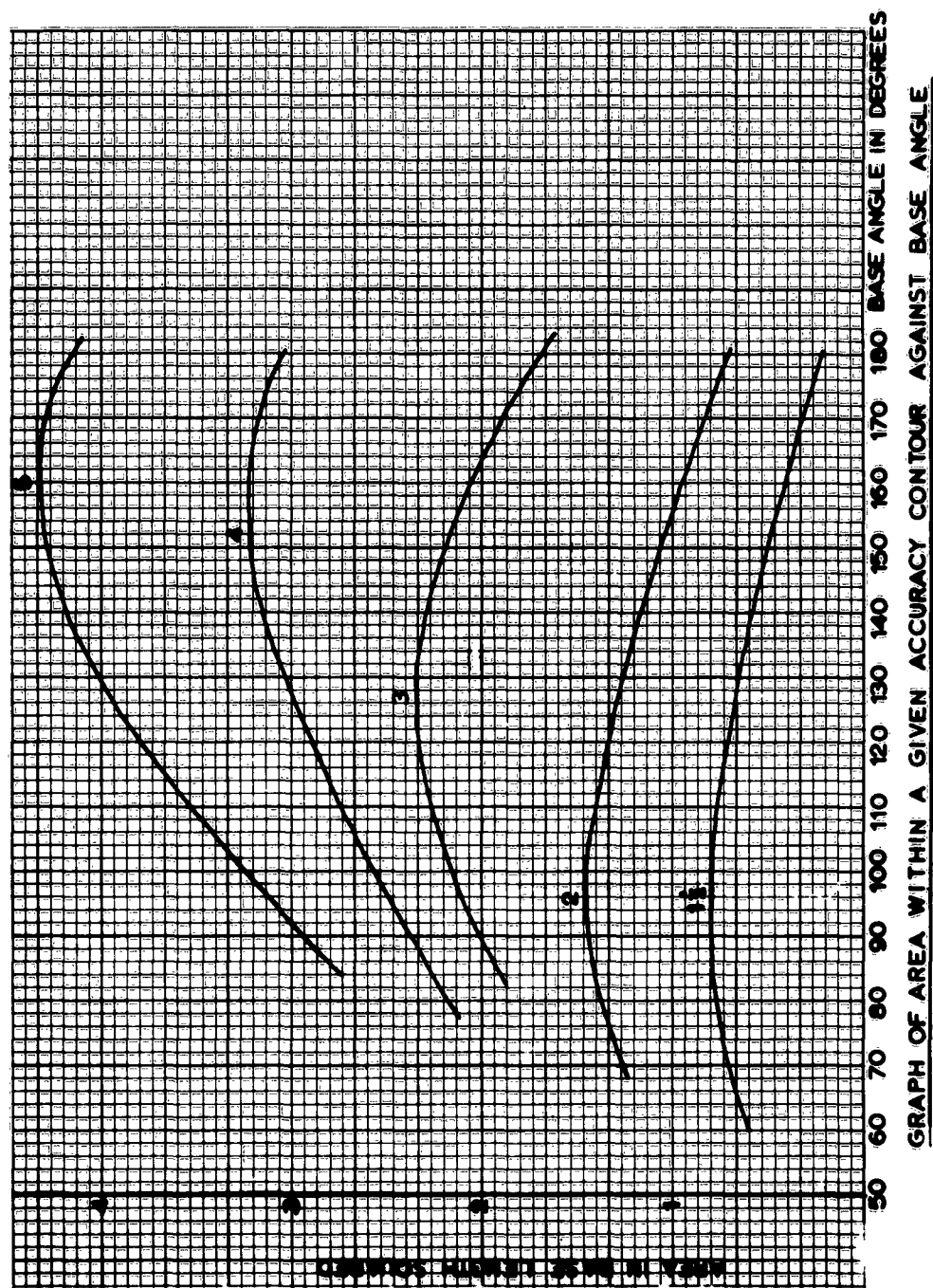


Figure 19. Plot of Accuracy Areas Against Base Angle

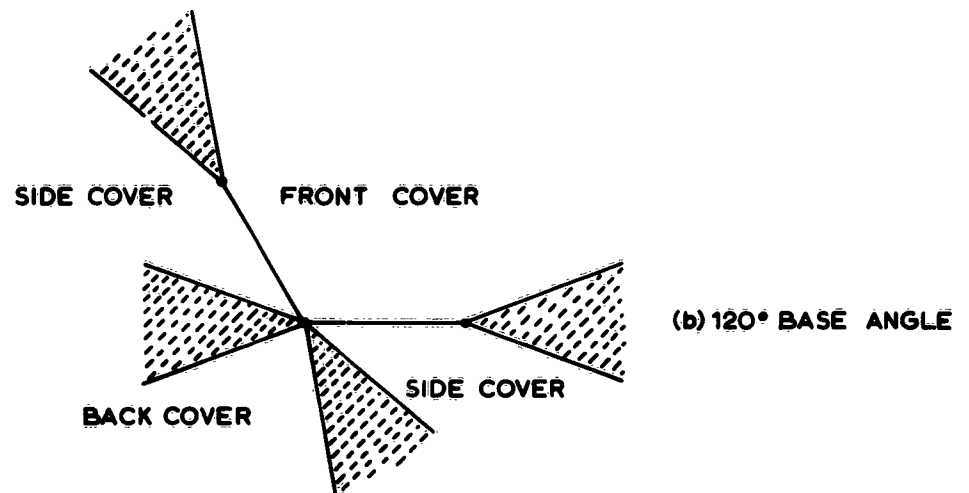
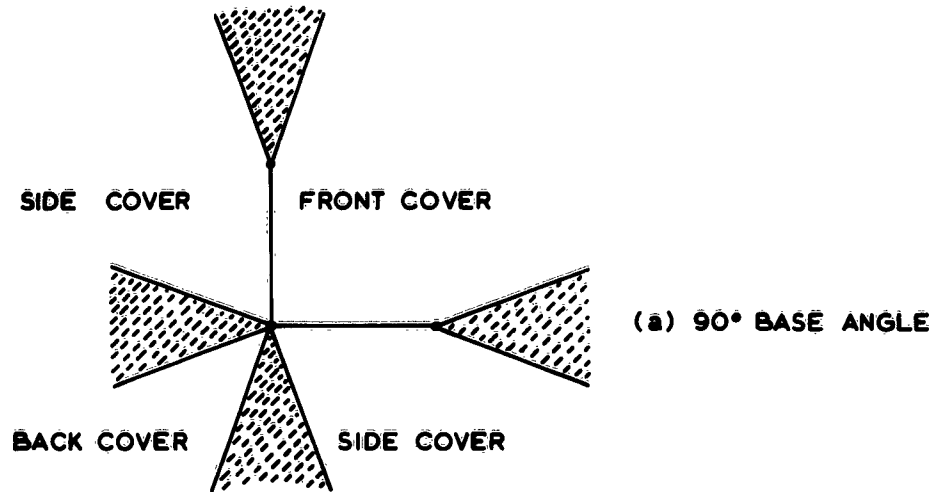


Figure 20. Coverage Areas

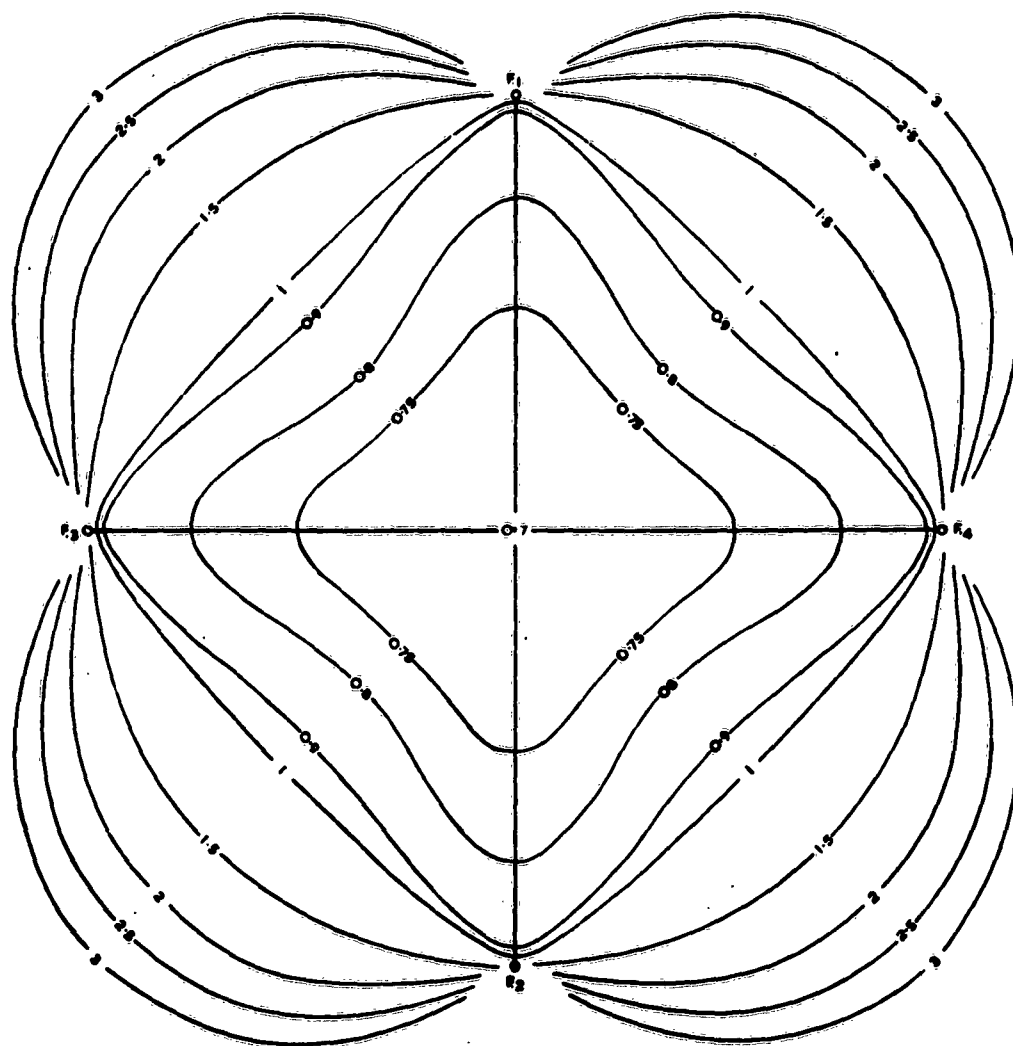


Figure 21 . Accuracy Contours, 2-base Cross

time this procedure is carried out, for the errors involved in positioning the three points will become errors in the base-line data, which are applied to the second set of points. However, if small advances are made at each step, or if substantial errors can be tolerated, the method may often be of use.

d. Base-line Calibration

Because the Synchronizing Receiver is not coincident with the Control Station transmitter, and because there may be variations in the velocity of the radio waves, a direct read-out at the Search Receiver is not an exact measure of the distances from the transmitters. The eccentricity of the Synchronizing Receiver gives rise to a zero error, and the separation of the Search Receiver from the transmitters gives rise to a range error.

(1) Zero error

If the Search Receiver is sited at the Synchronizing Receiver, the position reading is zero. This fact follows from the synchronizing action of the Synchronizing Receiver. In general, the hyperbola corresponding to zero phase difference does not pass through the Control Station but intersects the base line in a point between the Control Station and the Outstation. The error involved is termed the zero error. It is usually negative, but can be positive.

Two methods of determining the zero error have been evolved. The first method involves taking series of readings at intervals across the Control Station base extension, plotting those readings, and drawing a curve through the minima of the plotted curves. The difference between the asymptote to the curve and the axis is the zero error.

The second method, which is less laborious, involves taking position measurements at a number of known points. The mean difference between the computed and the measured hyperbolic co-ordinates of the points is the zero error.

(2) Range error

The range error can be considered to consist of two errors. In the first place, a correction must be made to the assumed value of the velocity of the radio wave if that value differs from the true value. In the second place, on account of the induction field of the transmitting antennae and the finite conductivity of the ground, the phase of the radiation field lags behind the phase of the radiation field that would exist if the conductivity were infinite. At a transmitter the phase lag is half a phase rotation (50 base units); as the range increases the effect of the induction field diminishes and the actual field comes more and more into phase with the radiation field till the phase lag is a minimum. Then, as the finite-conductivity effect becomes operative, the phase lag increases with increase in range, till at long range it reaches a constant value. The effect is shown in Figure 22.

To correct for variations in velocity a curve is drawn through the minima of readings taken across the Control Station base extension, as described in a above. A similar curve is plotted for the Outstation base

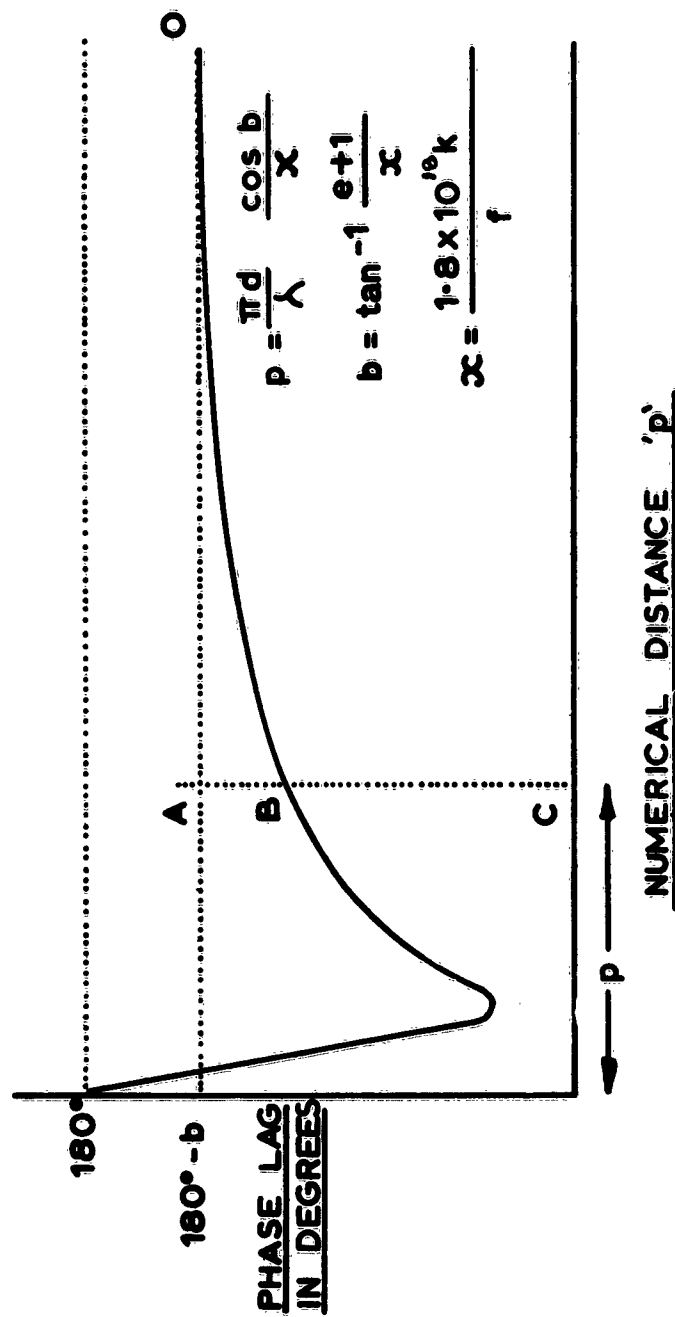


Figure 22. Plot of Phase Lag Against Range

extension. The electrical distance between the asymptotes, relative to the geodetic base length, gives the correction to the velocity.

Thus, if for a base length of 7.5 km the distance between the asymptotes is equivalent to 9000 base units, the correction to the velocity is $\frac{9000 \times 8.37}{10000 \times 7.5} = 1.0044$. This follows since 8.37 km is equivalent to 10 000

base units and, therefore, 7.5 km is equivalent to 8960 base units.

The range correction is determined in the following manner.

It is assumed, firstly, that at long range the above curves actually touch the asymptote. Then, on either curve, the asymptote is drawn to touch the curve at a distant point. From some intermediate point A, where the distance of the curve from the asymptote is AB, a length equivalent to the base length is marked off on the asymptote. If this gives a point C, which is a distance CD above the curve, then a distance CD + AB below the asymptote is a point on the range-correction curve. This is repeated for a number of intermediate points until a smooth curve can be drawn. Then the correction for the Outstation range is subtracted from the correction for the Control Station range to give the net range correction.

Section III. PRACTICAL REDESIGN

a. Crystal Clocks and Tone Signals

To carry out the pattern switching, stable crystal clocks were used for a number of reasons. The alternative to crystal clocks is the generation of tone signals in the Control Station and their reception by the Outstation.

For the 5 patterns involved, 4 tone oscillators would be required. These would be gated in turn, the gates being controlled by delay switches, such as multivibrators. No tone signal would be transmitted with one of the patterns, and one of the tones would be transmitted with each of the four remaining patterns.

At the Outstation, a detector and a series of filters would enable the received tone signal to actuate one of five gates, so that the correct, locally generated pattern would be transmitted at the same time as the corresponding pattern from the Control Station.

A modification of this method is the generation of a single tone frequency at the beginning of each pattern cycle and its use in the Outstation for operating a low-stability clock, which would switch the patterns in turn. As the duration of a switching cycle is only 60 seconds, the stability of the clock would need to be no greater than 1 part in 60.

The method of transmitting tone signals requires complex circuitry. Not only must the Control Station have tone oscillators and the Outstation tuned filters, and, in the first method, must there be gates and switching control circuits, but also, for two Outstations, two sets of tones must be generated so that the Outstations are transmitting alternately. Although the

method has the advantage of never losing synchronization, its disadvantages precluded its use.

The alternative method, which was adopted in the equipment, was the use of synchronized crystal clocks in both Control Station and Outstation. Their stability is better than 1 p.p.m., so that only periodic synchronization needs to be carried out.

The action of the crystal clocks is to generate a very stable 400-c/s signal, which is amplified and fed to a synchronous motor. This motor runs at a speed of 2 rev/min and drives a rotary switch. Thus, the patterns can be switched in any desired sequence at all stations with a synchronizing stability of better than 1 second in 12 days.

b. F.M. Oscillator

The ROUGH FINE pattern, which is not a difference pattern, is obtained by frequency-modulating the lower channel of the Control Station transmitter by a 200-c/s signal and demodulating it in the Search Receiver. To preserve simplicity of circuitry in the latter unit, it was decided not to include a frequency discriminator but to generate an amplitude modulation in the mixer stage.

To do this, the modulating signal is made a square wave. As a result, at the Search Receiver there is a frequency swing out of and back in to the pass band of the i.f. amplifier. This swing gives rise to an amplitude modulation of the i.f. signal, which can be demodulated by a conventional diode detector. The deviation must be large enough to take the frequency out of the pass band but not large enough to amplitude-modulate the carrier wave. For this reason a deviation of 5 kc/s is used; this is sufficient to take the carrier out of the pass band of 4 kc/s (to 3-dB points).

c. Read-out at the Search Receiver

The form of the display at the Search Receiver is a diametral line on the face of a cathode-ray tube. The angle of the line, relative to a zero position, is a measure of the phase difference between the received signals. Readings are obtained by setting a rotatable cursor over the line and viewing a fixed scale over which the cursor moves. This method eliminates centring errors.

The diametral line is produced by circuitry that was specially developed. Each signal is applied to both sets of c.r.t. plates through a 90° phase shifter, so that in the absence of one signal a circular trace would be produced. By correct phasing, the two signals produce a straight line. The angle of the line changes by 180° for a 360° change in phase angle.

Then, for the single-rate patterns, a 180° rotation of the line corresponds to 100, 1000, or 10 000 base units; for the double-rate patterns it corresponds to 100 or 10 base units. The scales are marked 0-10 for the single-rate patterns and 0-5 for the double-rate patterns.

To present both direct and difference patterns it was necessary to have two cursors on concentric drums. The inner drum carries a black cursor and the outer a red cursor. The friction between the drums is sufficient to enable

both drums to rotate when the inner one is rotated but not sufficient to prevent the outer from being rotated independently of the inner.

The read-out procedure is to set the black cursor to the reference pattern and the red to zero. Then for subsequent readings the black cursor indicates direct readings and the red cursor indicates difference readings.

The pattern read-out is:

COARSE DIFFERENCE against red cursor on top scale

ROUGH FINE against black cursor on top scale

DOUBLE FINE against red cursor on bottom scale

MEDIUM against black cursor on top scale

DOUBLE MEDIUM against red cursor on bottom scale.

d. Types of Co-ordinate Converter

(1) Concentric Circle Plotting

The method of plotting concentric circles for the conversion of hyperbolic to U.T.M. co-ordinates involved the plotting of the base stations, on a plotting table, to a scale of 1 in 50 000. A circle whose radius is equal to the difference distance is described round one Outstation. A transparent sheet that has a family of concentric circles engraved on it is laid on the plotting table in such a way that a particular circle is tangential to the circle round the Outstation and passes through the Control Station. The position of the centre of the circle is marked on the chart. This is repeated for a number of concentric circles. A curve is drawn to connect all the marked points; this curve is a hyperbola.

The procedure is repeated for the other Outstation, and the intersection of the two hyperbolae gives, to a first approximation, the position of the unknown point. The sign of the difference distance indicates which tangent to the Outstation circle has to be used.

To obtain a closer approximation, the scale is increased by a factor of 50 and a special geometric construction is used. The method was regarded as being accurate but not suitable for operation in the field by unskilled personnel.

(2) Mechanical Analogue Computers

(a) Type A The first mechanical analogue computer consisted of a board on which were located three sliding bearings that carried three sliding rods pivoted at a common point. The centres of the bearings represented the base stations and the common point the unknown position (the Search Receiver).

Attached to each rod were cables suitably suspended and wound round two differential-gear systems in such a way that the differences between adjacent bearing-to-pivot distances were indicated on clock gauges.

The station analogues were non-adjustable and were placed in a straight line (180° base angle).

Initially, piano wire was used for the cables, but it was found to fracture because of fatigue. The only satisfactory wire that was tried was stainless-steel surgical cord.

The technique for operating the computer was to set up one difference distance on one clock gauge and then to continuously increase or decrease the lengths of the two rods in equal amounts till the second difference distance was registered on the second clock gauge. The position of the common point was the position of the Search Receiver, and it could be plotted on an underlying chart.

- (b) Type B The second mechanical analogue computer was based on the method of concentric-circle plotting.

A plotting board carried an accurately engraved grid, made of a dimensionally stable material (Cronoflex).

Three base-line arms were pivoted together at one end and could be adjusted for length and angle in order to enable sighting slides on the arms to be set over the base-station positions.

Base lengths up to 20 km could be accommodated on the scale.

The slides were of such a construction as to enable an eyepiece and graticule to be used for setting the centres of the slides to the station co-ordinates. A special hand flash-lamp provided illumination of the grid underneath the slides.

Three common-range arms, sliding in jockeys fitted to the pivot of the base-line arms, each carried a centimetre scale that, together with a Mercer dial on the jockey, enabled the lengths between the common-range arms and the centre of the pivots to be read to 0.1 mm (corresponding to a distance of 10 m).

Three range-difference arms, pivoted at a common point, could slide inside the common-range arms. They carried a millimetre scale that, together with a vernier scale on the common-range arms, enabled the range differences to be set to 0.1 mm (corresponding to a distance of 10 m). In operation, one of the range-difference arms is set to zero.

The pivot on the base-line arms is set over the centre of the grid, and two base-line arms are rotated and their sighting slides are moved till the graticules are exactly over the Outstation positions. The slides and arms are locked in position. The range-difference arm corresponding to the shortest range measurement is set to zero and the other two range-difference arms are adjusted to represent the differences between the ranges and the shortest range. The arms are locked in position.

The common pivot of the common-range arms is moved around till the three readings on the common-range arms are equal. Then the

position of the pivot is read off the grid. The third arm enables any base-line configuration to be used without the necessity of orienting the grid.

Section IV. TEST RESULTS

a. Tests in February-March, 1961

(1) Short base lines

The terrain of the test area was, on the whole, rolling countryside with large portions that were heavily wooded. Power and telephone lines criss-crossed most of the area. The ground was snow covered during the initial stages of the tests; later on it was very wet and muddy.

The original base-station sites, Greenvue (Control Station), Lee, and Riverland, were well chosen, being in open fields and at least 500 yards from the nearest power lines.

The Riverland site could not be located beneath the snow, and Woodbourne was used instead. This latter site was not quite as well situated, through having power lines only 80 = 100 yards away.

Test points Warrenton and Routes Hill were very poor sites. The results for these points were recorded but not included in the determination of errors.

The base lengths were: Woodbourne-Greenvue 8697.22m
Lee-Greenvue 7417.96m

These lengths are not corrected for scale.

The test area was on a U.T.M. grid centred approximately on E256.000. The central meridian was E500.000. For the U.T.M. system, the scale factor at the central meridian was 0.9996.

Then the scale factor in the test area is $0.9996 + \frac{y^2}{2R}$,

where $y = (500-256) \times 10^3 = 244 \times 10^3$, and R is the radius of the Earth. This reduces to a scale factor of 1.000343, which can be taken as a velocity correction.

Hence, the velocity to be used in the test area was 299 800 km/s instead of the average value 299 700 km/s.

The base lines were calibrated in accordance with the base-line extension method discussed in Section II of this chapter.

The results can be summarized as follows:-

	<u>Woodbourne-GV</u>	<u>Lee-GV</u>
Zero correction	+66 b.u.	-9.5 b.u.
Measured base length	10 382 b.u.	8857.0 b.u.
Actual base length	10 387 b.u.	8859.3 b.u.
Error	-5 b.u.	-2.3 b.u.

From the universal curves for numerical distance p and phase constant b, the following values were derived:-

$$p = 0.29R \text{ and } b = 40^\circ$$

The high dielectric constant was possibly due to the fact that the ground was either snow covered or waterlogged.

High a.g.c. readings were obtained. These indicated high ground conductivity, as was also shown by the value of p.

It can be seen that the above zero errors are not equal in magnitude to the zero corrections given in Section V b of Chapter 2. The latter are probably more accurate than those derived from the calibration curve, since the asymptote to the curve is very much influenced by one or two long-range measurements that may be in error by several base units.

(2) Long base lines

An initial test on a single, 24-km base line showed that, because synchronization was just possible but very noisy even during daytime, a 16-km base line was the maximum over which reliable synchronization could be obtained during daytime. In consequence, the line Tapp-Greenview-Williams was used.

The base lengths were: Tapp-Greenview 16 720.0m
Williams-Greenview 12 446.6m

The scale velocity used was the same as was used for the tests over the short base lines.

In the Greenview-Williams extension an anomaly that persisted for several kilometres along the base extension was observed. This anomaly was that the maxima of the Search Receiver traverses did not coincide with the position of the base-line extension. However, from readings in the Control Station extension this anomaly could be resolved, for the two calibration curves should be symmetrical about the axis.

The calibration results can be summarized as follows:-

	<u>Tapp-GV</u>	<u>Williams-GV</u>
Zero correction	+132.5 b.u.	+30 b.u.
Measured base length	19 955 b.u.	14 866 b.u.
Calculated base length	19 967 b.u.	14 864 b.u.
Error	-12 b.u.	+2 b.u.

The conclusion drawn from these tests was that, if it was correct to assume that the Greenview-Woodbourne line was a particularly poor base line, r.m.s. errors of the order of 3 base units could be expected with the equipment. In terms of movement along the base line, this value represents approximately 2.5 metres. Peak errors of up to 6 base units (5 metres along the base) can be expected for this type of terrain.

b. Tests in September, 1961

The GIMRADA personnel who operated the equipment were quite unfamiliar with it and with the reading procedure for the Search Receivers. Training in receiver reading took place on the first day of station installation,

and proficiency in reading was attained in most cases after about one day of reading at about 20 different points.

The proving tests for the equipment had been planned for 16-km base lines. This figure was agreed upon after discussion, since it was expected that the noise in Summer time would be considerably worse than during the previous tests (in February, 1961) and that operation through afternoon thunder-storms would be practically impossible for 16-km base lines. However, a demonstration was called for, and a 16-km base line was established between Greenview and Tapp. Operation of the system was reasonable during the morning but deteriorated considerably in the afternoon; the system was unworkable at night owing to the noisy phase lock.

A test was then planned for the maximum designed length of base line, viz., 8.4 km. The ideal configuration would have been Riverland-Greenview-Lee, but Riverland was isolated owing to very heavy rain. Hence Woodbourne was used again. The full calibration procedure was carried out for each base line.

On the first day of test reading, twenty-eight points were measured, each point being visited at least 3 times on one day. Long-range points were included in these tests, the furthest point being 42 km from Greenview. The long-range points remained readable up to sunset, after which the conditions deteriorated over a period of approximately 45 minutes, when the points became unreadable. The range limit at night was approximately 25 km owing to noise at the Search Receiver. The phase lock remained quite noise free for the short (8.4-km) base line. Within the range limit of 25 km no significant difference between daytime and night-time readings could be detected.

Section V. MAN-POWER AND TRAINING

- a. Excluding the personnel required to operate the Search Receivers at the unknown points, six men are required for installing the base stations and carrying out the base-line calibrations. Their duties can be summarized as follows:-
- (1) Two men (one a driver and the other trained to erect a transmitter) to set up each Outstation. Each team then carries out a calibration of the Outstation base-line extension. After this, the personnel are no longer required.
 - (2) Two men (one a driver and the other trained to erect a transmitter) to set up the Control Station (Control Unit, Control Station transmitter, and Synchronizing Receiver). The team then carries out the calibration of both of the Control Station base-line extensions. After this, the trained operator must derive the zero and range corrections from all the base-extension readings.
- When the personnel have performed the above tasks, they are no longer

required except insofar as they may become operators of Search Receivers.

- b. The periods of training given below are only approximate in that highly intelligent personnel can be trained in shorter times than personnel of low intelligence can. The periods are considered to be average training times.

(1) Search Receiver. Operation can be learned in 2 hours. Most of this time is taken by practice in reading the rapidly changing patterns and in becoming familiar with cursor operation. A further period of 2 hours is required for interpretation of the readings (resolution of ambiguities).

(2) Computer. Proficiency in making the final adjustments can be attained in 1 hour.

(3) Outstation. Installation and operation can be learned in half an hour.

(4) Control Station. Installation and operation of all the units can be learned in 3-4 hours.

(5) Planning. Training in the functional principles of the system, to enable the trainee to plan base-station configuration and Search Receiver operation and to assess the value of the results, should take a period of 1-2 hours.

(6) Maintenance. To become fully conversant with the details of the equipment and its maintenance, a service engineer requires a period of training amounting to about 3 weeks.

Section VI. OPERATION OVER WATER

Greater range can be expected over water because of the considerably lower attenuation and the greater antenna efficiencies if the antennae are mounted in the water. Daytime ranges of up to 100 miles and night-time ranges of 70 miles are possible.

Owing to the homogeneity of the transmission path, lower standard deviations of the hyperbolic readings can be expected. These deviations are probably of the order of 1 base unit.

If the antennae are erected on land, they should be as close to the edge of the water as possible in order to reduce errors due to change of terrain. The base-line calibration procedure may be difficult.

CHAPTER 4

CONCLUSIONS

The Short Range Electronic Positioning equipment of this Report has been developed, fabricated, and delivered; means of calibration and of reduction of readings have been provided, as required in the Contract.

The equipment is highly portable, and positions can be obtained, with an error of only a few metres, within minutes of arrival at an unknown point. Operation of the equipment is simple and can be taught to the average soldier.

Various base-line configurations are possible, but the 8-km base with a 120° base-angle appears to be the optimum. Operation over a variety of terrain is possible, but errors that are due to reflections in mountainous country and reradiation from power lines, fences, and telephone wires, in built-up areas can be expected.

The equipment, which is sufficiently rugged for military purposes, can be operated over a temperature range of -40°C to $+40^\circ\text{C}$.

At the present stage of development the range of the equipment appears to be about 40 km by day and somewhat less by night. The standard deviation of a receiver reading over land, by day, is 3.2 base units.

The equipment appears to be ideal for highly mobile, military roles such as artillery location and tactical deployment.

CHAPTER 5

RECOMMENDATIONS

As the equipment appears to be suitable for military purposes such as deployment of patrols, combat groups, and artillery and weapon sites, it is recommended that it be given operational checks during manoeuvres to establish the lines along which further systems should be developed.

It is also recommended that a development programme be carried out to extend the capabilities of the system. These include:-

- a. Extension of day - and night-time ranges by the use of higher radiated powers (higher antenna power inputs and higher radiation efficiencies), antennae with smaller high-angle radiation, and directional synchronizing antennae.
- b. The study of methods of identifying station transmissions and the problems of adjacent systems.
- c. The study of the use of the two-base cross and separated base lines.
- d. The development of a pointer-type indicator for the Search Receiver.
- e. The further development of the mechanical analogue computer.
- f. The study of quicker methods of base calibration.
- g. The study of positional determination on the move, particularly on vessels at sea.