The use of elliptically polarized radiation for gap-filling in the vertical pattern of the Canadian ZPI antenna. Comparison of horizontally polarized and elliptically polarized ZPI antennae

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RADIO BRANCH

PART I

THE USE OF ELLIPTICALLY POLARIZED RADIATION FOR GAP-FILLING IN THE VERTICAL PATTERN OF THE CANADIAN ZPI ANTENNA

PART II

COMPARISON OF HORIZONTALLY POLARIZED AND ELLIPTICALLY POLARIZED ZPI ANTENNAE

OTTAWA

MARCH, 1943

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NATIONAL RESEARCH COUNCIL OF CANADA
RADIO BRANCH

C O N T E N T S

This report is published in two parts; the first, "THE USE OF ELLIPTICALLY POLARIZED RADIATION FOR GAP-FILLING IN THE VERTICAL PATTERN OF THE CANADIAN ZPI ANTENNA" has not hitherto been published; and the second part, entitled "COMPARISON OF HORIZONTALLY POLARIZED AND ELLIPTICALLY POLARIZED ZPI ANTENNAE" is a reprint of PRB-80, included here for the sake of completeness.

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PART I

The Use of Elliptically Polarized Radiation for Gap-Filling in the Vertical Pattern of The Canadian ZPI Antenna

I. INTRODUCTION:

The horizontally polarized antenna commonly used in RDF is greatly restricted in its usefulness, by the gaps which are usually found in its vertical radiation pattern. These gaps are caused by interference between the ray travelling directly from the antenna to the target and the ray reflected from the ground to the target. A typical vertical radiation pattern for such a horizontally polarized antenna is shown by the broken curve in Drawing No. RI-15-69.

These gaps can of course be filled by using two radiators, with complementary patterns, in conjunction with one another; the success of the operation depending on how completely complementary the two patterns happen to be. Such patterns, complementary over a considerable range in the angle of elevation, are presented by vertically and horizontally polarized radiators at the same height above their reflecting surface, or ground.

It is well known that horizontally polarized radiation undergoes a phase change of very nearly 180° on reflection quite regardless of the angle of incidence, the conductivity of the reflecting surface or the frequency of propagation. It is also well known that vertically polarized radiation undergoes a phase change of very nearly 0° on reflection for all angles of incidence greater than the Brewster angle. For this reason a vertically polarized radiator presents a pattern above the Brewster angle which is complementary to that presented by a horizontally polarized radiator placed at the same height above the ground, and excellent gap-filling should be realized in this region. On the other hand, below the Brewster angle, vertically polarized radiation undergoes very nearly 180° change of phase on reflection, which is the same as for horizontally polarized radiation. (The shift from 180° change of phase on reflection below the Brewster angle for vertically polarized radiation, to 0° above, is made in a very small neighbourhood about the Brewster angle, except in the case of sea water, where the neighbourhood is larger.) Thus, below the Brewster angle, the two patterns are not in the least complementary; but even here some gap-filling should be realized since the nulls in the vertical pattern are not as deep for vertically polarized as for horizontally polarized radiation.

For reflecting surfaces actually encountered in practice the Brewster angle at ultra high frequencies varies from about 2° for salt water and 6° for fresh water up to about 24° for very dry land. Now the first null for any horizontally polarized radiator is on the horizon and thus always falls below the Brewster angle. Thus one cannot expect to fill this gap by using vertically polarized radiation. The position of the first null above the horizon in the vertical pattern of the horizontally polarized radiator depends on the height in wavelengths of the radiator above the ground. For example, in the case of the Canadian ZPI, the antenna height is 3.7 wavelengths, giving the first null above the horizon at about 8°. This is just above the Brewster angle on wet sites, but below the Brewster angle on dry sites. Then in this application, complete gap-filling above the horizon should be realized on wet sites. But as the site becomes drier the first null at 8° should begin to appear, and as the site becomes quite dry the second null at 16° should begin to appear. The third null occurs at 24° and should always be filled in practice together with all higher nulls, since the Brewster angle never goes above 24° and only reaches it under most extreme desert conditions.

II. THE CALCULATION OF PATTERNS:

The field intensity presented at short distances over a finitely conducting plane earth by a vertically polarized doublet is given by Norton[1] as

$$E = \frac{E_o}{d}\left[\cos^3\psi_1\, e^{\frac{i2\pi r_1}{\lambda}} + R\cos^3\psi_2\, e^{\frac{i2\pi r_2}{\lambda}} + (1-R)\, f(P,B)\cos^2\psi_2\, e^{i\left[\frac{2\pi r_2}{\lambda}+\phi\right]}\right] \quad (1)$$

where E_o is the field strength at unit distance, R is the plane wave reflection coefficient of the ground, λ is the wavelength, and where other quantities are defined in Figure 1. In this expression the first term is the direct wave, the second the ground reflected wave, and the third is the surface wave. In the case under consideration the third term is found to be negligible. Also d is much greater than h_1 so that ψ_2 becomes equal to ψ_1. Then equation (1) may be written

$$E = \frac{E_o}{d}\cos^3\psi\left[e^{\frac{i2\pi r_1}{\lambda}} + Re^{\frac{i2\pi r_2}{\lambda}}\right].$$

where ψ is the angle of elevation of the target. Furthermore, this equation was developed by Norton for a vertical doublet at the receiving end, thus introducing an extra cos ψ factor to take care of the doublet's directivity in the vertical plane. The target, in the case under consideration, can only be assumed to have a non-directional pattern and so equation (1) takes the form

$$E = \frac{E_o}{d}\cos^2\psi\left[e^{\frac{i2\pi r_1}{\lambda}} + Re^{\frac{i2\pi r_2}{\lambda}}\right]$$

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1 K.A. Norton, "The Calculation of Ground-Wave Field Intensity over a Finitely Conducting Spherical Earth". Proc. I.R.E., Vol. 24, pp. 623-639; December, 1941.

In calculating patterns only the absolute value of the vector E is of interest, and this may be written

$$|E| = \frac{E_o}{d} \cos^2\psi \left| \left[1 + R e^{\frac{i2\pi(r_2 - r_1)}{\lambda}} \right] \right| .$$

Substitute $r_2 - r_1 = 2h_1 \sin\psi$, which is an excellent approximation when d is much greater than h_1. Then

$$|E| = \frac{E_o}{d} \cos^2\psi \left| \left[1 + R e^{\frac{i4\pi h_1 \sin\psi}{\lambda}} \right] \right| .$$

Next substitute

$$R = -|R| e^{-iC}$$

and

$$\Theta = \frac{4\pi h_1 \sin\psi}{\lambda}$$

Then finally, for a vertically polarized doublet,

$$|E| = \frac{E_o}{d} \cos^2\psi \left[1 - 2|R| \cos(\Theta - C) + R^2 \right]^{1/2} \qquad (2)$$

The following expression may be derived in a similar manner for a horizontally polarized doublet

$$|E| = \frac{E_o}{d} \cos\psi \left[1 - 2|R| \cos(\Theta - C) + R^2 \right]^{1/2} \qquad (3)$$

These expressions are now in a convenient form for calculating the vertical radiation patterns of vertically polarized and horizontally polarized doublets. The plane wave reflection coefficient is of course different in the two cases. It is given by Norton as

$$R = \frac{\sin\psi \sqrt{\frac{x \cos b'}{\cos^2 b''}}\; e^{i\left(\frac{\pi}{4} - \frac{b}{2}\right)} - 1}{\sin\psi \sqrt{\frac{x \cos b'}{\cos^2 b''}}\; e^{i\left(\frac{\pi}{4} - \frac{b}{2}\right)} + 1} \qquad (4)$$

for vertical polarization, and

$$R = \frac{\sin\psi \sqrt{\frac{\cos b'}{x}}\; e^{-i\left(\frac{\pi}{4} - \frac{b'}{2}\right)} - 1}{\sin\psi \sqrt{\frac{\cos b'}{x}}\; e^{-i\left(\frac{\pi}{4} - \frac{b'}{2}\right)} + 1} \qquad (5)$$

for horizontal polarization, where x, b, b' and b'' are defined by the following relations:

$$x = \frac{1.789 \times 10^{15} f_{mc}}{\sigma_{emu}}$$

$$\tan b' = (\varepsilon - \cos^2 \psi)/x$$

$$\tan b'' = \varepsilon/x$$

$$b = 2b'' - b' \text{ (vert. pol.)}$$

$$b = 180° - b' \text{ (hor. pol.)}$$

f_{mc} = the frequency in megacycles per second

ε = the dielectric constant

and σ_{emu} = the conductivity in electromagnetic units.

At ultra-high frequencies and when the conductivity is low; e.g. over land or fresh water:

$$b' \cong \frac{\pi}{2}$$

$$b'' \cong \frac{\pi}{2}$$

$$b \cong \frac{\pi}{2}$$

$$\cos b' \cong \cot b' = \frac{x}{\varepsilon - \cos^2 \psi}$$

$$\cos b'' \cong \cot b'' = \frac{x}{\varepsilon}$$

Using these approximations, the above expressions for R may be greatly simplified without too great a loss of accuracy. The simplified expressions are

$$R = \frac{\varepsilon \sin \psi - \sqrt{\varepsilon - \cos^2 \psi}}{\varepsilon \sin \psi + \sqrt{\varepsilon - \cos^2 \psi}} \qquad (6)$$

for vertical polarization, and

$$R = \frac{\sin\psi - \sqrt{\varepsilon - \cos^2\psi}}{\sin\psi + \sqrt{\varepsilon - \cos^2\psi}} \qquad (7)$$

for horizontal polarization.

Theoretical vertical interference patterns for vertically and horizontally polarized radiation are shown in Figures 2 to 6 for various reflecting surfaces encountered in practice. These calculated patterns show clearly the gap-filling which should be realized above the Brewster angle by using a vertically polarized radiator in conjunction with a horizontally polarized radiator at the same height.

III. ELLIPTICAL POLARIZATION:

Vertically and horizontally polarized radiators may be used for gap-filling by switching at will from one to the other. Such switching is of course an undesirable complication and should be avoided if possible. This is readily done by combining the two arrays into a single elliptically polarized array, where the polarization is chosen primarily to give the smoothest possible pattern in the vertical plane. Such an elliptically polarized array has three advantages over two arrays used separately by switching from one to the other.

1. The nuisance of switching is eliminated.

2. The entire vertical arc is under observation continuously so that there is less chance of an aircraft coming in unobserved.

3. Erratic variation in signal strength is considerably less for elliptically polarized waves than for plane polarized waves. Such variations in signal strength are probably caused by irregularities in the ground about the antenna and by the continuously changing aspect of the aircraft. Experimental evidence in support of this contention is given in the last section of this report.

IV. OPTIMUM PHASING OF AN ELLIPTICALLY POLARIZED ANTENNA:

For best performance the two components of an elliptically polarized array must be arranged so that the signals received on each are not too far out of phase whenever they are anywhere near the same magnitude. Fortunately, there is considerable tolerance here; for two equal components, even $\pi/2$ radians out of phase, have a resultant more than 70% of their in-phase resultant.

Consider an RDF antenna in the position of the first dipole in Figure 1, and a target plane in the position of the second. Let the phase of the horizontally polarized portion of the radiation be zero radians when transmitting, and let the phase of the vertically polarized portion lead by θ radians. Let the change of phase on reflection from the ground be α_V radians for the vertically polarized radiation and α_H radians for the horizontally polarized radiation.

The horizontally polarized radiation reaches the aircraft over two paths, the direct path r_1 and the indirect path r_2 (see Figure 1). Then this radiation has two components on arriving at the aircraft which are very nearly equal in magnitude because the absolute value of the reflection coefficient is nearly unity for horizontally polarized radiation. Then the phase of the resultant wave on arriving at the aircraft is

$$-\frac{2\pi}{\lambda} r_1 - \left\{\frac{\pi}{\lambda}(r_2 - r_1) - \frac{\alpha_H}{2}\right\} = \frac{\alpha_H}{2} - \frac{\pi}{\lambda}(r_1 + r_2).$$

The phase shift on reflection from the target can only be assumed to be the same for horizontally polarized radiation as for vertically polarized radiation, and will therefore be neglected. Then the phase of the horizontally polarized radiation on returning to the antenna is

$$P_H = \alpha_H - \frac{2\pi}{\lambda}(r_1 + r_2)$$

But α_H is always very nearly equal to π for horizontally polarized waves. Then finally

$$P_H = \pi - \frac{2\pi}{\lambda}(r_1 + r_2) \tag{8}$$

Similarly the vertically polarized radiation reaches the target plane over the two paths r_1 and r_2, but in this case the two components are quite different in amplitude, that for the indirect path r_2 being considerably smaller than that for the direct path r_1. The phase of the component coming over the direct path is independent of the angle of elevation of the target, is constant for r_1 constant, and is given by $\Theta - \frac{2\pi}{\lambda} r_1$. On the other hand, the phase of the indirect component continuously recedes as the length of the path r_2 increases with respect to r_1; that is, as the angle of elevation of the target increases, and it is given by $\Theta + \alpha_V - \frac{2\pi}{\lambda} r_2$.

Let the direct component D and the indirect component I have the phase relations shown in Figure 7. Then the phase difference is

$$\phi = \left[\Theta - \frac{2\pi}{\lambda} r_1\right] - \left[\Theta + \alpha_V - \frac{2\pi}{\lambda} r_2\right]$$

$$= \frac{2\pi}{\lambda}(r_2 - r_1) - \alpha_V$$

Let the path difference angle $\frac{2\pi}{\lambda}(r_2 - r_1)$ be δ. Then

$$\phi = \delta - \alpha_V \qquad (9)$$

Also the phase of the resultant field at the target is $\Theta - \frac{2\pi}{\lambda} r_1 - \beta$ and the phase on returning to the antenna is

$$P_V = 2\Theta - \frac{4\pi}{\lambda} r_1 - 2\beta \qquad (10)$$

It is readily shown from Figure 7 that

$$\beta = \tan^{-1} \frac{I \sin \phi}{D + I \cos \phi} \qquad (11)$$

Finally the phase difference between the horizontally polarized wave and the vertically polarized wave on returning to the antenna is obtained by subtracting equation (10) from equation (8). Thus

$$P_H - P_V = \left[\pi - \frac{2\pi}{\lambda}(r_1 + r_2)\right] - \left[2\Theta - \frac{4\pi}{\lambda} r_2 - 2\beta\right]$$

$$= \pi + \frac{2\pi}{\lambda}(r_2 - r_1) - 2\Theta + 2\beta$$

$$= \pi + \delta - 2\Theta + 2\beta \qquad (12)$$

It is observed from Figure 7 that β oscillates between bounds of the order of $\pm \pi/4$ radians, for I less than about 0.6 D as is almost always true in practice. Furthermore, whenever I and D are exactly in phase or exactly π radians out of phase, β is exactly equal to zero. That is, whenever the vertical radiation pattern for vertically polarized waves passes through a maximum or a minimum value, β takes the value zero, thus simplifying the expression (12) in the neighbourhood of these points.

It is now desired to choose Θ, the angle of polarization of the antenna, such that no deep nulls will occur in the resultant vertical pattern of the combined array. This will be so if $P_H - P_V$ is quite different from π, 3π, 5π etc., for all angles of elevation such that the amplitudes of the vertically polarized and horizontally polarized waves are of the same order of magnitude. But $P_H - P_V$ must pass through a number of complete cycles along with δ since π and Θ are constant and β is roughly constant (see Equation 12). Thus $P_H - P_V$ will take on the values 3π, 5π, 7π, etc., one after another as δ increases; and Θ should be chosen so as to line these values up, as far as possible, with nulls in the vertical radiation patterns for horizontal polarization of Figures 2 to 6.

It is readily shown from Figure 1 that the path difference angle $\delta = \frac{2\pi}{\lambda}(r_2 - r_1)$ is related to ψ, the angle of elevation of the target, by the expression

$$\delta = \frac{2\pi}{\lambda} h_1 \sin \psi$$

for d much greater than h_1. Then the vertical radiation patterns of Figures 2 to 6 could have been plotted as functions of δ instead of functions of ψ. A typical pair of such radiation patterns, plotted as functions of δ, is shown in Figure 8. It is observed that the field strength for horizontally polarized radiation is very nearly equal to zero for

$$\delta = 0,\ 2\pi,\ 4\pi,\ 6\pi,\ \text{etc.}$$

and that the field strength for the vertically polarized radiation passes through maximum values for all such points above the Brewster angle. Thus, for such points $\beta = 0$ and Equation 12 takes the form

$$P_H - P_V = \pi - \delta - 2\theta$$

Then if θ is chosen equal to zero $P_H - P_V$ takes the values 3π, 5π, 7π, etc. for δ equal to 2π, 4π, 6π, etc. and the desired alignment is realized.

It is now possible to calculate the theoretical patterns for the elliptically polarized array by simply adding the two patterns of Figures 2 to 6 according to the phase relation given in Equation 12. Such a pattern, for θ equal to zero and for fresh water is shown in Figure 9. It is seen that in this case the desired gap-filling is fully realized, a pronounced maximum replacing each null in the patterns for horizontally polarized or vertically polarized radiation taken alone, with the one exception of the first null above the horizon in the pattern for horizontally polarized radiation. This gap is very close to the Brewster angle, but even so it is largely filled. An experimental pattern for the same case is shown in Drawing No. RI-15-69.

V. OPTIMUM DIVISION OF POWER BETWEEN THE HORIZONTALLY POLARIZED AND VERTICALLY POLARIZED PORTION OF THE ARRAY:

It is observed that the nulls in the vertical radiation patterns are not nearly as deep for vertically polarized radiation as for horizontally polarized radiation. This means that there is a more uniform power distribution; and therefore, for a given power output, the peaks cannot be as high for vertically polarized radiation as for horizontally polarized radiation. For this reason the vertically polarized portion of the array must be driven harder than the horizontally polarized portion, for the most uniform gap filling. This is done satisfactorily for dipoles with a power division of 3:2.

VI. THE ZPI ELLIPTICALLY POLARIZED ARRAY:

The object in designing this array was to modify the existing horizontally polarized RI array into an elliptically polarized array in such a fashion as not to entail any great delay in production. The existing array was simply a seven element collinear with parasitic reflectors.

It was decided that the vertically polarized portion of the array should consist of six half-wave dipoles fed in phase with parasitic reflectors. The number six was selected because it was planned to mount the dipoles and reflectors inside the phasing stubs of the horizontally polarized portion of the array, where use could be made of supporting cross-pieces in the frame. Folded dipoles were to be used to provide a mechanically rigid and self-supporting system, as well as to present a reasonable driving point impedance when paralleled. The parasitic reflectors were to be used with close spacing in order that they might be mounted on the same supports as the dipoles.

A folded dipole having an impedance of approximately 300 ohms was constructed (Drawing No. RI-15-48). An impedance of this order was selected so that the final array would not have too low an impedance. An array consisting of six vertical dipoles and six reflectors of 5/16" brass tubing was constructed. The spacing and length of the reflectors was varied until a suitable radiation pattern was obtained. It was found that the length was 97.5 cm. and the spacing between the dipole and the reflector was 10 cm. or .05λ. The pattern is given in Drawing No. RI-15-74. It was found that a single unit, dipole and reflector combined, had an impedance of 150 ohms. The feeder lines for the array consisted of a 300 ohm line, i.e. 1/8" rods at 3/4" spacing.

After the adjustments were completed, the vertically polarized array was mounted on the same frame as the horizontal array. One problem was to feed the vertical elements so that the horizontal pattern of the horizontal array would not be affected. It was decided to run the feeders down the centre line of the array.

Since the phase difference between the vertical and horizontal components of the received signal vary with the elevation of the aircraft, no attempt was made to check patterns of the combined array. In each case the individual pattern of each component was checked. It was found that by changing the collinear back to the standard one for a spot frequency of 150 mc/s and using a shorting bar on the end phasing stub, a good horizontal pattern was obtained. See drawing No. RI-15-75.

In order to join in with the existing type of coupling ring assembly, it was found necessary to feed the elements with lines 57° long. The phasing of the two sections, due to space lag and change of phase in the feeders was then 30° to 40°. The impedance of the combined arrays was of the order of 260 ohms resistive.

Vertical patterns were taken in the following manner. The array was placed on the trailer, pointed at the 200-foot E.W. tower and fed by a C.W. oscillator. The distance between tower and trailer was 400 feet. It was found that the power division between the two components was such as to give equal field strengths on the main lobes of the vertical patterns.

At first it was intended to use the antenna at a spot frequency of 150 mc/s. However, it was found that by shortening the vertical reflectors and adjusting the shorting bars, good patterns could be obtained over the band 150 - 155 mc/s inclusive. This band was checked in actual operation, and match and operation were satisfactory. In fact it may be said that due to an error in setting frequency, the array was used at a frequency of 159 mc/s while adjusted for 155 mc/s and performance was satisfactory.

VII. FLIGHT TESTS ON THE ELLIPTICALLY POLARIZED ZPI ANTENNA:

Vertical radiation patterns for the combined antenna were taken in actual operation by bringing an aircraft in toward the set at different constant elevations, noting the ranges at which return signals were received. Results of such tests using a fresh water lake as a reflecting surface are shown in Drawings RI-15-69, 70 and 71.

In the first drawing RI-15-69, the pattern for the new antenna is shown superimposed upon the pattern for the old style horizontally polarized antenna. On this site the Brewster angle is about 6° which is below the lowest normally occurring null at 7-1/2°. Thus excellent gap-filling is realized, but with a decrease in maximum range as would be expected. As the site becomes drier the Brewster angle moves upwards and the first null becomes deeper and deeper. At the same time more and more energy is crowded into the bottom lobe giving greater range on this lobe. Only on an extremely dry site would the Brewster angle rise above the second normally occurring null at 15°.

A further advantage of the elliptically polarized antenna over the old horizontally polarized antenna is brought out in drawings RI-15-70 and RI-15-71. This advantage is a greater steadiness in signal strength as observed on the PPI tube. In the elliptical case, the aircraft is seldom lost once it is picked up, but may be lost even in the middle of a lobe in the horizontal case.

It should be observed that the vertical and horizontal scales in Drawings RI-15-69 and RI-15-71 are magnified and that the drawings are thus distorted. The same patterns are shown again in Drawing RI-15-73 with the true proportions between vertical and horizontal scales.

An elliptically polarized ZPI antenna is shown in the accompanying photographs. In one case the mast is erect and the antenna is ready for operation (see Figure 10). In the other case the mast has been lowered and the antenna is ready to be removed and packed (Fig. 11).

OTTAWA
March, 1943.

N.R.C. Antenna Group

PART II

Comparison of Horizontally Polarized and Elliptically Polarized ZPI Antennae

This report summarizes comparison tests made between the new (elliptically polarized) ZPI antenna and the old (horizontally polarized) ZPI antenna. These tests made using an Avro Anson (fabric covered) aircraft flying at various altitudes up to 15,000 feet demonstrated that a ZPI equipped with an elliptically polarized antenna has a range of 50,000 yards. In addition, targets are observed continuously as they fly in from 40,000 yards range when they are above 3,000 feet. For altitudes between 3,000 feet and 500 feet, the range for continuous observation decreases proportionately from 40,000 yards to 16,000 yards. Although tests were not made above 15,000 feet, it is predicted that the coverage will be virtually complete to 25,000 feet with most initial observations near 40,000 yards. These data were compiled on an ideal site, which, however, is more than offset by the use of reduced transmitter power and a fabric covered target.

I. INTRODUCTION

The horizontally polarized antenna originally designed for the ZPI had very deep nulls, several of which passed through the region in which consistent readings are required for the transfer of targets from ZPI to APF.

Consideration was given to several methods for gap-filling, and it was finally decided that, all things considered, the elliptically polarized antenna held the greatest promise for this application. A standard array of seven half-wave dipoles horizontally polarized was modified by the addition of six vertical dipoles displaced in space by $\lambda/8$.

This antenna is shown in comparison with the old type in photograph No. 1035-B* (the old type appears in the background). Photograph No. 1035-A, Fig.10 shows a closer view of the elliptical antenna only. The antenna shown in these photographs is, of course, an experimental version and the vertical dipoles are permanently affixed. However, the production design allows the vertical dipoles to be very easily demounted for storage purposes.

II. TEST RESULTS

Print No. NRC-RI-15-73 shows the limit of operation for both the old and new ZPI antennas in vertical cross section plotted to scale. An Avro Anson (fabric covered) aircraft was used, and the ZPI was sited at the water's edge of Lake Deschenes in such a way as to have the aircraft viewed across the water. The transmitter power was considerably below the present standard, but was carefully maintained constant, as were all adjustments. (Subsequent modifications to this transmitter and receiver showed a great increase in the echo received from a fixed target, thereby equalling the performance of production sets.)

* Fig. 11.

Print No. RI-15-71 shows the same data plotted to an exaggerated vertical scale for more accurate analysis. Additional data are included in the form of heavy horizontal lines representing the actual usable indication of the aircraft during the test flights. With the elliptical antenna it will be noted that after the initial observation of an incoming target, the indication on the cathode ray tube remained dependable and continuous, whereas with the old antenna the indication was intermittent even between gaps. This indicates a great improvement in random fading of the elliptical antenna over the old antenna.

This is further emphasised by print No. RI-15-70 which shows a comparison of intensity of signal for both antennae for a flight at one altitude.

Print No. RI-15-69 compares the patterns directly by superimposition and makes the elimination of nulls very clear. A reduction in range will be observed, but this is unimportant, and it is inherent in any simple gap filling method as a result of the power fed into the nulls being taken from that formerly producing the lobes.

From an operational point of view the elliptically polarized antenna is completely lacking in the nulls and fading phenomenon which led to many failures in transferring incoming targets to the APF when using the old antenna. It will also be noted that the observation of planes coming in at low angles is better with elliptical polarization. Dry land will tend to increase the slight null exhibited by the elliptically polarized antenna at approximately six degrees, but cursory tests made on several dry sites indicate that this does not disturb the region in which transfers are made. Under such conditions the lower portion of the curve extends in such a manner as to give greater range on aircraft coming in at medium altitudes.

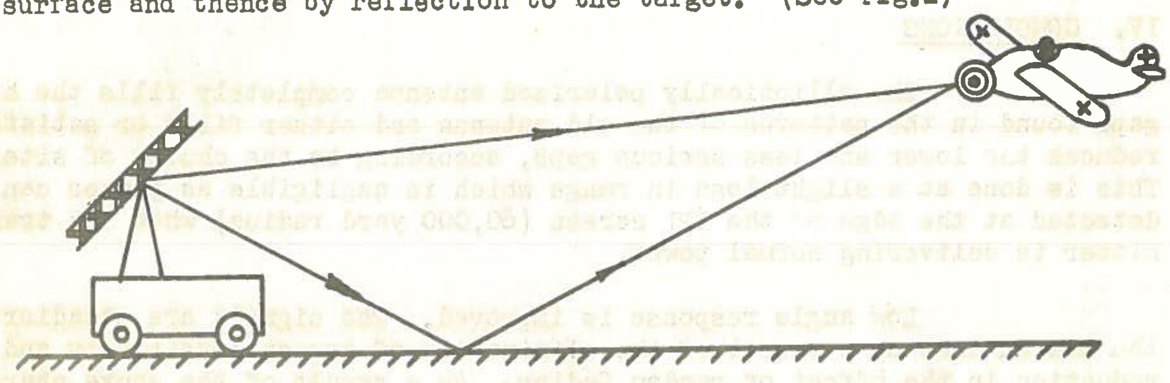
After all data had been recorded for both antennae on this route the RI trailer was moved back from the shoreline for an attempt to take comparison data over flat land. The move was necessary in order to avoid a course passing over a house located on the lake shore. The initial runs on this second route indicated, by complete lack of gaps and close agreement in range with the first test above, that this new course exhibited the characteristics of a water site. The surface of the ground along the direction of the course was examined and it was found that while, for about the first hundred feet the ground was solid, that this was followed by a stretch of marshy land which was causing the unexpected results.

An easterly course was unsuitable due to a sharp rise in the ground in this direction. However, a flight was made and the results were of interest when the contour of the ground was considered with them. The extrapolation of the ground slope was found to intersect the path of the aircraft at a range beyond which the response fell off rapidly, which is of course expected, as beyond this point only the direct wave reaches the aircraft. Print No. RI-15-78 illustrates this and demonstrates the reductions in range to be expected as a result of a bowl shaped site.

The clutter diagrams NRC-RI-15-79 and NRC-RI-15-80 show that with the elliptically polarized antenna greater detail appears in the ground clutter. It is of course obvious that low angle response can only be had at the expense of increased ground clutter.

III. THEORETICAL CONSIDERATIONS

Briefly the electromagnetic waves emanating from the antenna follow two paths to the target. These are: (1) direct from antenna to target, and (2) from the antenna to an intermediate point on the earth's surface and thence by reflection to the target. (See Fig.1)



Dependent upon the relative length of path (measured in λ units) the two waves reaching the target will have various phase relations and may add or subtract. The result of this is that at some points nulls are produced, while at others maxima are produced. Below the Brewster angle a 180° phase change is produced, on ground reflection in both vertically and horizontally polarized waves, while above this angle the phase shift takes place only in the horizontally polarized waves, and the nulls resulting from the use of vertically polarized waves occur at the points at which maxima occur for horizontally polarized waves. Thus a combination of vertical and horizontal polarization eliminates nulls above the critical angle. On a water site this angle is 6°, and as the gaps for a horizontally polarized antenna occur at 7-1/2°, 15°, 23°, and higher angles, complete gap filling results.

When the site is drier the Brewster angle increases, passing the 7-1/2° null, and the drier the site the deeper the null becomes while more energy is crowded into the lower lobe, resulting in greater ranges in the altitudes affected by it. It is not to be expected that the Brewster angle will increase beyond 15° (the second null in a horizontally polarized antenna) except over a desert.

Due to the sensitivity of many targets to polarization of the signal, elliptical polarization results in reduced aspect sensitivity which results in more consistent response on the PPI.

The site for this antenna should be considered as starting at not more than fifty feet from the trailer and extending out to about 500 feet. Within this area the land should be level, reasonably flat, and free from large obstructions such as houses. It should be kept in mind that the antenna performs best over wet sites, and wherever possible full advantage should be taken of lakes, ponds and swamps. Most important, however, is the choice of a flat, unobstructed site. It should be realized here that for the purposes of this antenna the site conditions stipulated above need only exist in the sector or sectors in which observations are to be made. The ground conditions in other directions do not affect the operation of the antenna with respect to targets in a given direction.

IV. CONCLUSIONS

The elliptically polarized antenna completely fills the higher gaps found in the patterns of the old antenna and either fills or satisfactorily reduces the lower and less serious gaps, according to the choice of site. This is done at a slight loss in range which is negligible as planes can be detected at the edge of the PPI screen (60,000 yard radius) when the transmitter is delivering normal power.

Low angle response is improved. The signals are steadier with the new antenna as a result of the elimination of aspect sensitivity and the reduction in the effect of random fading. As a result of the above characteristics of the elliptically polarized antenna, its use makes the ZPI very dependable.

V. ANTENNAE TEST TECHNIQUE

For the purpose of the test, the equipment consisted of an RI Trailer, complete with antennae, RIR unit and RIT unit; a second trailer housing an RII rack; the third trailer housing a communication transmitter and receiver; a Diesel generator set, and the necessary trucks and cables. The communication trailer and the RII unit were interconnected by telephone, so that the RII operator could communicate with the aircraft at any time. The aircraft used for these tests was an Avro Anson aircraft (fabric construction) equipped with two-way communication, and a Mark II I.F.F. airborne set, pretuned to the RI frequency of 150 mc/s.

With all RII units set up and operating normally (with exceptions noted below), the aircraft was sent on a course at a prearranged altitude, and the path of the echo observed on the PPI tube. When a question of identity occurred, the IFF was operated for approximately 25 seconds on request by a prearranged signal from the ground. This period allowed the unit to give a response, after a warming up, of from 3 to 6 seconds (sufficient time to identify the aircraft during one or two rotations of the antenna). The aircraft operator had further instructions whereby he identified himself over each of several towns along the route, and during the turn at the completion of the flight before returning to the site.

On the return flight, no identification was given unless requested by the RII operator. All the recorded data were taken during the incoming flights to avoid the question of the response being different for an incoming aircraft as compared to that from an outgoing aircraft. This condition was especially noticeable when using the horizontally polarized antenna with which the response from an incoming aircraft is considerably better than that from an outgoing craft. The elliptically polarized antenna, on the other hand, is not affected to any serious extent. During the outgoing flight, the aircraft climbed or descended to the altitude required for the next incoming flight.

After flights had been made and data recorded at all altitudes required using the elliptically polarized antenna, a clutter diagram was made by marking the fixed echoes on the face of the tube by means of a red china-marking pencil. A pencil tracing on tracing paper was then made from these markings. The horizontally polarized antenna was then mounted in the place of the other and the whole procedure repeated.

While the above technique was being developed the unit was situated on a very dry land site. A number of flights were made, using both the elliptically polarized antenna and the old antenna, over two courses. One course started over flat land and the resulting vertical patterns are shown to scale on print No. RI-15-76. The complete filling of the upper gaps by elliptical polarization is demonstrated by this print, while the lower gaps are merely reduced as is to be expected in the case of a dry site. Print No. RI-15-77 shows the pattern which resulted from flights over rising ground. Here again the upper gaps are eliminated by the elliptical polarization and the lower gap only, remains but is greatly reduced. Print No. RI-15-42 shows the patterns of the old and new antennae superimposed.

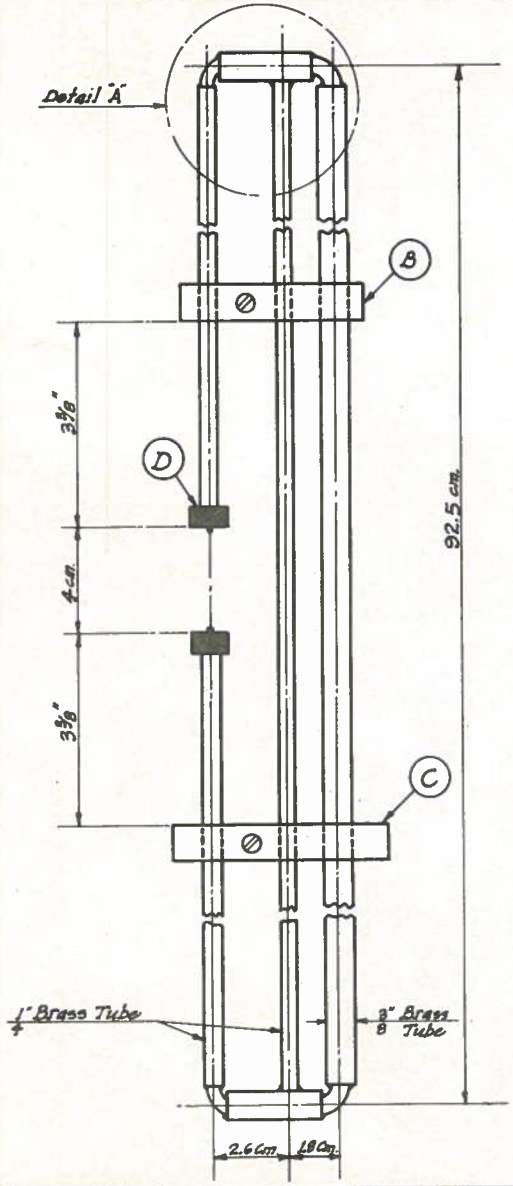
Owing to inconsistent operation of the transmitter and receiver during these flights, the range comparison between the two antennae is unreliable. In fact a decrease in range is to be expected from the elliptically polarized antenna, rather than the increase indicated. This apparent contradiction is explained simply by the information obtained with the old antenna given in prints Nos. RI-15-41 and RI-15-39. The first shows the ZPI clutter diagram taken during the flights recorded. After the flights were completed with the old antenna the transmitter oscillator tubes were replaced, and the transmitter was retuned, with the result shown in RI-15-39. A great increase in overall sensitivity is indicated by the greater detail shown on this second diagram. From the above it is obvious that the ranges indicated for the old antenna are far too short in comparison with those achieved by the new. Print No. RI-15-40 shows the clutter diagram due to the elliptically polarized antenna under improved conditions.

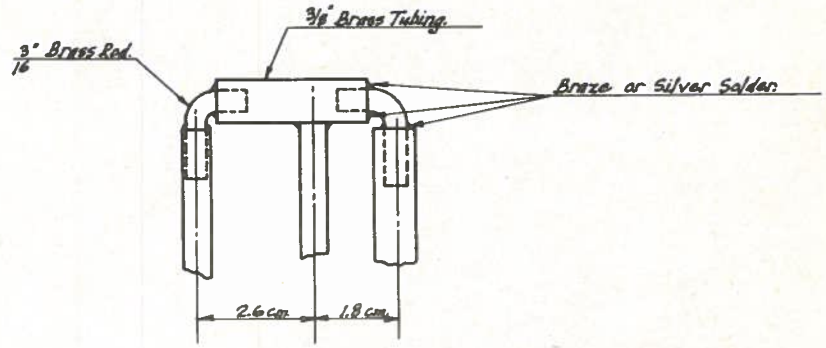
These data confirm the expectations for the elliptically polarized antenna for extremely dry sites.

J. H. Bell
E. F. V. Robinson

N R C
PHOTO
FIG.10

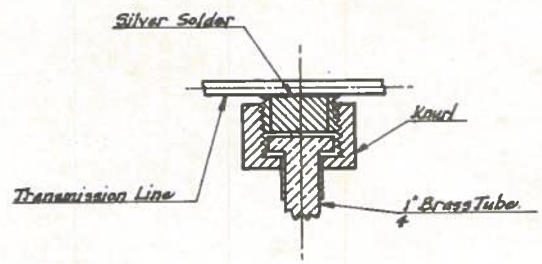
N R C PHOTO FIG.11





DETAIL "A"

12 REQ'D PER UNIT.



DETAIL "D"

12 REQ'D PER UNIT.

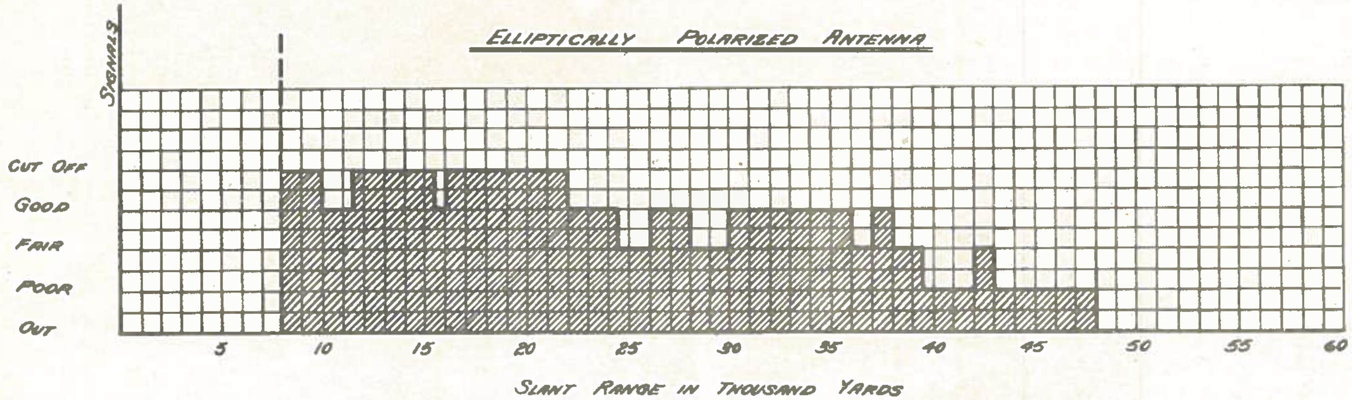
See Dwg. No's NRC-RI-15-45, NRC-RI-15-47, NRC-RI-15-50

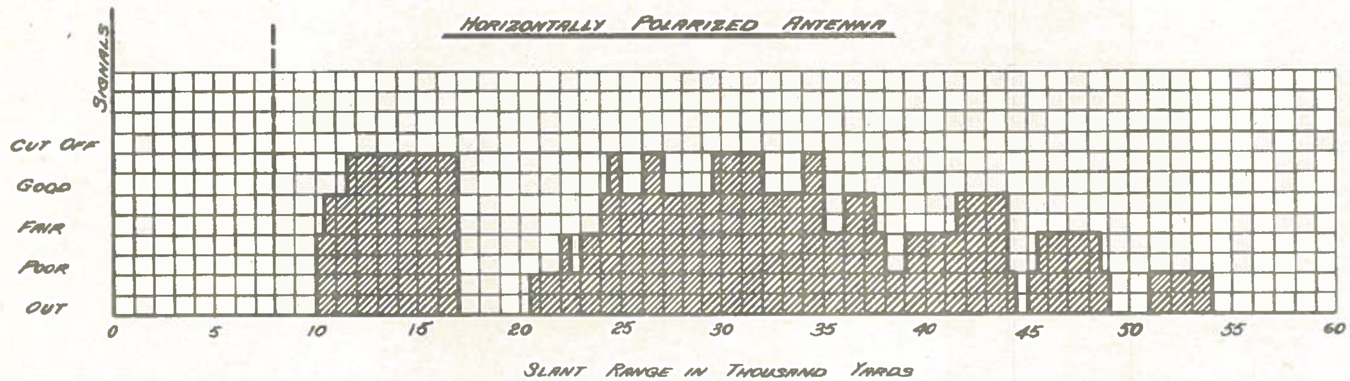
ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY H.A.B. Traced by R.C.S.	DATE Aug. 5. 1942	SUPERSEDES	
CHECKED cea	DATE 10 · 8 · 42	SCALE	—
ENG. APPROV. J.A. Bell	DATE 10 · 8 · 42	FINISH.	—

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

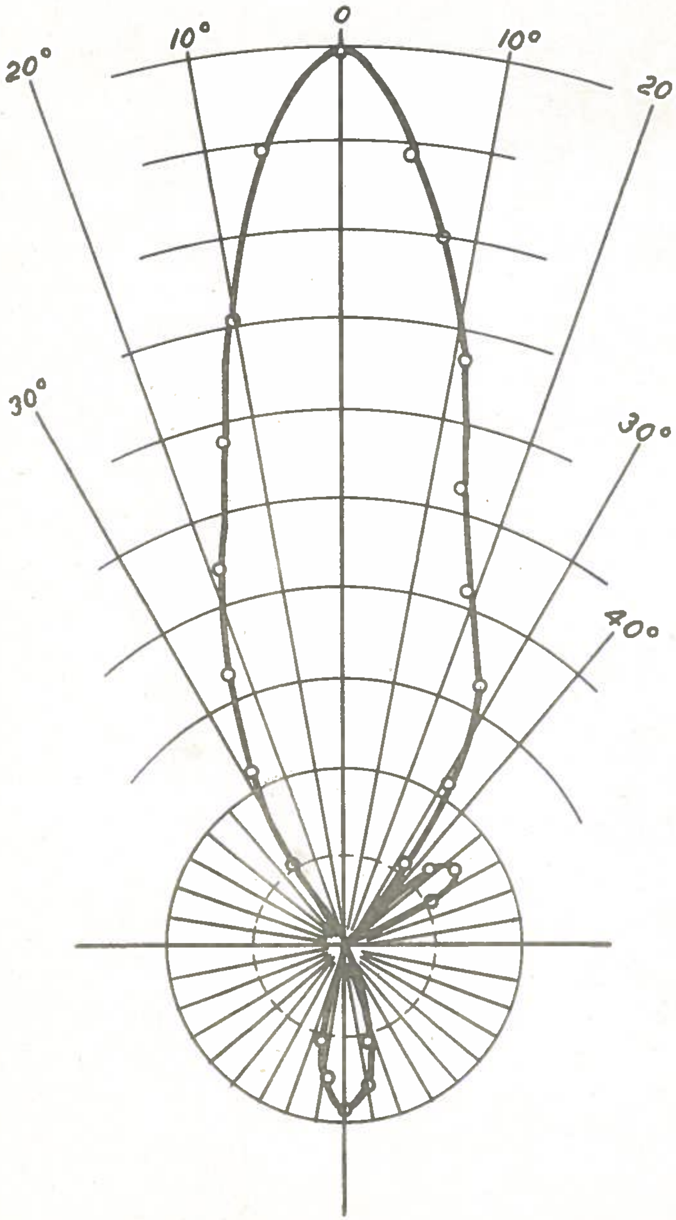
NAME	DWG. NO.
FOLDED DIPOLE & DETAILS	NRC-RI-15-48





NOTE: FLIGHT TESTS ON ELLIPTICALLY POLARIZED & HORIZONTALLY POLARIZED Z.P.I. ANTENNAS FOR AN ANSON AT 7,500 FEET. THE REFLECTING SURFACE (GROUND) CONSISTED OF FRESH WATER IN THE IMMEDIATE FOREGROUND.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION	
DRAWN BY E.H. BELL		DATE SEPT. 21, 1942		SUPERSEDES	
CHECKED CCA.		DATE 22-9-42		SCALE	
ENG. APPROV. G.A.M.		DATE 22-9-42		FINISH.	
NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA					
NAME RANGE GRAPHS FOR ANTENNA.				DWG. NO. NRC-RI-15-70	



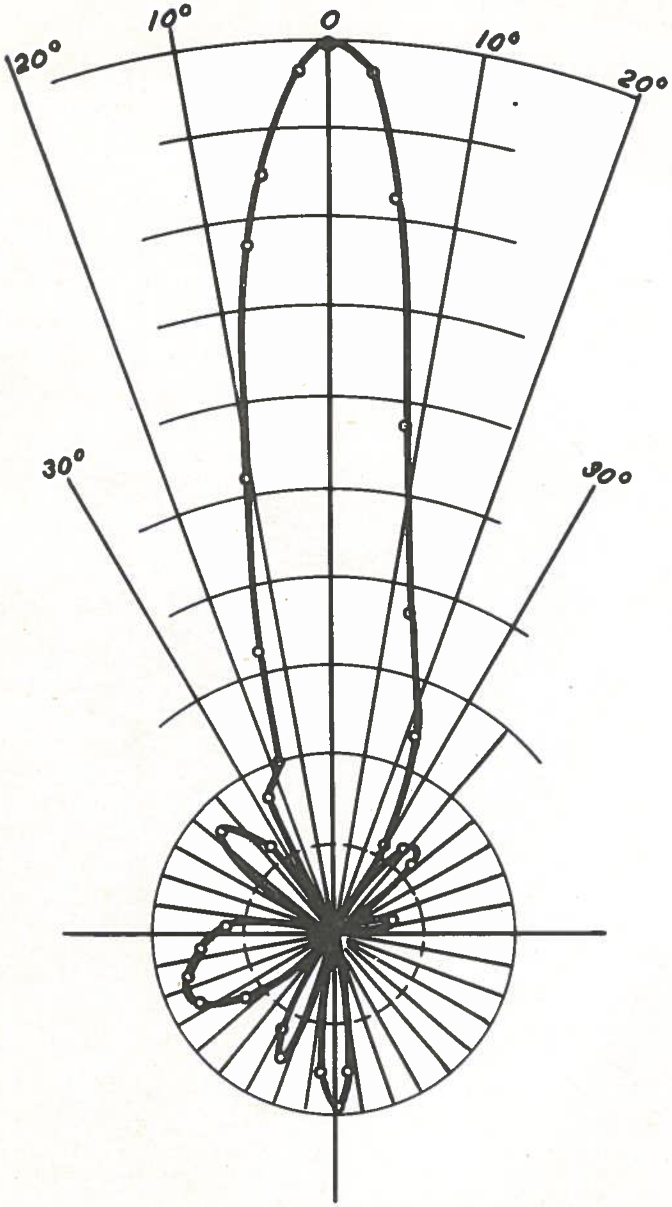
VERTICAL PORTION OF THE ELLIPTICALLY POLARIZED ARRAY.
HORIZONTAL FREE SPACE PATTERN—150MC.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY J. R. D.	DATE Sept. 23, 1942	SUPERSEDES
CHECKED cca.	DATE 25/9/42	SCALE
ENG. APPROV. b. a. m.	DATE 25/9/42	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME VERTICAL PORTION ——	DWG. NO. NRC-RI- 15-74



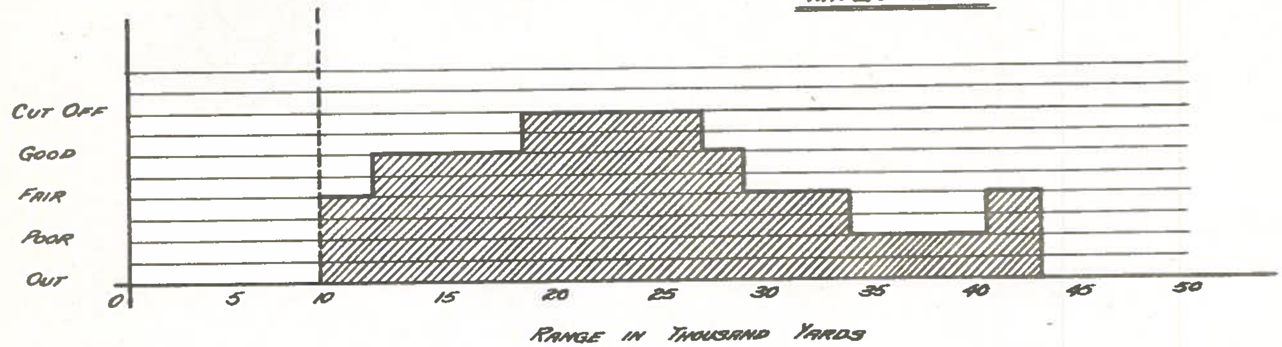
HORIZONTAL PORTION OF THE
ELLIPTICALLY POLARIZED ARRAY
HORIZONTAL FREE SPACE PATTERN – 150 MC.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION
DRAWN BY J.R.D.		DATE SEPT. 23, 1942		SUPERSEDES
CHECKED cca.		DATE 25/9/42		SCALE
ENG. APPROV. G.A.M.		DATE 25/9/42		FINISH.

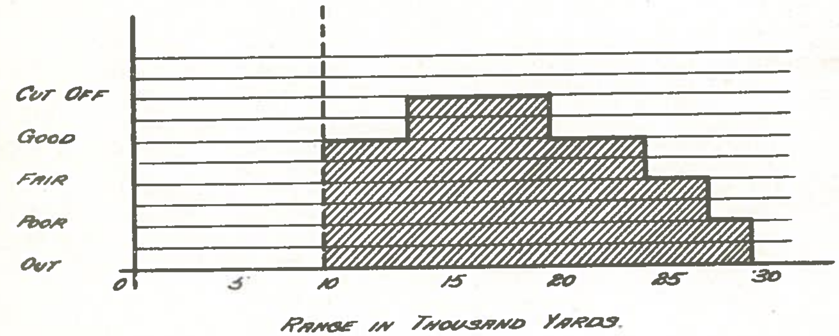
NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

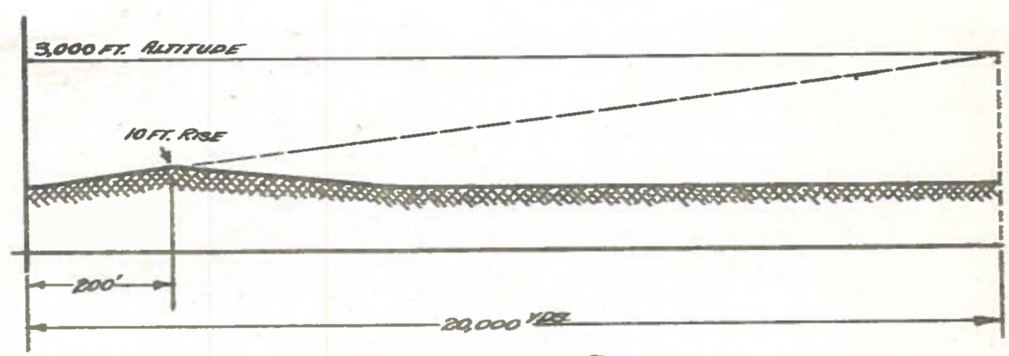
NAME	DWG. NO.
HORIZONTAL PORTION —	NRC - R.I - 15 - 75

WATER SITE



LAND SITE





SKETCH OF LAND SITE

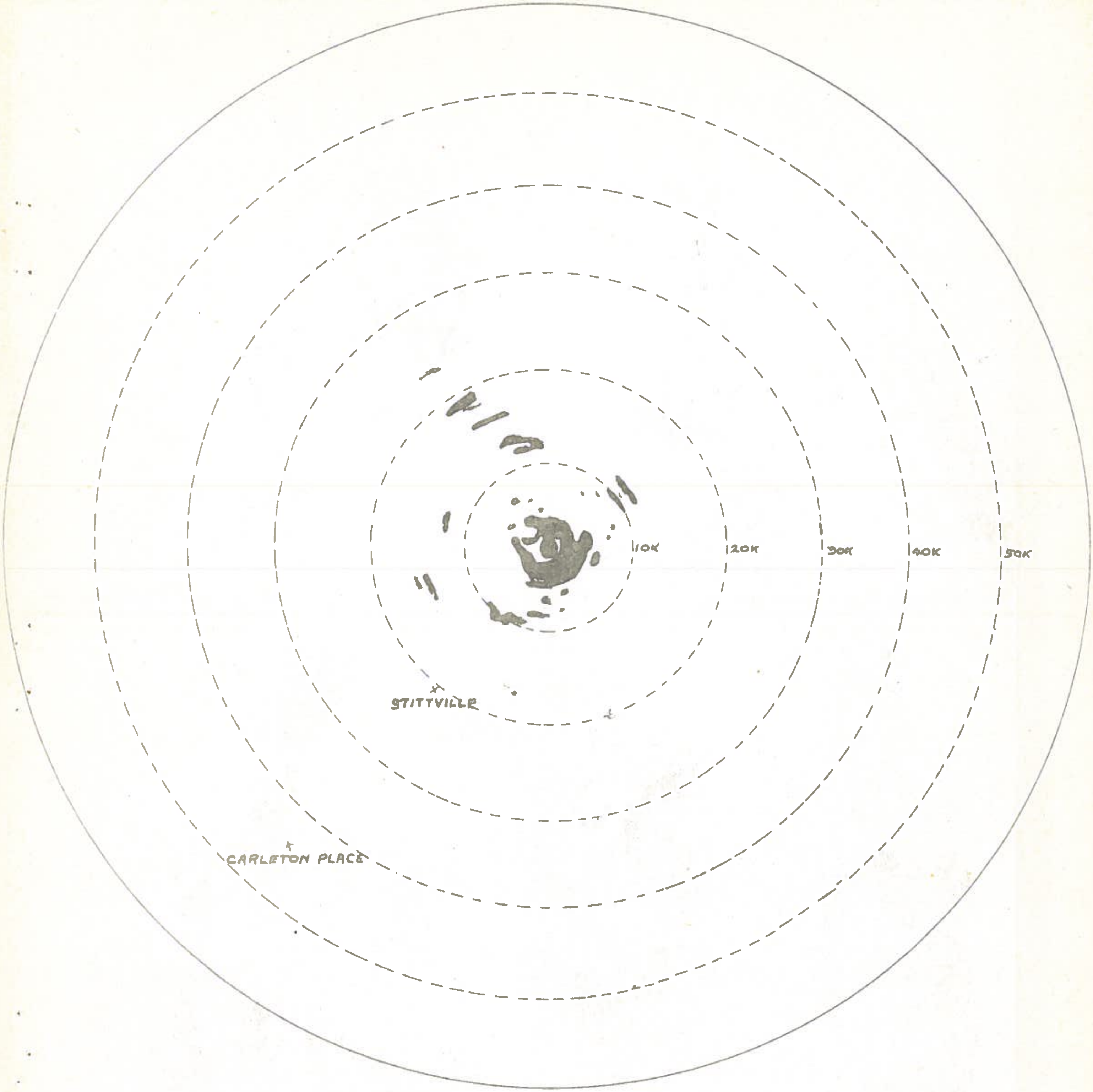
NOTE: FLIGHT TESTS ON AN ELLIPTICALLY POLARIZED Z.P.I. ANTENNA FOR AN ANSON AT 3000'. FIRST FLIGHT OVER A WATER COURSE; THE SECOND FLIGHT WAS OVER A SPECIAL LAND COURSE SHOWN DIAGRAMATICALLY ABOVE.

ITEM	PART NO.	QUAN.	MAT.	DESCRIPTION

DRAWN BY E.N.B.	DATE SEPT. 29, 42	SUPERSEDES
CHECKED COQ	DATE 29/9/42	SCALE
ENG. APPROV. [illegible]	DATE 29/9/42	FINISH.

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME. Z.P.I. ANTENNA RANGE GRAPHS	DWG. NO. NRC-RI-15-78



Z.P.I. CLUTTER

SEPT. 1942

LAKE DESCHENES

OLD ANTENNA

NRC-RI-15-79

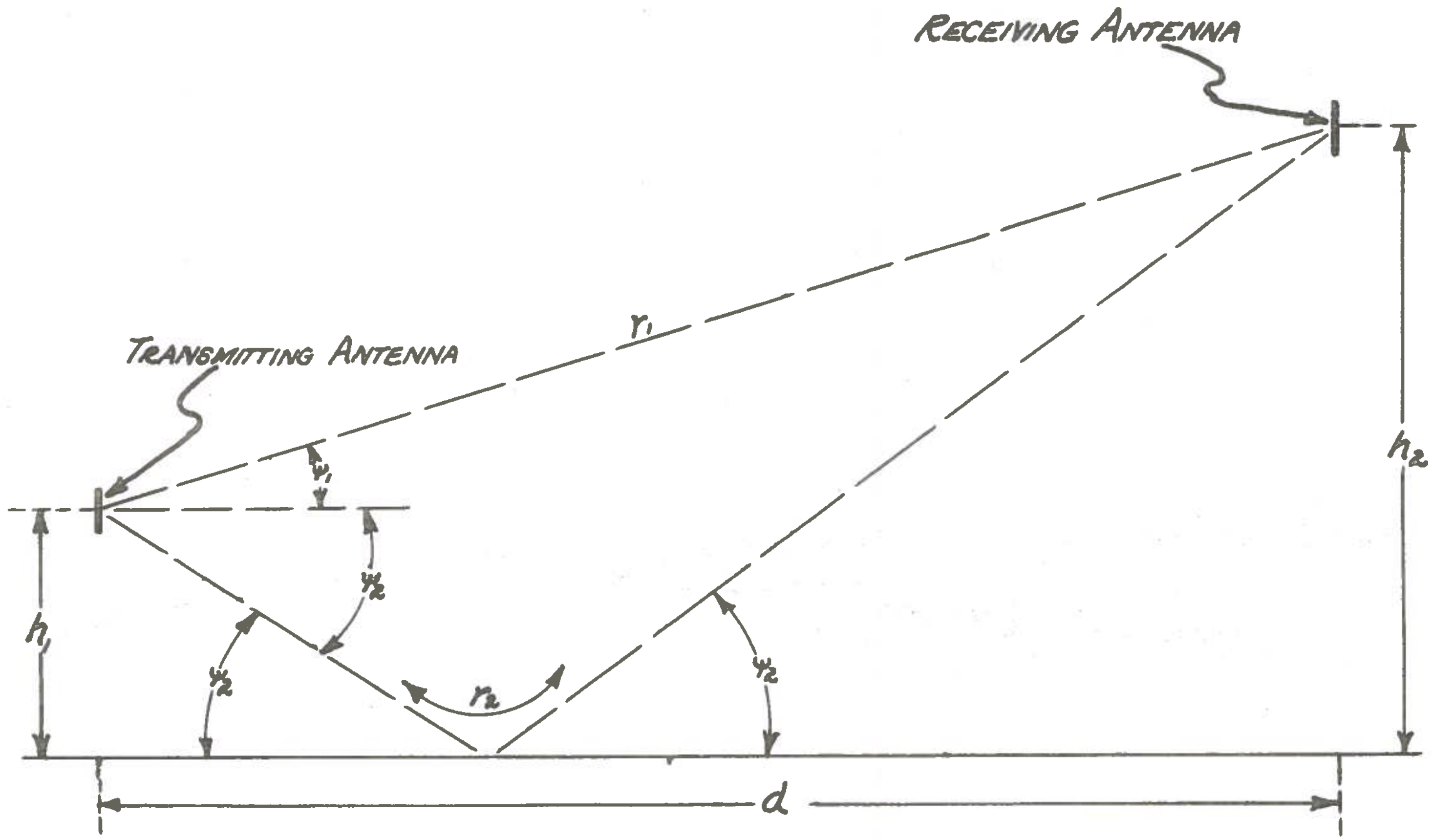


FIG.1.

PRA 73	389	NATIONAL RESEARCH COUNCIL – RADIO BRANCH.		OTTAWA CANADA
		APPROVED –		DATE

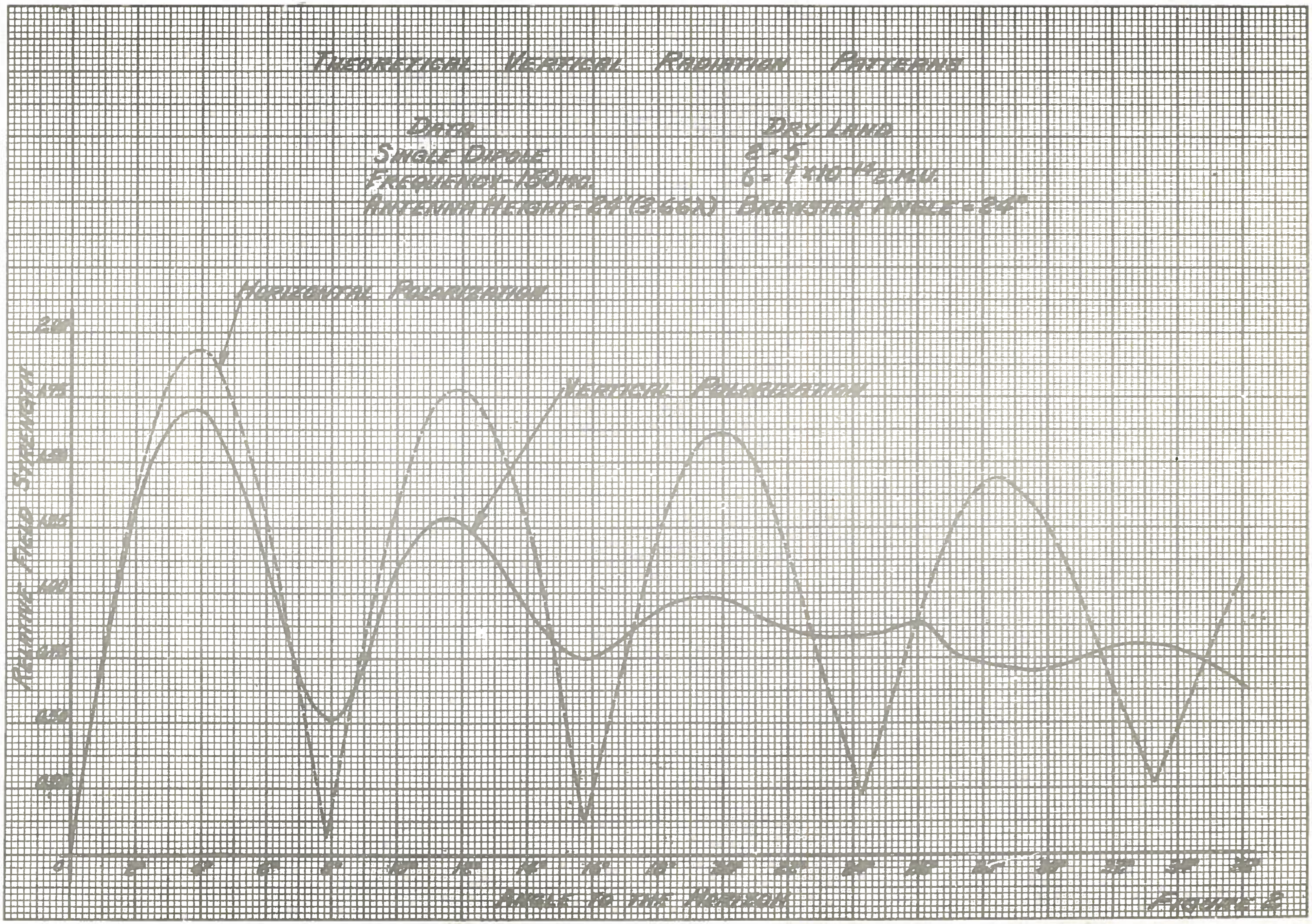
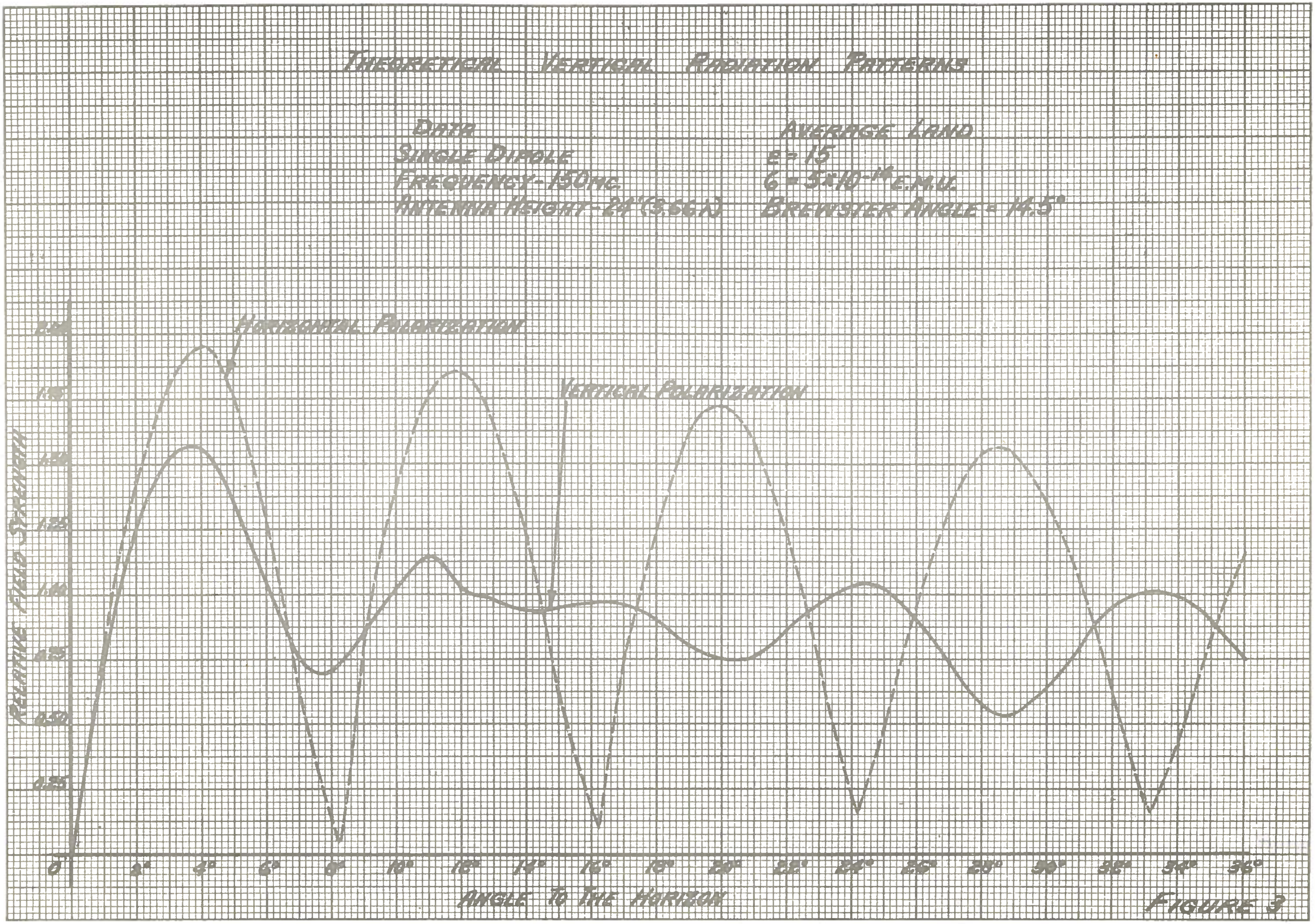


FIGURE 2

PRA-73 390


THEORETICAL VERTICAL RADIATION PATTERNS
DATA
SINGLE DIPOLE
FREQUENCY - 150MC.
ANTENNA HEIGHT - 24' (3.66λ)
AVERAGE LAND
ε = 15
σ = 5×10⁻¹⁴ E.M.U.
BREWSTER ANGLE = 14.5°
HORIZONTAL POLARIZATION
VERTICAL POLARIZATION
RELATIVE FIELD STRENGTH
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
32°
34°
36°
ANGLE TO THE HORIZON
FIGURE 3

PRA-73 391

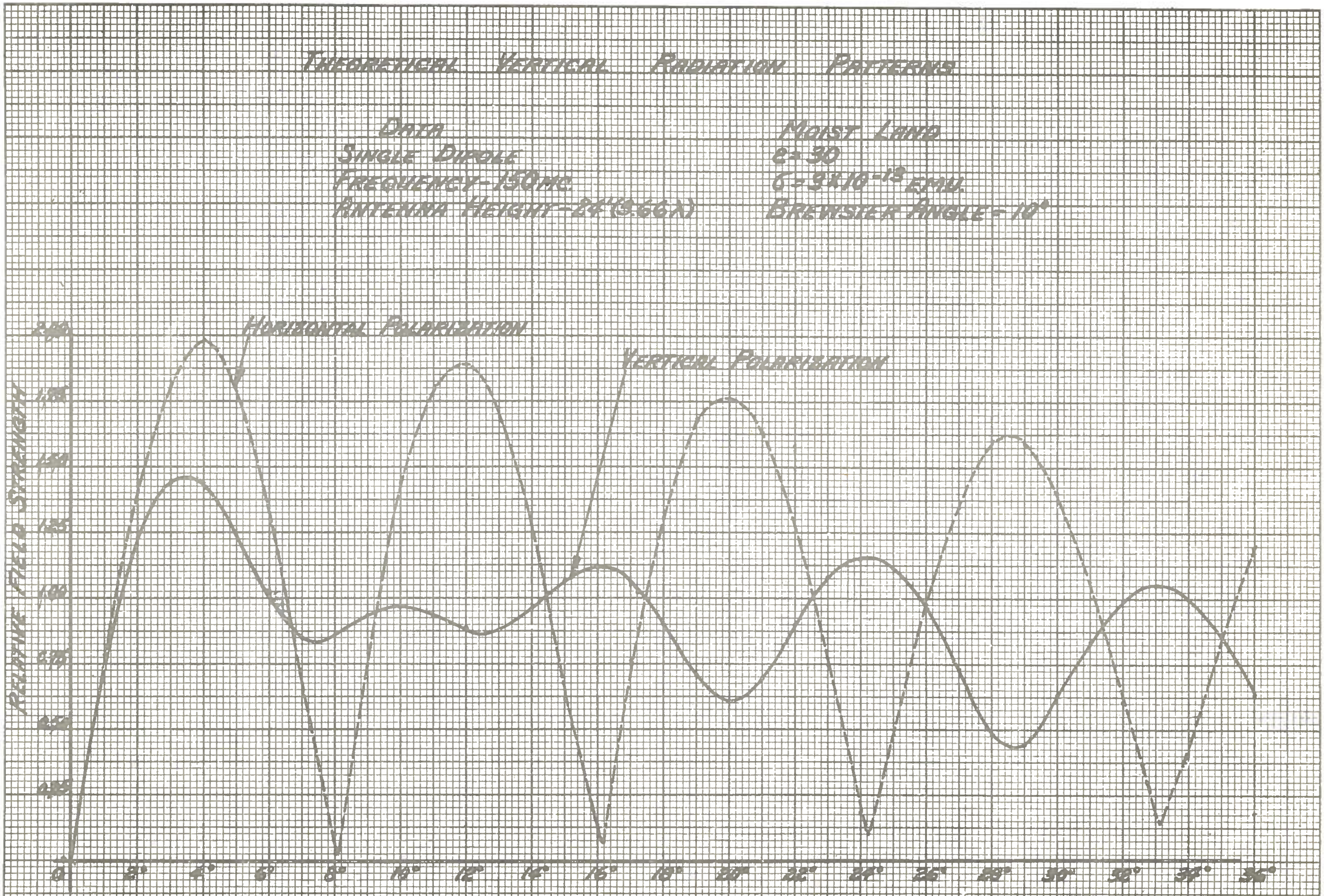
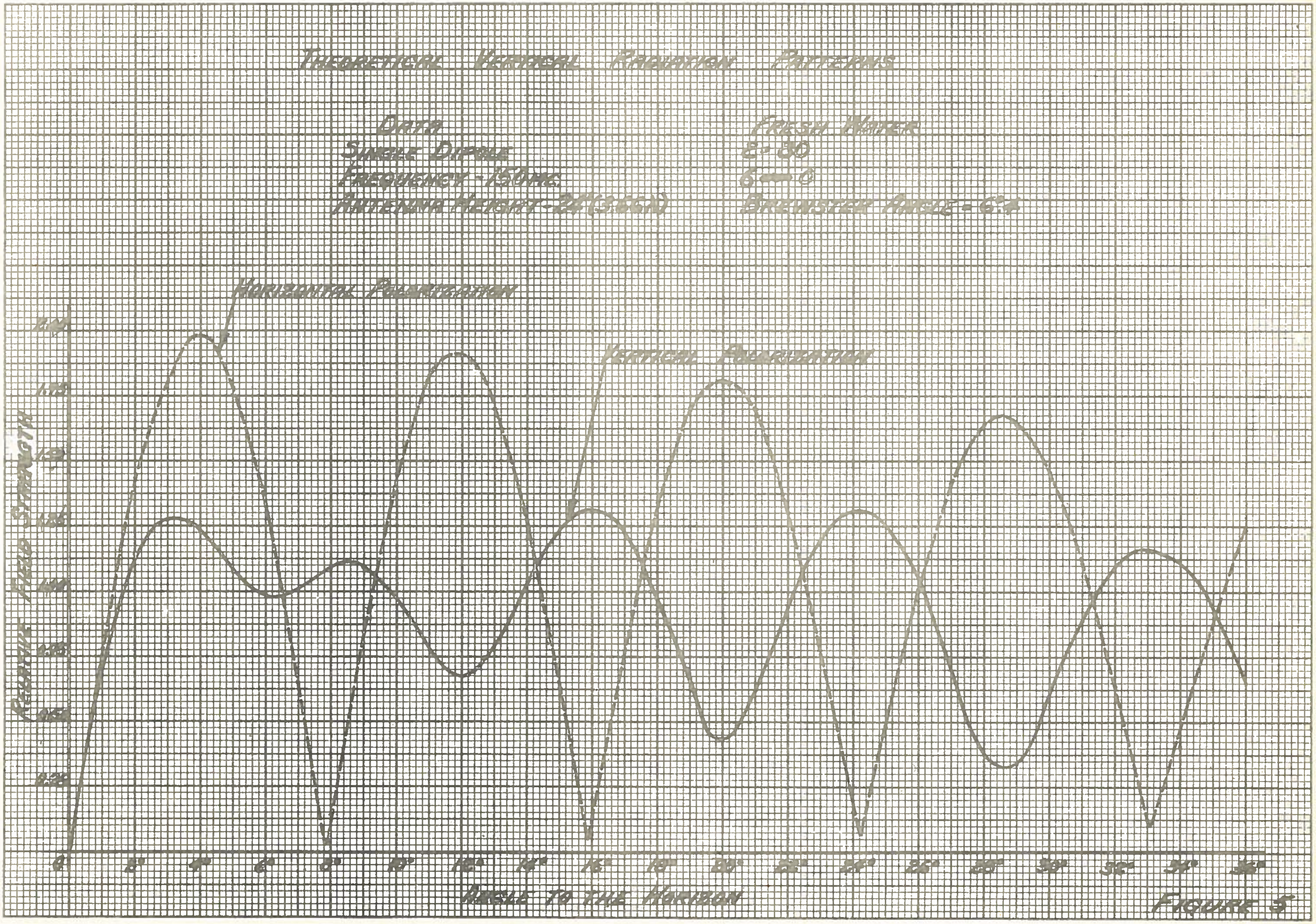


FIGURE 4

P A-73 392



THEORETICAL VERTICAL RADIATION PATTERNS
DATA
SINGLE DIPOLE
FREQUENCY - 150 MC
ANTENNA HEIGHT - 24' (3.66 M)
FRESH WATER
ε = 80
σ ≈ 0
BREWSTER ANGLE - 6°4
HORIZONTAL POLARIZATION
VERTICAL POLARIZATION
RELATIVE FIELD STRENGTH
0
2°
4°
6°
8°
10°
12°
14°
16°
18°
20°
22°
24°
26°
28°
30°
32°
34°
36°
ANGLE TO THE HORIZON

FIGURE 5

PRA-73 394

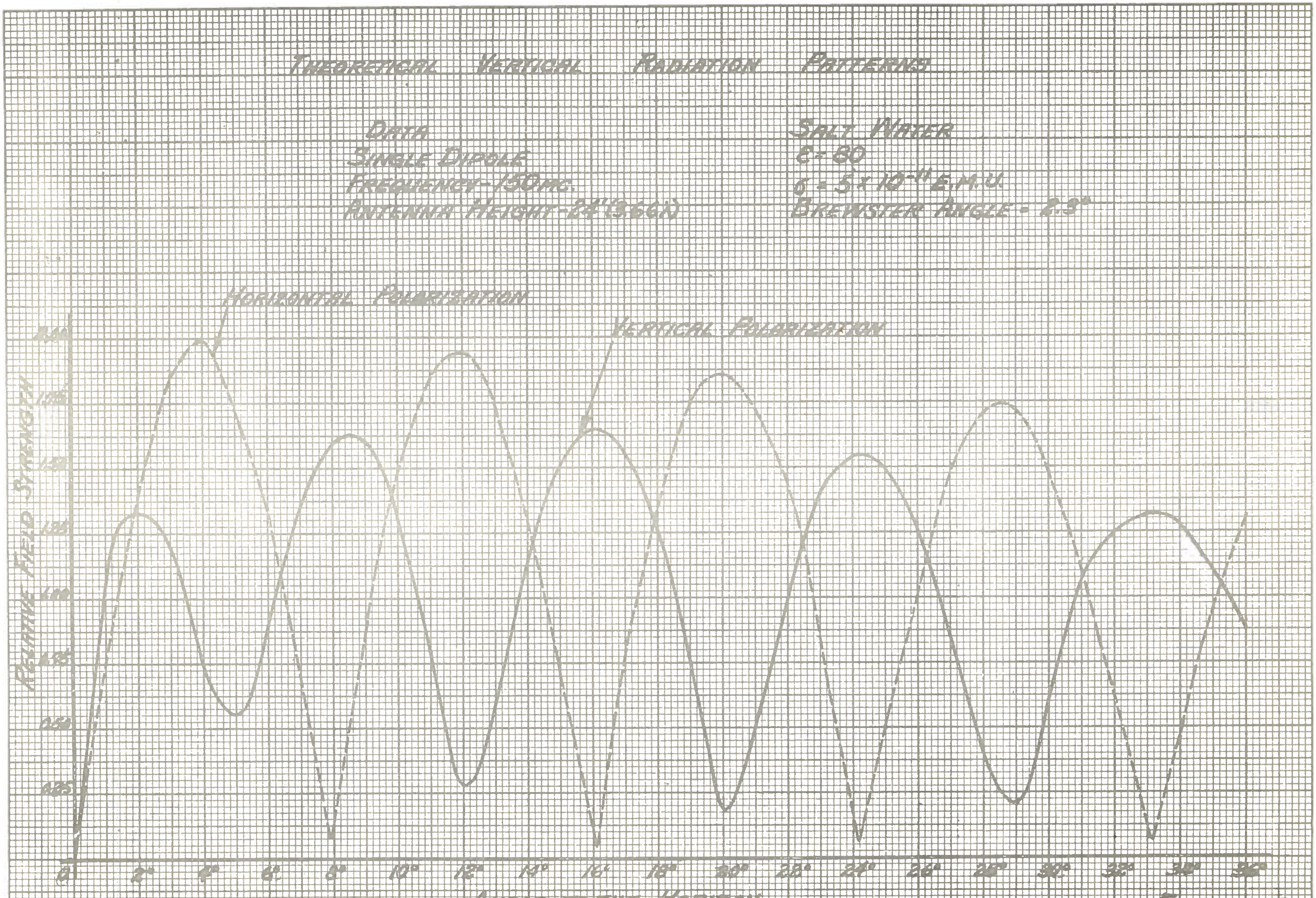


FIGURE 6

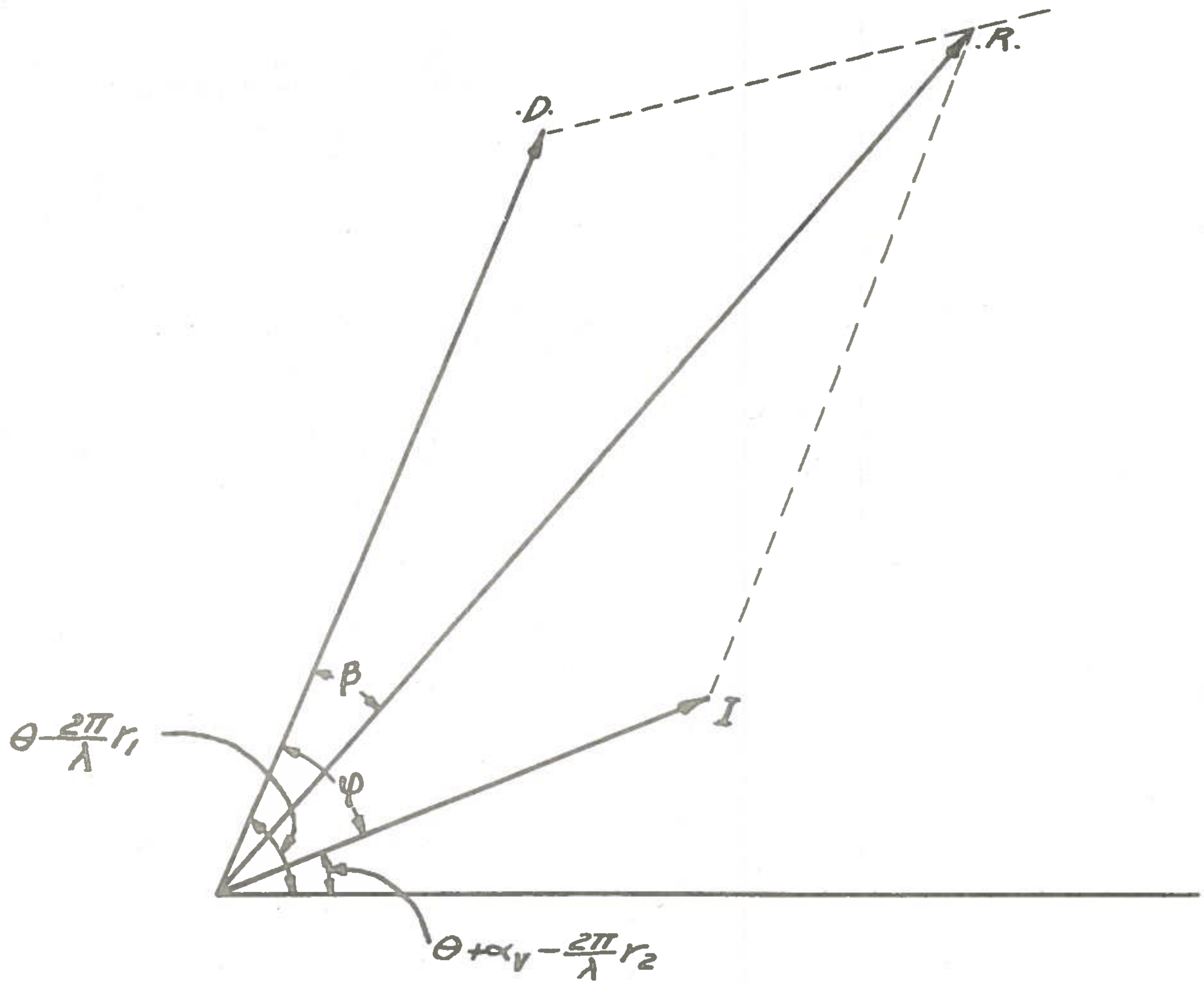


FIG. 7.

PRA 73	395	NATIONAL RESEARCH COUNCIL – RADIO BRANCH.		OTTAWA CANADA
		APPROVED –		DATE

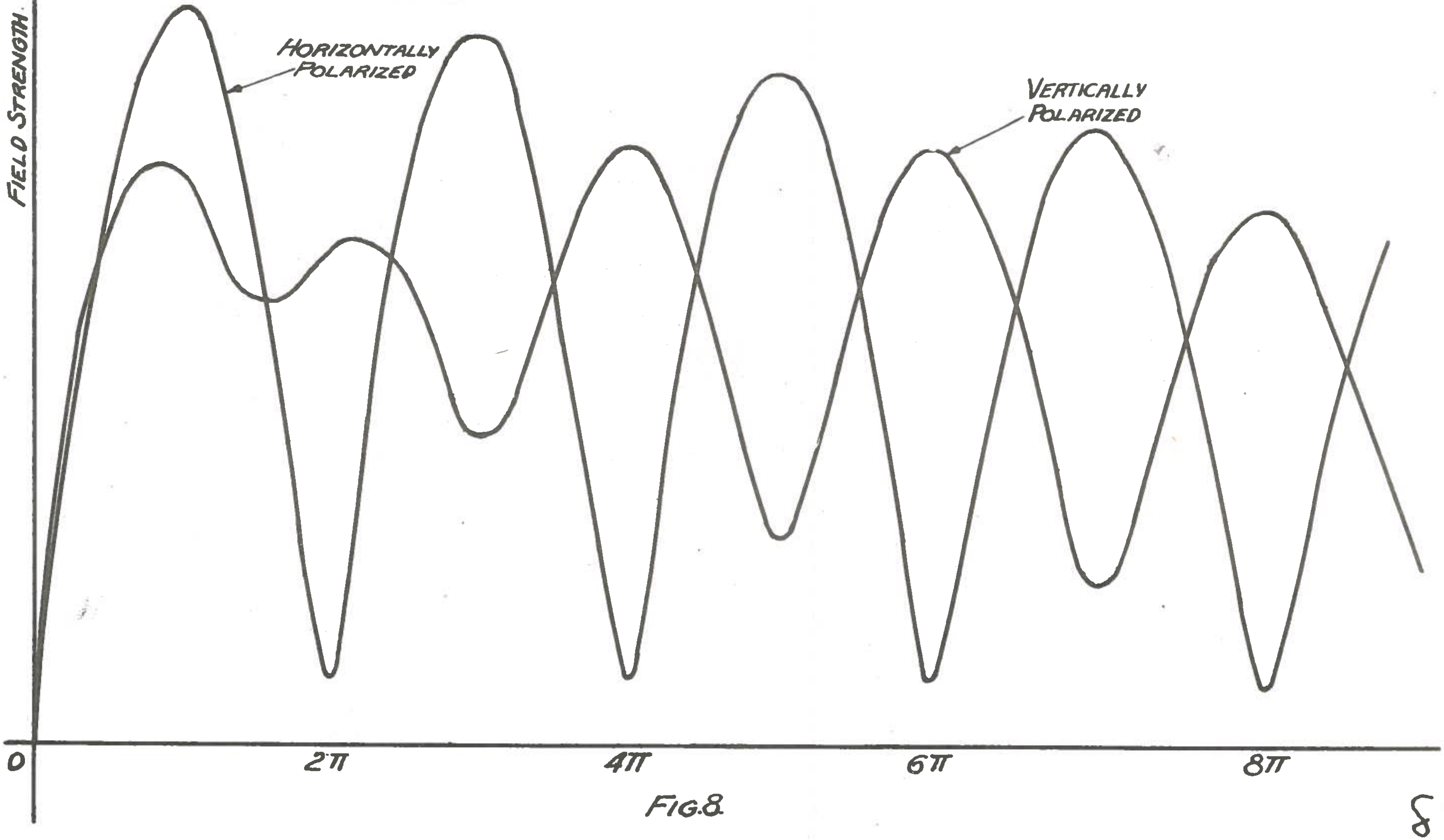


FIG. 8.

PRA 73	396	NATIONAL RESEARCH COUNCIL – RADIO BRANCH. OTTAWA CANADA
		APPROVED – DATE

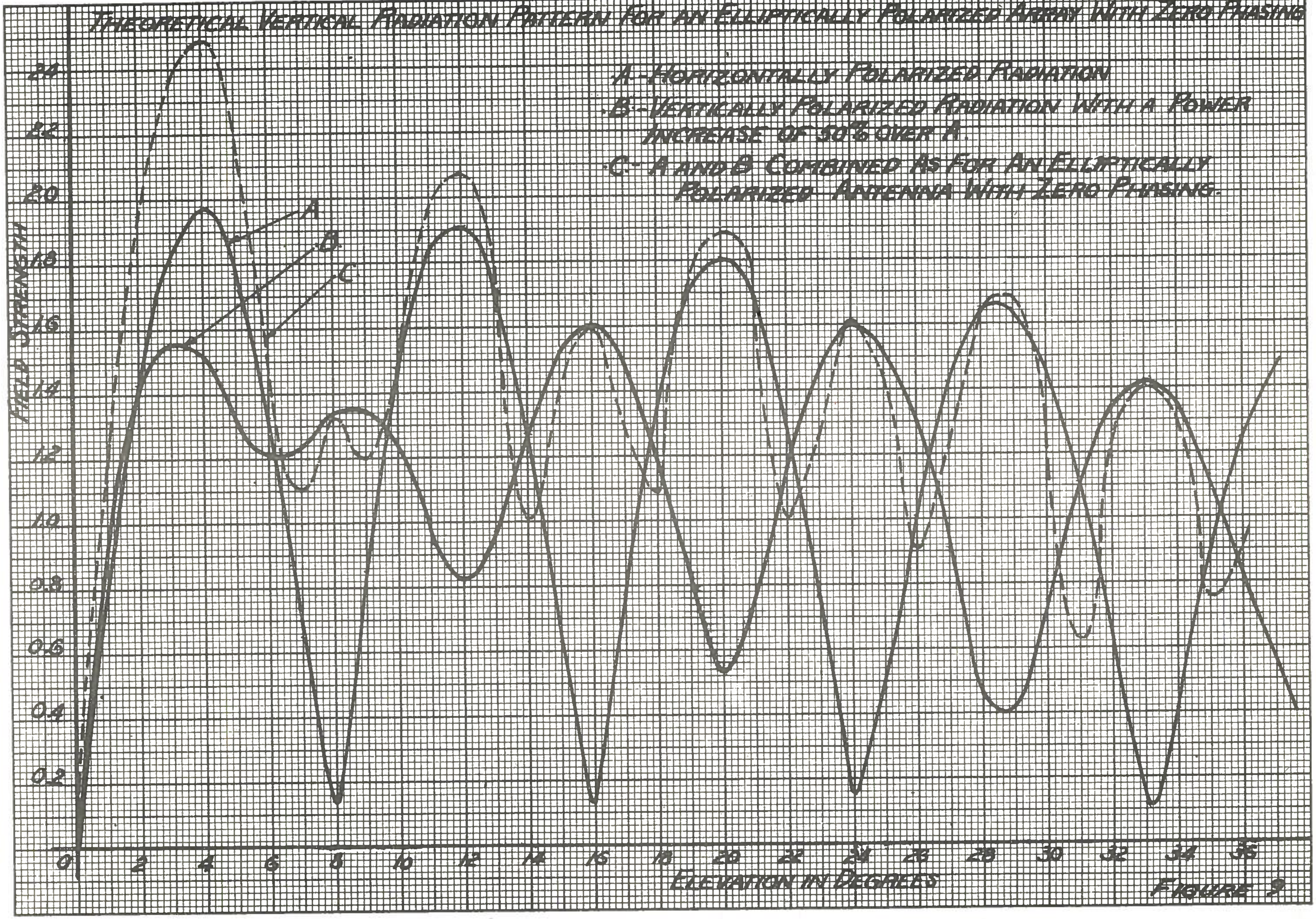
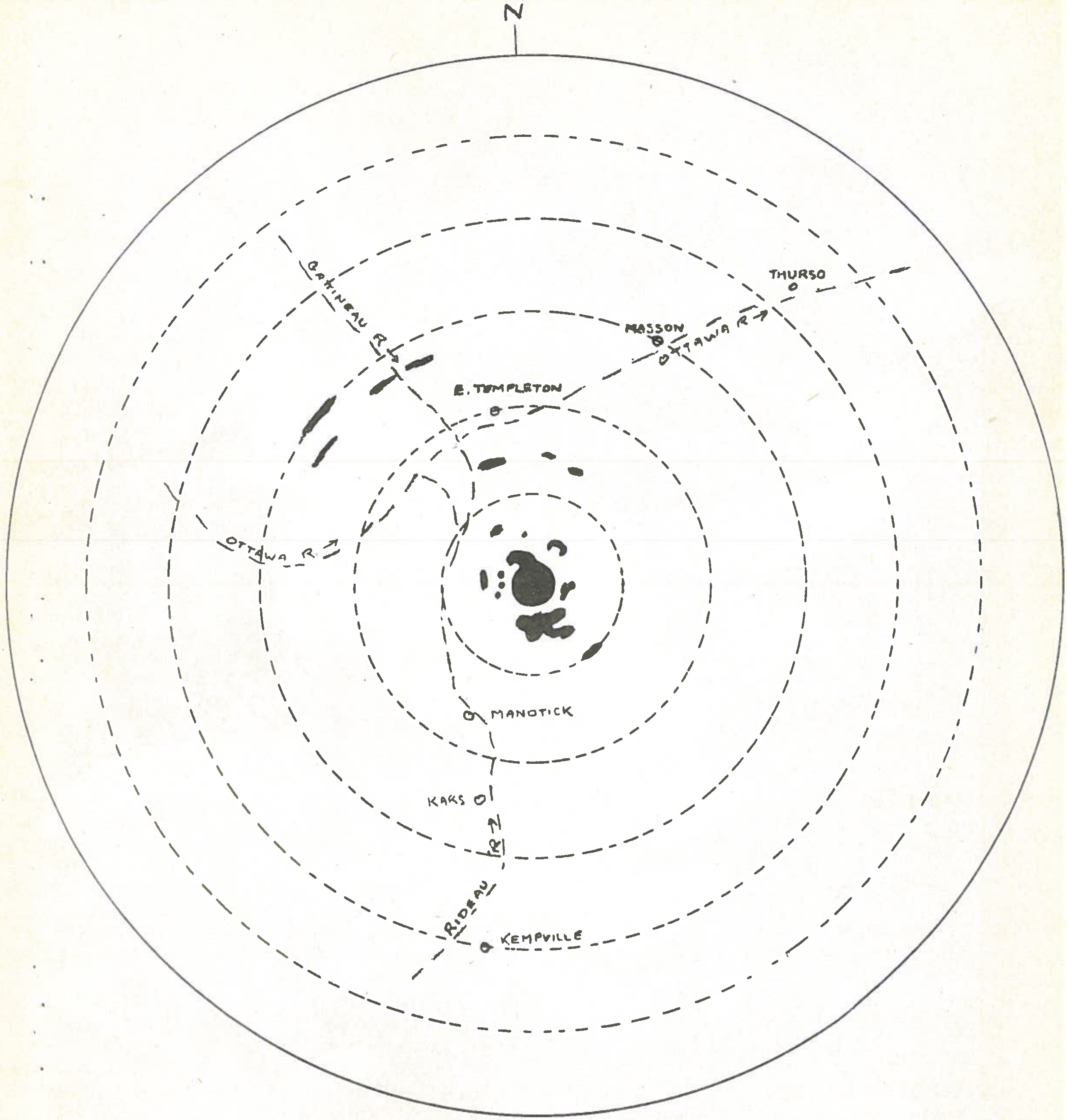


FIGURE 9

PRA-73 397



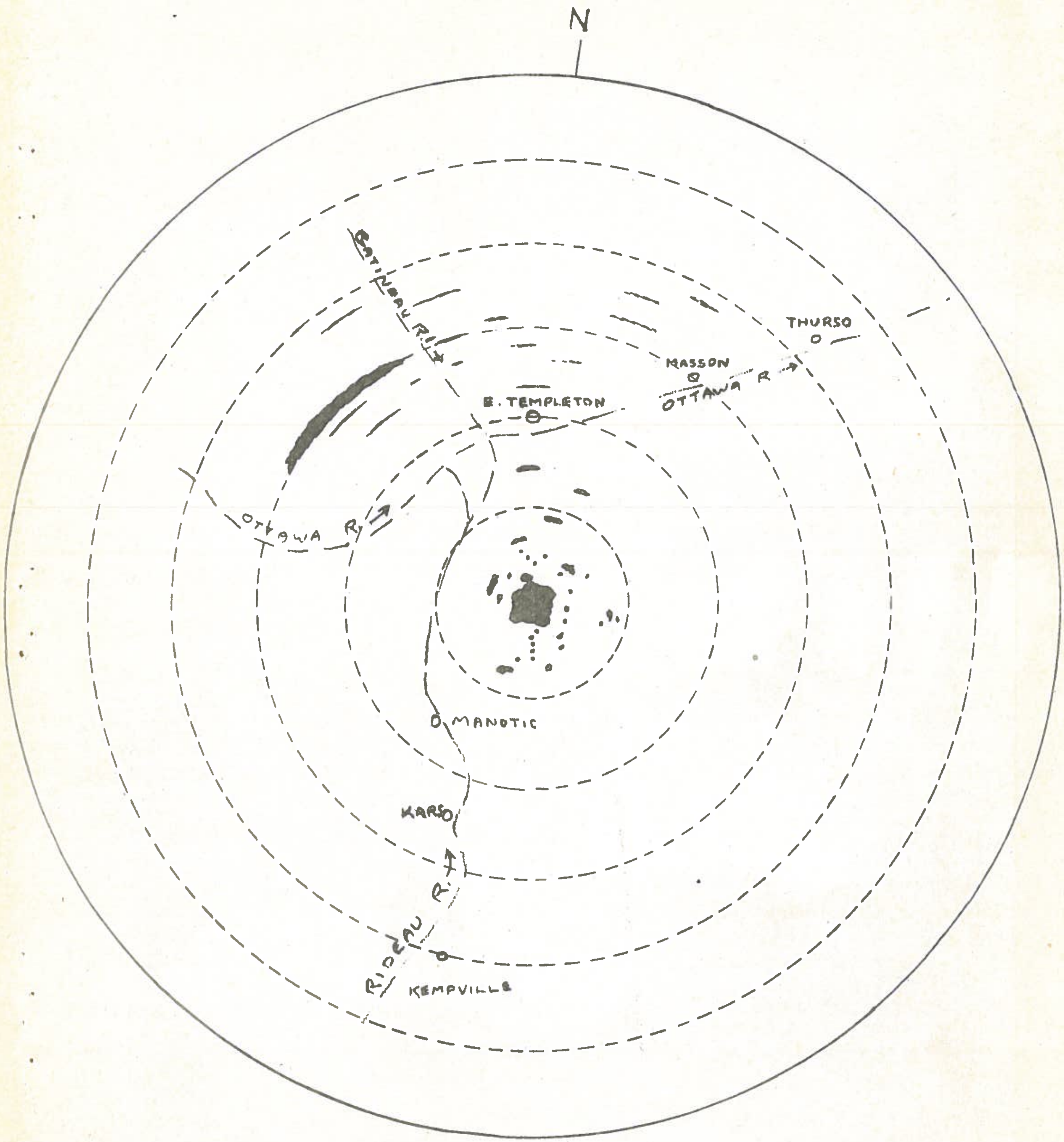
Z.P.I. CLUTTER
½ MILE EAST of LEITRIM
"OLD" ANTENNA

JULY 1942

NOTE

Oscillator Tubes Good

NRC-RI-15-39

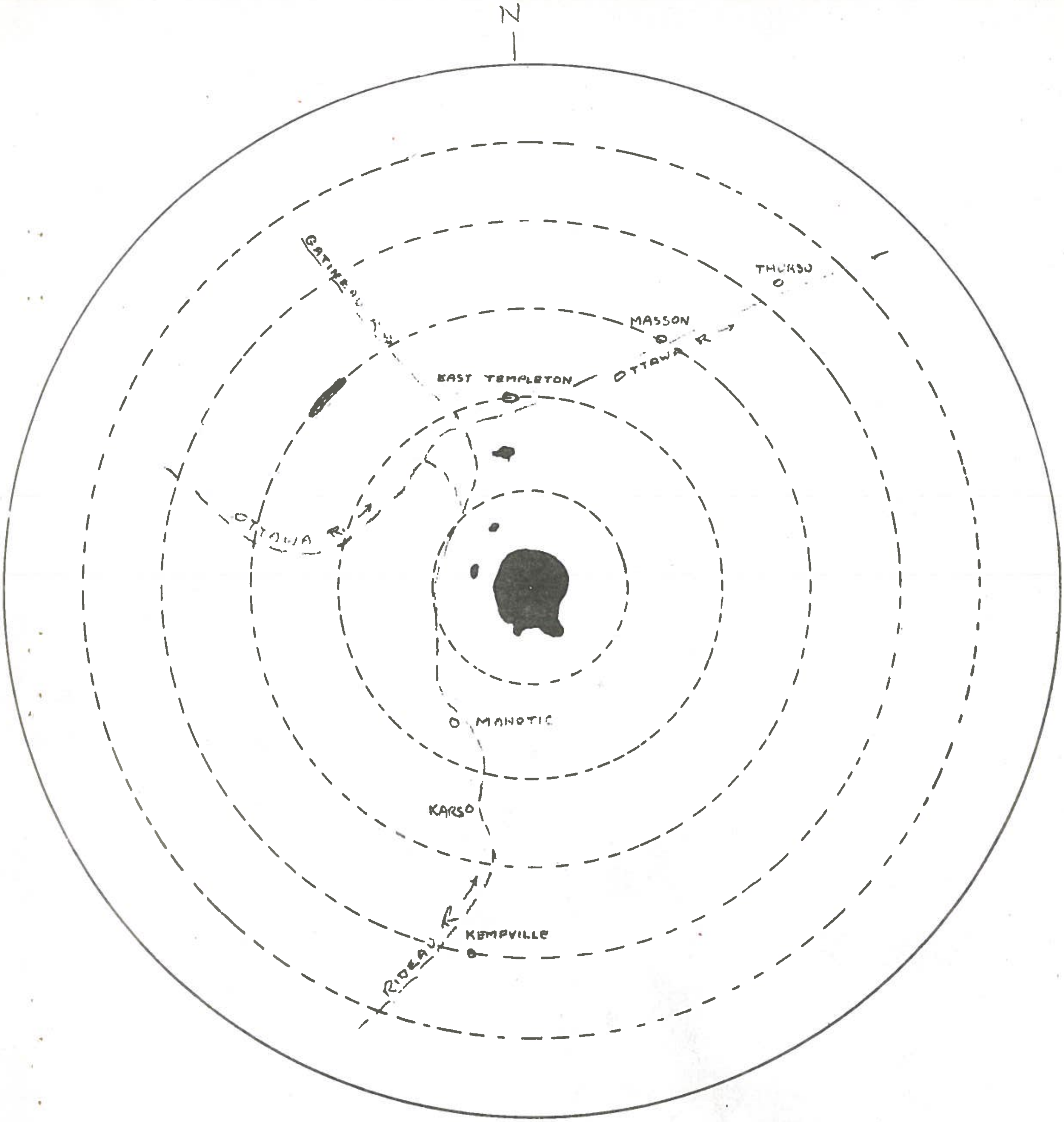


Z.P.I. CLUTTER
½ MILE EAST of LEITRIM
"NEW" ANTENNA

JULY 1942

NOTE
OSCILLATOR TUBES FAIR

NRC-RI-15-40

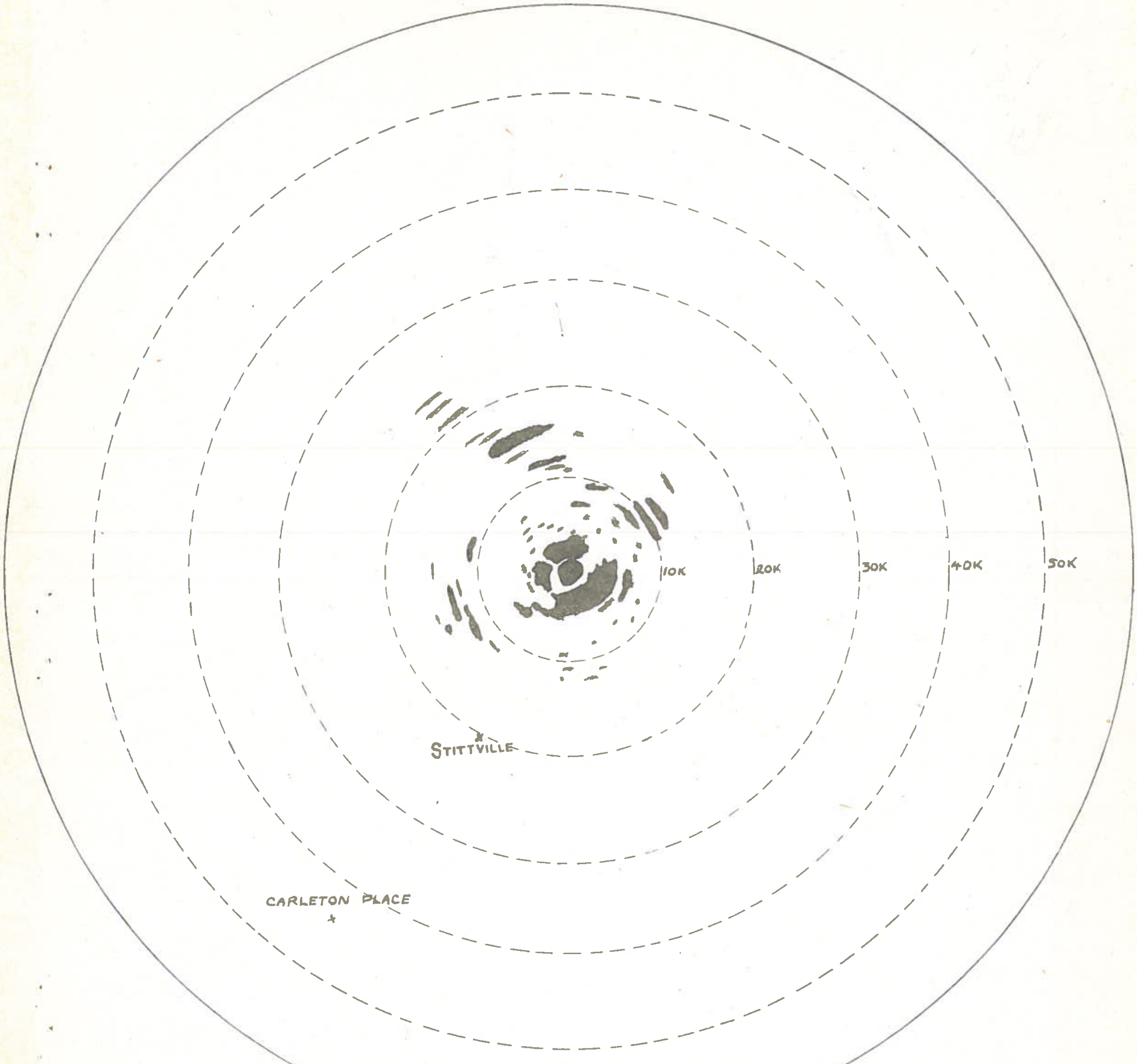


Z.P.I. CLUTTER
½ MILE EAST of LEITRIM
"OLD" ANTENNA

JULY 1942

NOTE
OSCILLATOR TUBES WEAK

NRC-RI-15-41



Z.P.I. CLUTTER

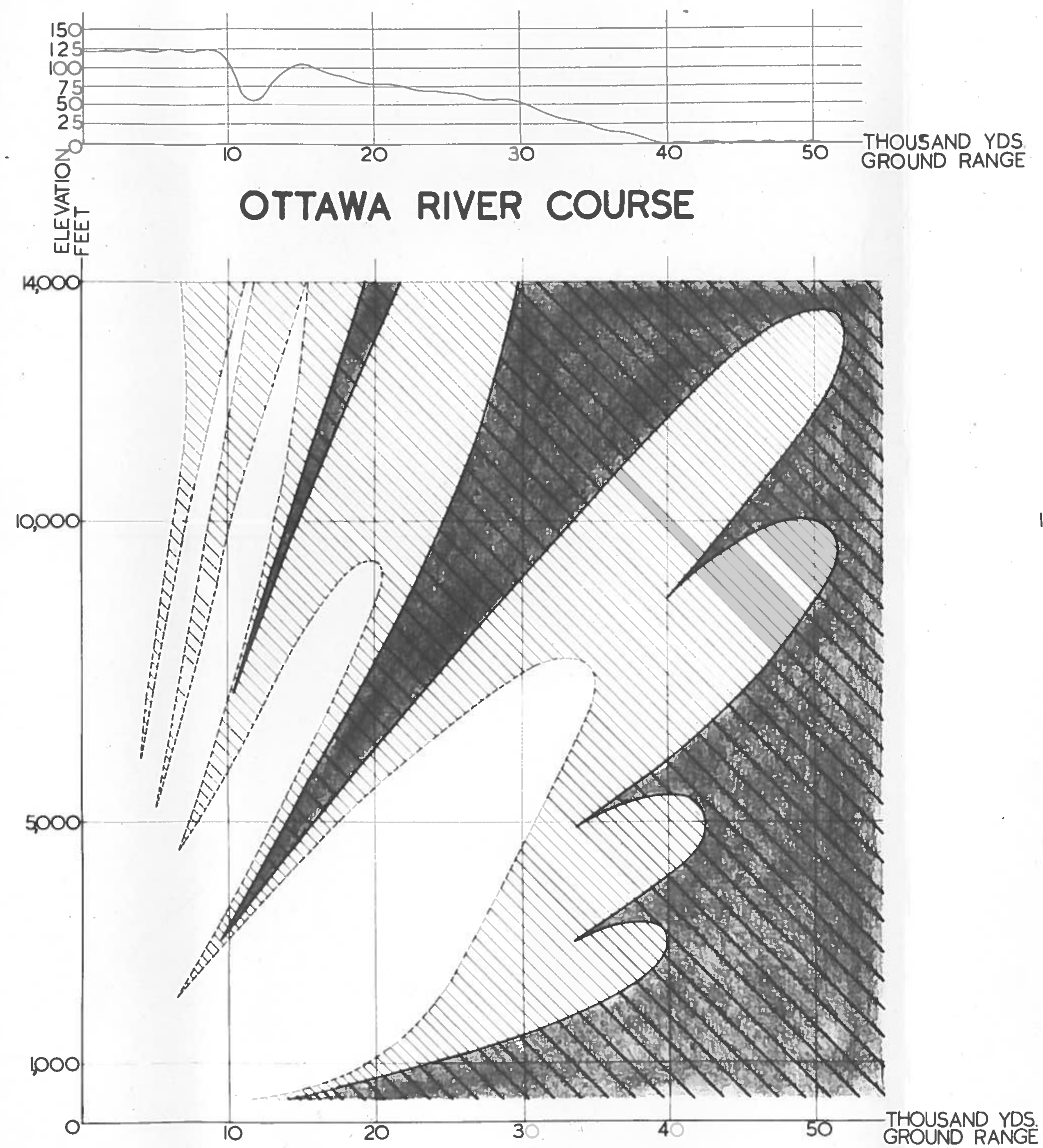
LAKE DESCHENES

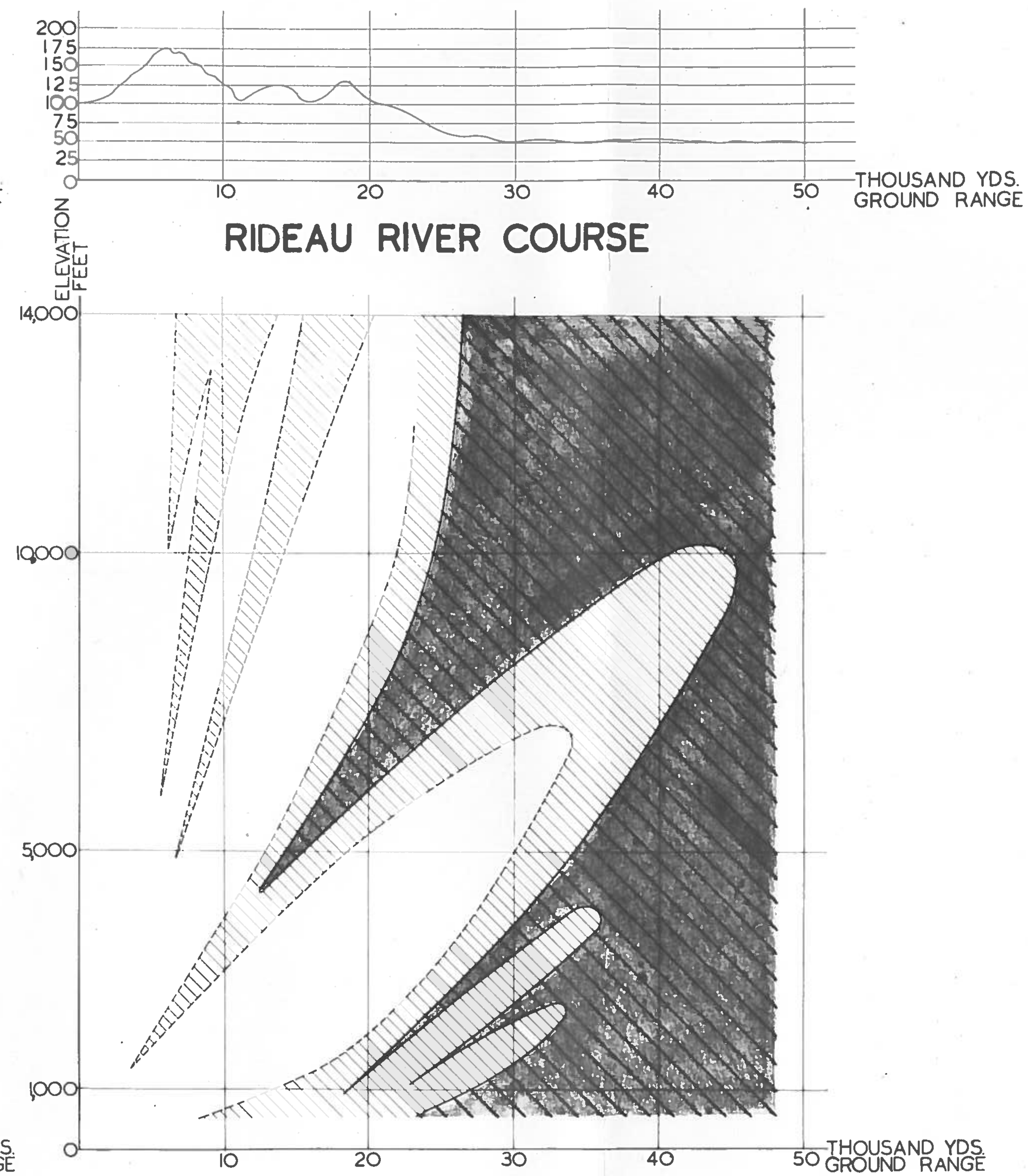
NEW ANTENNA

SEPT. 1942

NRC-RI-15-80

Cross Section of Ground Contours.





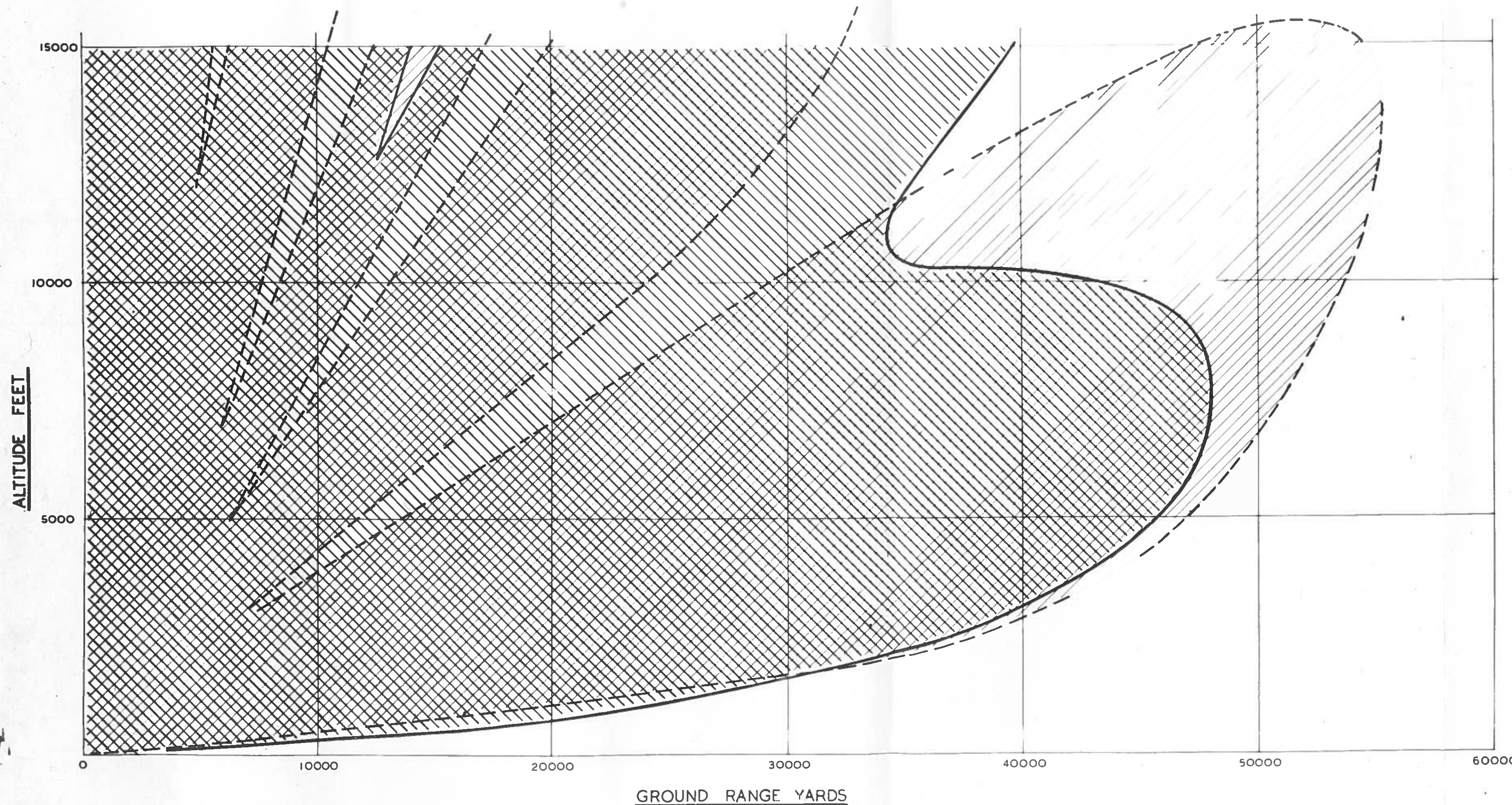
NOTE:-
Dotted lines - Old antenna - Horizontally polarized.
Full lines - New antenna - Elliptically polarized.
Power reduced to approx. 30 K.W. peak in both cases.

Vertical polar diagram made with
target plane for old & new R.I. antennas.

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION
DRAWN BY G.N.D.	DATE 10/8/42	SUPERSEDES		
CHECKED	DATE	SCALE		
ENG. APPROV.	DATE 27-3-43	FINISH		
NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA				
NAME GROUND RANGE R.I. VERTICAL POLAR DIAGRAM	DWG. NO. NRC-RI-15-42			

DESCHENES SITE

RADIAL COURSE OVER LAKE DESCHENES THROUGH STITTVILLE, ASHTON STATION, CARLETON PLACE, FERGUSON FALLS.



NOTE –

Dotted Lines – Horizontally Polarized Antenna

Full Lines – Elliptically Polarized Antenna

REVISED. 20-11-42. RBT

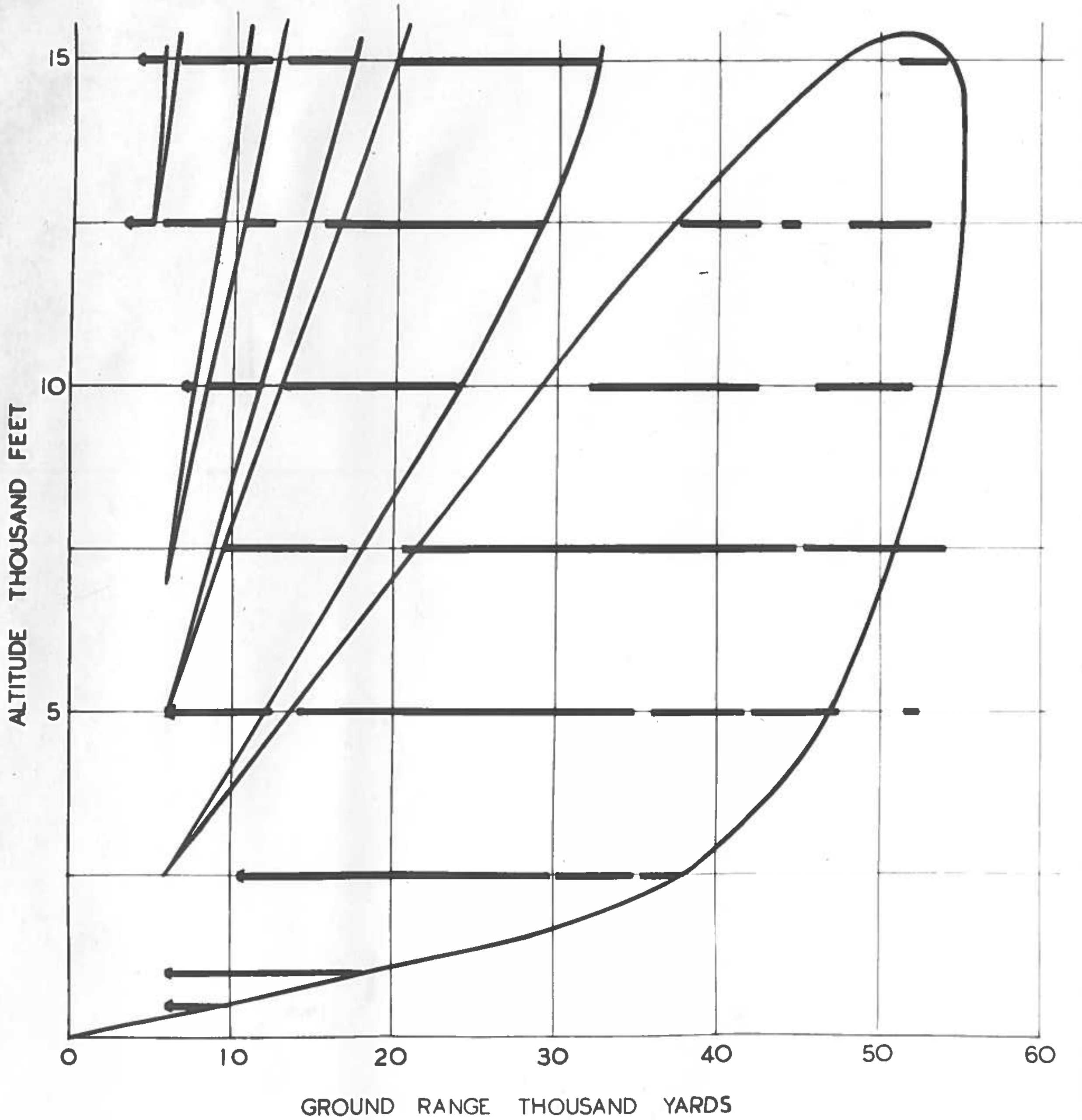
ITEM	PART No	QUAN	MAT'L	DESCRIPTION

DRAWN BY R.B.T.	DATE 22-9-42	SUPERSEDED
CHECKED oca	DATE 22-9-42	SCALE
ENG. APPROV. EP	DATE 22-9-42	FINISH
NATIONAL RESEARCH COUNCIL-RADIO SECTION- OTTAWA CANADA		
NAME DESCHENES SITE R.I. VERTICAL POLAR DIAGRAM		DWG. No. NRC. R.I.-15-69.

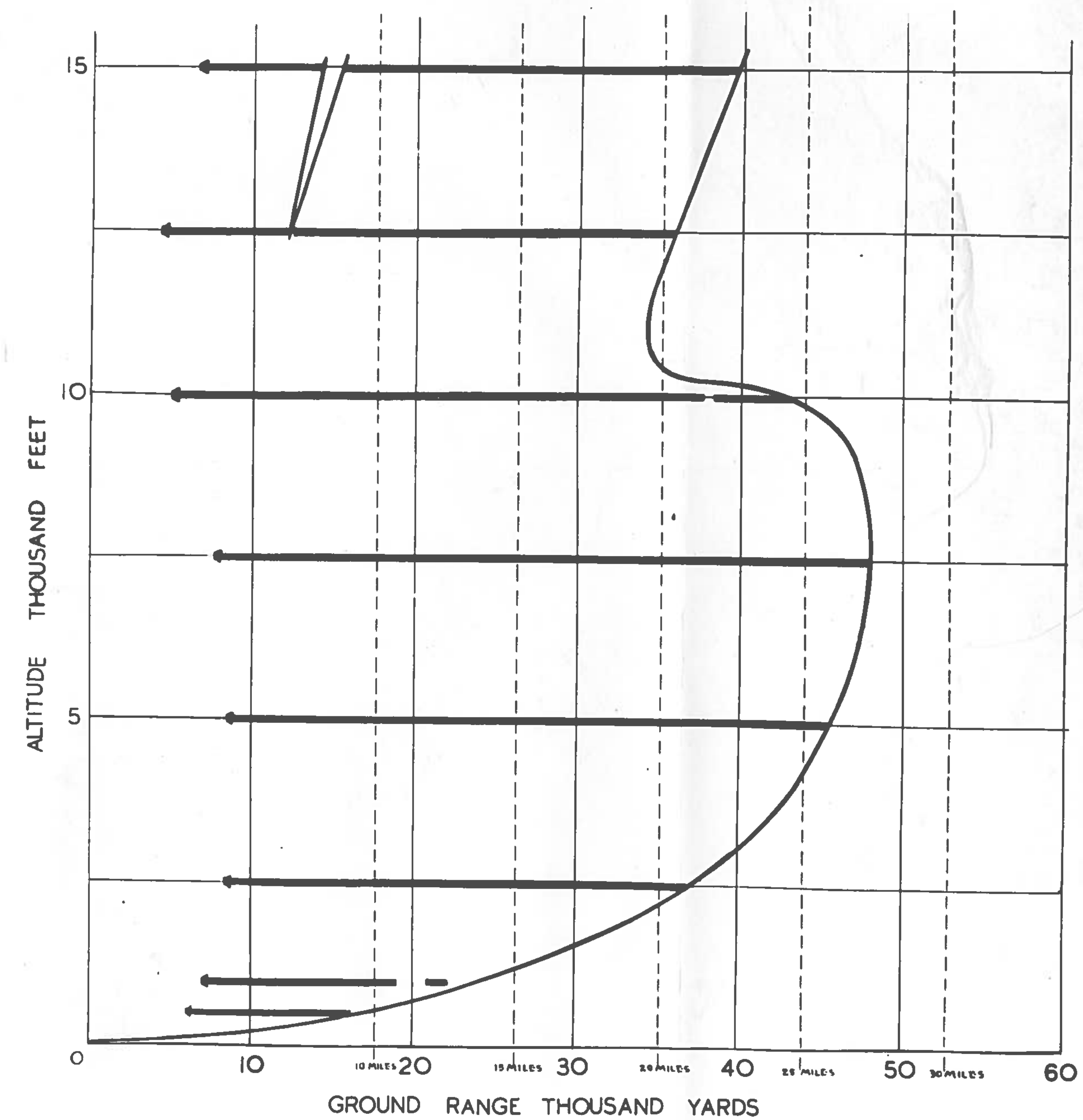
DESCHENES SITE

COURSE OVER LAKE DESCHENES

HORIZONTAL POLARIZATION



ELLIPTICAL POLARIZATION



NOTE

▬ Aircraft visible

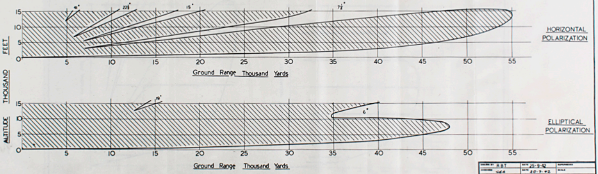
◀▬ Aircraft lost in clutter at this point

ALL PLOTS TAKEN ON AN AVRO ANSON AIRCRAFT ON RETURN FLIGHT

DRAWN BY RBT	DATE 24-9-42	SUPERSEDES	
CHECKED cca	DATE 24-7-42	SCALE	
ENG. APPROV. ER	DATE 24-9-42	FINISH.	
NATIONAL RESEARCH COUNCIL-RADIO SECTION- OTTAWA CANADA			
NAME DESCHENES SITE WITH DATA PLOTTED		DWG. NO. RI. 15-71.	

ROUTE OVER LAKE DESCHENES

TAKEN ON LAKE SHORE AT VILLAGE OF DESCHENES



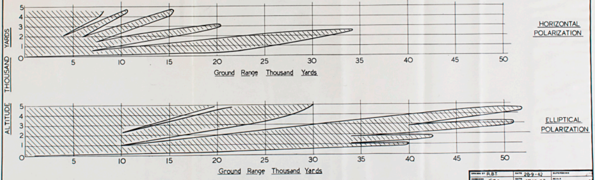
ALL DATA TAKEN ON AN AVRO ANSON AIRCRAFT APPROACHING SITE

Revised 20-11-42 RBT

DRAWN BY RBT	DATE 25-9-42	SUPERSEDES
CHECKED	DATE 20-9-42	SCALE
ENG. APPROV.	DATE 20-9-42	FINISH
NATIONAL RESEARCH COUNCIL-RADIO SECTION		
NAME ROUTE OVER LAKE DESCHENES		DWG. NO. NEC — R1-15-73

OTTAWA RIVER ROUTE

TAKEN AT LEITRIM



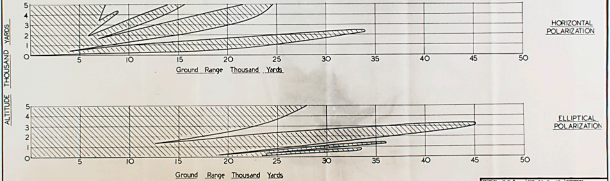
ALL DATA TAKEN ON AN AVRO ANSON AIRCRAFT APPROACHING SITE

REVISED 20-11-42 RBT

DRAWN BY R.B.T.	DATE 28-9-42	SUPERSEDES
CHECKED CCa	DATE 15-10-42	SCALE
ENG. APPROV. ER	DATE 15-10-42	FINISH
NATIONAL RESEARCH COUNCIL-RADIO SECTION- OTTAWA CANADA		
NAME OTTAWA RIVER ROUTE		DWG. NO. RF 15-76

RIDEAU RIVER ROUTE

TAKEN AT LEITRIUM



ALL DATA TAKEN ON AN AVRO ANSON AIRCRAFT APPROACHING SITE

Revised 20-11-42 RBT

DRAWN BY R B T	DATE 28-9-42	SUPERSEDES
CHECKED C.C.G.	DATE 13-10-42	SCALE
ENG. APPROV. E.P.	DATE 13-10-42	FINISH
NATIONAL RESEARCH COUNCIL-RADIO SECTION		
NAME RIDEAU RIVER ROUTE		DWG. NO. NRC RI-15-77