MEW A/S microwave early warning anti-submarine. Book A

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NATIONAL RESEARCH COUNCIL OF CANADA

RADIO BRANCH

MEW A/S
MICROWAVE EARLY WARNING
ANTI-SUBMARINE

BOOK A

Designed and Built by the National Research Council

for the

ROYAL CANADIAN AIR FORCE

OTTAWA

JANUARY, 1944

MEW A/S

BOOK A

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BOOK A

MEW A/S

MICROWAVE EARLY WARNING

ANTI-SUBMARINE

BOOK A

THEORY AND DESCRIPTION

CHAPTER I - INTRODUCTION

1. Two books will be issued in connection with the MEW A/S equipment.

2. Book A will be entitled "MEW A/S. Theory and Description" outlining the general principles considered in designing the equipment and giving a brief description of its operation. No attempts will be made to include details such as power supplies, cabling etc. which are irrelevant to an understanding of the system. The circuit diagrams used in this book will be schematic sketches with all unessential details removed in order to clarify the description. However, the same notation will be employed in Book A and Book B to avoid confusion and duplication.

3. Book B will be entitled "MEW A/S. Operating, Maintenance and Servicing". It will include all detailed drawings, full circuit diagrams, cabling connections, and servicing and maintenance instructions. Detailed operating instructions will be included. For example, a schematic diagram in Book A will be fully explained in the text in regard to circuit functions but little or no mention will be made of operating procedure or the troubles likely to be encountered. The diagrams in Book B will have every component marked, all colour coding shown, all test points indicated, and the accompanying text will cover the circuit details from the maintenance and servicing viewpoint. It may be necessary to bind Book B in several volumes which will then be designated Book C, etc.

4. Due to procurement difficulties some of the components may vary from model to model of the first few sets. For this reason a new edition of Book B will be issued for each of the first models, which will have its drawings clearly marked to show that they refer to that particular model only. Since Book A deals with general principles the one edition will suffice for all models, although where necessary, some differences in the models may be pointed out.

5. Some very elementary theory of the magnetron, waveguide, local oscillator, etc. will be included in Book A for the benefit of those who are new to centimetric technique. The more experienced reader will be asked to overlook the non-rigorous treatment in these sections.

CHAPTER II - PRINCIPLES OF MICROWAVE EARLY WARNING

6. Toward the middle of 1942 some serious consideration was given in the United States and Canada to the design of microwave sets for the particular application of long range early warning of aircraft. Up to that time, frequencies from 22 mc/sec. to 200 mc/sec. or even to 600 mc. were employed for the basic function of early warning, for the reasons that it was possible to obtain a large amount of peak power output with a reasonably long pulse length, receivers could be designed with low noise factors, and aircraft echoes as seen on the low frequency equipment were subject to less fading than was apparent on the microwave equipments then in use, most of which were for fire-control operation.

7. On the other side of the balance sheet the low frequency early warning equipment suffered from the disadvantages of an interference pattern in the vertical plane containing rather large nulls which required special attention for gap filling and which prevented the radiation from reaching targets below a certain minimum vertical angle, thus permitting low-flying aircraft to approach without warning. Also, the size of the antenna structures that could be used in practice limited the angular resolution which could be obtained. At the very low frequencies, as on the British CH stations, fairly good azimuthal accuracy was obtained by using single crossed dipoles and standard goniometer technique for comparing amplitudes of the echo received on each antenna. A direct presentation of position was not possible with this system, however, and it is now agreed that the Plan Position Indication type of display is basically desirable for early warning. In consequence nearly all the early warning sets developed since the start of the war have used PPI presentation.

8. Fire control and airborne sets were designed on 10 cms. in profusion but the ranges to be obtained on these sets with existing powers and antenna gains did not offer much hope for a successful application or extension to the long range early warning field. However, with the development of pulsed magnetrons capable of producing powers of the order of 300 to 500 KW, or greater, and with a better understanding of antenna design and receiver technique, there was some prospect of obtaining the requisite range on 10 cms. with the attendant advantages and disadvantages.

Conditions for Maximum Range

9. The maximum range* obtainable with a given RDF equipment depends upon:

a. The average power of the transmitter

*Technical Report ORG-E-9-1 entitled "The Translation of the Military Requirements of Range into the Technical Specifications for a Radar Set".

b. The transmitting and receiving antenna gains - these are equal for a T-R system

c. The effective pulse width

d. The effective bandwidth of the receiver

e. The r.f. frequency

f. The pulse recurrence frequency

g. The "noise figure" of the receiver

h. The atmospheric noise picked up by the antenna

i. The "effective area" of the target

j. The directivity of the antenna in elevation and azimuth - this is an additional condition to (b) above

k. The interference pattern caused by ground reflection, which is a function of the site, the wavelength, the number of wavelengths the antenna is above the ground, and the polarization of the radio wave.

These factors will now be considered.

10. Let E_t represent the energy in one pulse sent out from the transmitter. For the purposes of this argument we can assume that the transmitted pulses are rectangular and of duration t microseconds, so that the peak power will be equal to E_t/t. In practice the peak power is usually defined as the average power divided by the duty cycle. At a distance R from the transmitter the amount of energy E_e passing through one square meter, on the further assumption that the transmitting antenna is radiating uniformly in all directions, is given by:

$$E_e = \frac{E_t}{4\pi R^2} \qquad \text{.........} (1)$$

11. The target will intercept a portion of this energy and re-radiate it. It is convenient to define the "effective area", A_e, of the target such that this effective area may be considered as a new source of energy radiating uniformly in all directions. It has been found experimentally that a Spitfire has an effective "echoing" area of about

5 square metres and a large bomber an effective area of about 50 square metres. The energy re-radiated by the target may then be represented by multiplying the above expression by the effective area, A_e.

12. An actual aircraft or ship target does not have a simple re-radiation pattern. Interference from waves reflected from different parts of the target produces lobes and nulls in the re-radiation pattern. For a given aircraft this pattern becomes more complex as the wavelength of the incident radiation is lowered. As the target changes its orientation and position in space various aspects of its re-radiation pattern are presented to the receiving antenna so that the echo will flutter in amplitude. This fading will be much more pronounced on ten centimetres than on three metres because the 10 cm. re-radiation pattern has both more and deeper lobes and nulls than the long wave pattern. It is difficult to give full consideration to this target pattern effect but the "echoing" area A_e may be considered to be the average effective area having no lobes.

13. However, the transmitting antenna employed in practice does not radiate uniformly in all directions but has an effective gain, G, in a specified direction. From the definition of antenna gain the energy received (and re-radiated) by the distant target must now be multiplied by the factor G, assuming that the target is squarely in the maximum lobe of the radiation pattern.

14. The energy received at the receiving antenna (here considered to be the same antenna as that used for transmitting) will be, by the same reasoning as in paragraphs 10 and 11,

$$E_r = \frac{G.E_t.A_e}{4\pi R^2} \cdot \frac{A}{4\pi R^2} \quad ....(2)$$

where A is the effective area of the antenna.

15. This effective antenna area is directly connected with the antenna gain through the relationship:

$$G = k \cdot \frac{A}{\lambda^2} \quad ....(3)$$

16. Substituting for A we have

$$E_r = K_o \cdot \frac{G^2 . E_t . A_e . \lambda^2}{R^4} \quad ....(4)$$

(Note that the constants k and 4π are absorbed into a new constant K_o.)

17. It is now of interest to determine the maximum range at which the received energy, E_r, is just barely detectable. Re-writing Equation (4) for this case we have:

$$R_{max} = K_1 \cdot \frac{G^{\frac{1}{2}} \cdot \lambda^{\frac{1}{2}} \cdot A_e^{\frac{1}{4}} \cdot E_t^{\frac{1}{4}}}{E_{r_{min}}^{\frac{1}{4}}} \quad \ldots\ldots\ldots(5)$$

18. In developing Equation (5) for R_{max} we have considered the direct transmitted ray only. Let us now take into account the effect of the ground and consider the ray reflected from the ground in front of the antenna as adding to the energy received by the target. If these two outgoing rays are of equal amplitude at the points in space where the two rays have the same phase we must add amplitudes at the target and square the resultant to obtain the energy. At the target the energy will now be four times the previous value, and since each of the two ray paths will be retraced on the return journey, the energy arriving at the receiver will be sixteen times as great, which has the same effect as increasing the transmitted energy E_t by a factor 16. As the range depends on the fourth root of the transmitter power, and as $E_{r\ min}$ has the same value as before, it is seen from Equation (5) that the range will be doubled. (The general expression for E_r is given in Equation 9.)

19. Equation (5) shows that the maximum range varies directly as the fourth root of the transmitter power, or as the fourth root of the energy in one pulse, provided the pulse length remains fixed. In practice, the receiver is adjusted for optimum performance with a given pulse length. Equation (5) shows that if the pulse energy E_t is increased by increasing the pulse length but maintaining the peak power constant an increase in range should result, since $E_{r\ min}$ is defined as a fixed quantity. However, $E_{r\ min}$ is a fixed quantity only if the receiver characteristics are adjusted to the new conditions. That is, to realize the additional range in this case, the bandwidth of the receiver must be narrowed. This will be considered in Paragraph 24 in discussing the visibility factor, V. The maximum range also varies as the square root of the gain and as the square root of the wavelength. Considering these last two factors it is at once apparent that if the gain of the antenna is held constant a longer range should be obtained by the use of a longer wavelength.

20. In practice, however, the physical size of the antenna is usually the limiting feature so that it is more reasonable to postulate a constant effective area when comparing antennas on different wavelengths. Consequently by substituting for the gain in the above expression we have:

$$R_{max} = K_2 \cdot \frac{A^{\frac{1}{2}} \cdot A_e^{\frac{1}{4}} \cdot Et^{\frac{1}{4}}}{\lambda^{\frac{1}{2}} \cdot E_{r_{min}}^{\frac{1}{4}}} \qquad \text{..........(6)}$$

This expression shows that for a constant area the maximum range varies inversely as the root of the wavelength, which would appear to be a potent argument in favour of going to the shorter wavelengths for long range early warning. The LREW system operating on 3 1/2 metres has an antenna with an effective area approximately the same as that of the MEW system on 10 cms. and the two transmitters are of comparable power. On the basis of the above expression it would therefore appear that the MEW set should have nearly six times the range of the LREW. In practice it is found that the ranges are approximately equal and the reason is bound up in a consideration of the "noise figure" of the two receivers.

Receiver Noise Figure

21. The theoretical noise figure, NF, is defined to be equal to 1 (power ratio) for a perfect receiver over-coupled to the antenna, or equal to 2 (power ratio) for the more usual case of the perfect receiver matched to the antenna. Unfortunately the theoretical value can only be closely approached at frequencies of 50 megacycles or lower, and in point of fact, practical measurements on the best receivers at various frequencies may be summed up in the following table.*

Practical Noise Figures in db

Frequency	NF in db
50 mc.	2+
100 mc.	5
200 mc.	7
600 mc.	11
1000 mc.	14
3000 mc.	16
10,000 mc.	18

This shows that there is a spread of some 11 or 12 db between the LREW receiver and the MEW receiver so that the gain in range due to going to the higher frequency is neutralized to a large extent by the poorer performance of the high frequency receiver. A great deal of research is now being carried out in an effort to lower the effective noise factor of microwave receivers.

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*Report No. ORG-E-9-1 "The Translation of the Military Requirements of Range into the Technical Specifications for a Radar Set."

22. The expression for the noise figure of the receiver must also include the effect of external disturbances. One external source is terrestrial, that is, local thunder-storms and electrical discharges. It has been demonstrated that this noise energy varies inversely as the square of the radio frequency and that it is usually unimportant at frequencies greater than 100 megacycles. The other source has been shown to be due to "cosmic noise". What little evidence is available at hand indicates that the preponderance of this noise comes from the direction of the Milky Way and that its intensity is independent of the frequency. It will be convenient to define the minimum detectable energy by the expression:

$$E_{r\ min} = V(NF + N_e - 1)kT \qquad \text{.........(7)}$$

where V is a visibility factor to be discussed later, N_e is the "cosmic noise", k is Boltmann's constant, and T is the absolute temperature. In this equation NF is the noise factor of the receiver as measured experimentally. Rough measurements over a wide band of frequencies indicate that N_e in db may vary from 10 to 20, the latter figure being for conditions of extreme external noise. It is believed that the average value of N_e is not much greater than 10 db. (In the above equation NF and N_e must first be expressed as power ratios before adding the quantities.)

23. In the MEW A/S receiver, for example, the NF is about 16 db or a power ratio of 40. The average cosmic noise factor is 10 db or a power ratio of 10. To these figures must be added about 2 db, or a power ratio of 1.6 to allow for losses in the T-R box and r.f. system. Total value of $(NF + N_e - 1)$ is then about 52 in power ratio, or slightly over 17 db, which is not much worse than that of the receiver alone. If the cosmic noise factor is taken as 20 db, or a power ratio of 100, the resultant total noise figure is nearly 22 db.

24. The visibility factor in the expression for $E_{r\ min}$ is a factor dependent on the band width, on the pulse length and on the operator's interpretation of the display. A value for V has been worked out experimentally for the simple case of the type A display, but it is not easy to estimate V for the various types of display using long-delay tubes. For the A scope the expression for V depends on the effective pulse width, the shape of the pulse, the effective band width, and the recurrence frequency, but this does not necessarily hold for the PPI or B scope presentations. The effective pulse width in normal practice is bound up with the effective band width inasmuch as it can be shown that there is an optimum receiver band width for each value of pulse duration which is given by the approximate formula

$t.B = 1$, where t is in microseconds and B is in megacycles. However, as will be shown later in this book, there is some evidence to indicate that, using the special distorter incorporated in the MEW A/S video circuits, the band width should be much greater than the reciprocal of the pulse length for optimum signal-to-noise ratio on the PPI tube, that is, for minimum value of V.

25. Recapitulating, we find that the maximum range may be expressed as follows:

$$R_{max} = K_3 \cdot \frac{A^{\frac{1}{2}} A_e^{\frac{1}{4}} E_t^{\frac{1}{4}}}{\lambda^{\frac{1}{2}} \left[V(NF+N_e-1)kT \right]^{\frac{1}{4}}} \quad \ldots\ldots\ldots (8)$$

This equation contains most of the factors that are under the direct control of the set designer as well as some that are not. It is possible to assign a quantitative value to the coefficient K_3 when the variables are expressed in appropriate units, but such an undertaking is beyond the scope of this book, and in any case the resultant figure must be tempered to agree with actual experimental results. In the argument that follows the values of the controllable variables have been chosen mainly by extrapolation of the results obtained from existing equipments.

Choice of Wavelength

26. A wavelength of 10.7 cms. was selected for MEW rather than any other wavelength in the region 1 - 30 cms., chiefly because the present state of production allows us to use high power 10 cm. transmitting tubes, standard 10 cm. local oscillators and standard technique in the radio frequency portions of the circuit. It is probable that a better case could be built up for the use of 20 cms, for example, but it would be impossible to produce a practical set in a reasonable time. The standard 10.7 cms. strapped magnetron available from Canadian suppliers has been shown to be capable of from 300 - 400 kilowatts of peak power and this is much more power than is available at present on other frequencies in the microwave region.

27. The noise factor of the 10 cm. receiver itself is made as low as possible by employing the best technique at present known to the art but it is still in the neighbourhood of 16 - 18 db.

Effective Area and General Design of Antenna

28. The effective area of the antenna, A, (which is related to the antenna gain, G) remains to be chosen. It can be shown, with some calculation and a good deal of intelligent guessing involving a determination of K_3, that in order to obtain a reasonably consistent range of 150 miles on the average aircraft, the effective area A should be approximately 200 square feet, which in turn is approximately equal to the physical area of the aperture of the reflector to be employed.

29. The linear dimensions of the reflector should be chosen to satisfy the operational requirements. This is really another way of phrasing the statement in paragraph 9(j). The directivity of the antenna in elevation and azimuth does not affect the maximum range on a target located squarely in the main beam, of course, but it is an important factor to consider in operational use where the average target will not be squarely in the beam but will usually be picked up at a lower field strength. In consequence, careful attention should be paid to the particular shape of the radiation cone. For early warning of aircraft it is desirable to cover as large a vertical angle as possible so that the vertical radiation pattern should be wide. In order to maintain the gain constant it will be necessary to narrow the horizontal pattern at the same time but there is a practical limit to which this can be carried.

30. It has been determined experimentally that a minimum of twenty pulses should be received from a target during one passage of the beam in order to take full advantage of the build-up ratio of the long-delay cathode ray tubes, and also to iron out some of the rapid fluctuations of the received echo. The pulse recurrence frequency of an early warning system must necessarily be low in order to accommodate a long time base on the display tubes, but it should be kept as high as this limitation will permit. Also the angular rotation rate of the antenna should be as high as is practical to ensure that a continuous stream of information may be received from the targets without too much delay between discrete observations. This is especially important in view of the rapid fading present at the high frequencies.

31. To sum it up, with a rotational speed of 2 to 4 r.p.m. and a beam width of, say, 1.5° in the horizontal plane, and a recurrence frequency of 300 cycles per second, it is seen that between 18 and 36 strikes will be received from a non-fading target. Some sacrifice in signal-to-noise with consequent loss of weak echoes will be

observed if the array is speeded up. Also, if the horizontal beam width is much greater than about 1.5° too much gain is lost, whereas if it is much less then resolution of weak echoes will be impaired which is equivalent to a loss either of gain or of information. To obtain this beam width, together with suppression of minor lobes, the horizontal aperture should be from 25 to 30 feet. To realize the figure of 200 square feet it follows that the vertical aperture must be of the order of 8 feet, which automatically causes the radiation pattern in the vertical plane to be from 4° to 5° wide. The MEW A/S antenna has an effective illuminated aperture of approximately 27 feet by 8 feet.

Vertical Coverage and Angle of Shoot

32. The vertical coverage of between 4° and 5° is not at all adequate for use against aircraft, and if the MEW set were to be employed for this purpose an auxiliary mirror of the same horizontal aperture but having a much smaller and specially designed vertical aperture would be used to provide high flying coverage. Since the MEW A/S will be used chiefly against surface craft the high angle coverage is no longer important and will be omitted. For aircraft warning the large mirror is tilted 1° above the horizon partly to give a better vertical coverage and partly to decrease the nulls in the vertical interference pattern. That is, instead of equal energies reaching the target by the direct and reflected paths, the contribution from the ground reflection is now very much smaller. This also has the effect of making the maximum range practically the same as the free space range, (which is the R_{max} considered in Equation (5).) It has been shown that, for equal amplitudes of direct and ground-reflected rays the range will be doubled for aircraft in the main lobes. This is counterbalanced by the fact that the range is greatly lessened or even close to zero in the nulls.

33. The first MEW A/S mirror was tilted 1° (because it was originally intended to use it against aircraft) but the waveguide feed may be adjusted off-centre in order to send the beam out horizontally. The second and succeeding models have the mirrors set to shoot horizontally so that the feed guide may be placed centrally in the aperture. For surface craft detection, interest is focussed on getting as much energy as possible into the lowest lobe, with only secondary consideration being given to aircraft detection.

Detection of Surface Craft

34. It may be shown for the case of detection of surface ships, where the target is always below the main lobe of the antenna, that the

right hand side of Equation (4) must be multiplied by a corrective factor. It is found that:

$$E_r = K_o \cdot \frac{G^2 \cdot E_t \cdot A_e \cdot \lambda^2}{R^4} \cdot \left[4 \sin^2 \left(\frac{2\pi h_1 h_2}{R\lambda} \right) \right]^2 \quad \ldots\ldots(9)$$

where h_1 = height of the RDF antenna above the sea

h_2 = effective height of the target above the sea.

For ship targets h_2 is small, and for large ranges the "angle" $\left(\frac{2\pi h_1 h_2}{R\lambda} \right)$ is so small that the angle itself may be written for the sine.

That is:

$$E_r = K_4 \cdot \frac{G^2 \cdot E_t \cdot A_e \cdot \lambda^2}{R^4} \cdot \frac{h_1^4 \, h_2^4}{\lambda^4 \, R^4} \quad \ldots\ldots(10)$$

If we re-arrange this equation as before, where $E_{r\,min}$ is the minimum detectable energy, and also substitute for G in terms of A as we did before we have:

$$R_{max} = K_5 \cdot \frac{A_e \cdot E_t^{\frac{1}{8}} \cdot (h_1 h_2)^{\frac{1}{2}} A^{\frac{1}{4}}}{\lambda^{\frac{3}{4}} \; E_{r\,min}^{\frac{1}{8}}} \quad \ldots\ldots(11)$$

35. For surface ships or for low aircraft flying at a constant height, it is seen that the range varies directly as the eighth root of the power. Since the variable λ is now raised to a higher power than in Equation (6), it is still more important to have the wavelength small. Obviously the maximum range is highly dependent on the height of the station, since it varies directly as the square root of this height.

36. Equation (11) holds reasonably well for ranges up to the line of sight. If we consider the earth's radius to be multiplied by a factor 4/3 to take account of the slight bending of the radio waves around the earth it is found that a fairly accurate formula for the line-of-sight distance to a target is given by:

$$D = \sqrt{2h_1} + \sqrt{2h_2}$$

where the heights h_1 and h_2 of the station and of the target are expressed in feet, and D is in miles.

37. Under conditions of rough sea the ray reflected from the water will be considerably scattered so that maximum reinforcement of the direct and water-reflected rays at the target will not be obtained. Hence the maximum range will not be doubled and in practice the increase may only be slight.

38. Abnormal meteorological conditions will occur during which the ranges on surface craft are greatly increased. There is not enough data available at present to correlate these extreme ranges with the weather conditions, with any degree of reliability. If a temperature inversion layer exists in the air just above the water then the radio waves are bent around the earth more than under normal conditions. The appearance of long-range permanent echoes which are normally well below the line of sight is the best indication of the existence of abnormal conditions.

39. It may add to the reader's confusion to point out that recently a "waveguide" phenomenon has been established as existing in the air immediately above the surface of the water under abnormal conditions. That is, a layer of air varying in height from thirty to several hundred feet may exist at times which, in effect, traps the radiation in a layer so that it does not propagate in its usual radiation pattern. (By "usual pattern" we mean the pattern that has been altered to include refraction and interference effects as discussed in preceding paragraphs.) Instead, nearly all the radiation hugs the curvature of the earth closely and consequently enormous ranges are sometimes achieved on surface craft. To take advantage of this phenomenon it would be necessary to site the station at sea level or only a few feet above the water, otherwise the radiation will be above this layer. Obviously, the deduction in paragraph 34 concerning the height of the station does not apply to this case.

40. It does not appear, on present evidence at least, that this "waveguide" propagation can be relied on for operational use. Therefore, the MEW A/S stations will be sited according to Equation (11), that is, just as high as possible. However, it is well to keep the existence of this phenomenon in mind because there may be times when the range of the station situated on a high site is greatly reduced and it is possible that the blame might be laid on this "waveguide" layer. To prove the point though, would require observations to be made from another station operating simultaneously at sea level. In general, it should be emphasized that loss of range is more frequently attributable to loss of efficiency in some component of the set than to atmospheric conditions.

41. The effects of the minor lobes in the vertical radiation pattern are not serious but it is important that the minor lobes in the horizontal pattern be kept down as much as possible to avoid ambiguous observations on very strong signals. If an attempt is made to cut out the minor lobes altogether, which actually can be done, it will be found that the main lobe has broadened and has lost considerable gain. The experience to date indicates that a reasonable compromise is reached if the minor lobes are held down to 2% of the power in the main lobe.

42. A side lobe of 2% means that the antenna gain in the direction of the minor lobe is 1/50 of the gain in the main direction. Therefore, referring to Equation (5) which shows that the maximum range varies as the square root of the antenna gain, we see that if a given target is just detectable in the major lobe at a range of 70 miles the same target will also be just detectable in the minor lobe at a range of 70 divided by $\sqrt{50}$ or about ten miles. In the case of surface craft where Equation (11) applies the target will be detectable in the minor lobes at a range of 70 divided by $\sqrt[4]{50}$ or nearly 19 miles. (This follows after re-substituting antenna gain for antenna area in Equation (11)).

43. However, at the ten-mile range, and to a lesser extent, at the 19-mile range, the major lobe echo will saturate the screen and no difficulty should be encountered in identifying it correctly on the PPI tube, especially in the case of the MEW where the side lobes are so close to the main lobe (within 1.5° on either side) that the effect is merely a broadening of the echo as seen on the B display.

44. A change in dimensions of the mirror would be permissible for MEW A/S, that is, the horizontal aperture might be shortened and the vertical aperture widened. However, it is felt that an operational need exists for low-flying coverage on aircraft in addition to the prime function of detection of surface vessels and submarines, so that no radical change has been made in the design other than making the angle of shoot zero instead of + 1°.

45. While this rectangular area of 8 feet by 25 feet might be represented by a parabolic or "cheese" slice illuminated by a single source at its focus, it was felt that the design of microwave linear arrays was sufficiently far advanced to abandon the single source feed in favour of the better flood-lighting obtainable with an array. In consequence both the MEW system developed at M.I.T. and the N.R.C. MEW use a single cylindrical parabola of length 25 to 32 feet and vertical aperture of 8 feet. A linear array runs along the focus of this parabola to flood it with 10 cm. radiation.

Elementary Waveguide Theory

46. It is not within the scope of this book to go into any detail in describing standard microwave technique and theory. However, as the magnetron, local oscillator and other r.f. elements may not be familiar to those who have had experience on longer wave R.D.F. equipment using triode oscillators, it might be in order to describe briefly and sketchily some of the circuit elements in the MEW A/S which are radically different from those encountered in existing early warning equipments.

47. While the standard transmission line theory dealing with lumped and distributed constants can be carried over to a discussion of waveguide transmission some care must be exercised to avoid drawing incorrect analogies. In general it is preferable to approach the problems from the view-point of the electromagnetic field. Without going into involved calculations based on Maxwell's equations, which can be found in most standard text books on the subject (c.f. J.C. Slater "Microwave Transmission"), it may be stated that at a point far from a dipole radiating into free space the electromagnetic wave can be described by three perpendicular vectors:

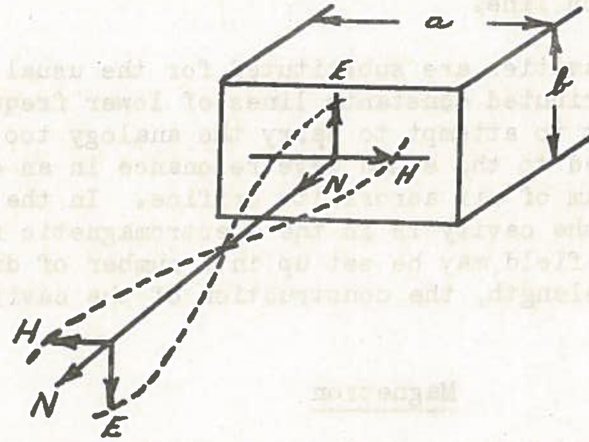
E - The electric vector, which shows the direction and magnitude of the force acting upon the positive charge.

H - The magnetic vector showing the direction of the magnetic field.

N - The direction of energy flow, which is the direction the charge will move under the combined action of E and H.

48. At a given point the vectors E and H vary in magnitude at the carrier frequency and remain in phase. They are orthogonal to each other and to the direction of energy flow.

49. It can be shown that such a plane electromagnetic wave may be confined inside a conducting boundary or may even be confined within a solid dielectric in the absence of metallic conductors. In the case of the hollow metallic conductor, the energy flows down the guide with the E and H vectors perpendicular to the sides.



50. The particular waveguide selected for 10 cm. work has dimensions of a = 2.84" inside measurement, b = 1.34" inside measurement. In such a guide it is found that if the electric intensity were to be plotted against distance along the guide, the wavelength obtained would be greater than the free space value. This is the guide wavelength, λ_g. The relationship connecting λ_g with λ_o, the wavelength in free space, is given by

$$\lambda_g = \frac{\lambda_o}{\sqrt{1 - (\lambda_o/2a)^2}}$$

51. If 2a is less than λ_o then λ_g is imaginary and the energy transmission through the guide is strongly attenuated. The attenuators on microwave signal generators make use of this property. In particular it will be observed in the MEW A/S antenna that the physical spacing of the dipoles or slots on the outside of the guide must be made about $0.8\lambda_o$ rather than $0.5\lambda_o$ to ensure that the dipoles will extract energy from the guide at points with a phase separation of exactly 180°

52. The waveguide has properties, such as a characteristic impedance and a standing wave ratio when mismatched, similar to an ordinary transmission line. In particular, a section of waveguide $\lambda_g/2$ long acts as a 1 to 1 transformer and

a section $\lambda_g/4$ long behaves as a transformer of impedance Z_o, which may be used to match two other guides of impedance Z_1 and Z_2 according to the relationship, $Z_o^2 = Z_1 Z_2$. If Z_2 is 0, then Z_1 will be very high. Stubs may be connected across the waveguide consisting of short lengths of waveguide which have much the same matching properties as stubs on an open wire transmission line.

53. Resonant cavities are substituted for the usual lumped LC circuits or the distributed constants lines of lower frequency technique. If one is careful not to attempt to carry the analogy too far, the resonant cavity may be compared to the sound wave resonance in an organ pipe set up by blowing a stream of air across its orifice. In the electrical case, the energy in the cavity is in the electromagnetic field and, as in the organ pipe, this field may be set up in a number of different modes depending on the wavelength, the construction of the cavity and the method of excitation.

Magnetron

54. Security restrictions at the present time preclude a detailed description of the power magnetron used in MEW A/S. It may be said, however, that this oscillator behaves in much the same manner as the simple magnetron, the operation of which may be found in many textbooks.

55. The anode is cut from a solid copper block which is grounded for convenience in attaching the r.f. output plumbing. The cathode is driven negative for a very short period several hundred times a second, thus causing plate current to flow in pulses. A magnetic field is so applied that the electrons leaving the cathode spiral about the cathode before approaching or striking the anode. Radio-frequency oscillations are generated, the frequency of which is chiefly a function of the internal dimensions though dependent to a slight extent on the applied voltage, on the applied field, and on the matching to the output load.

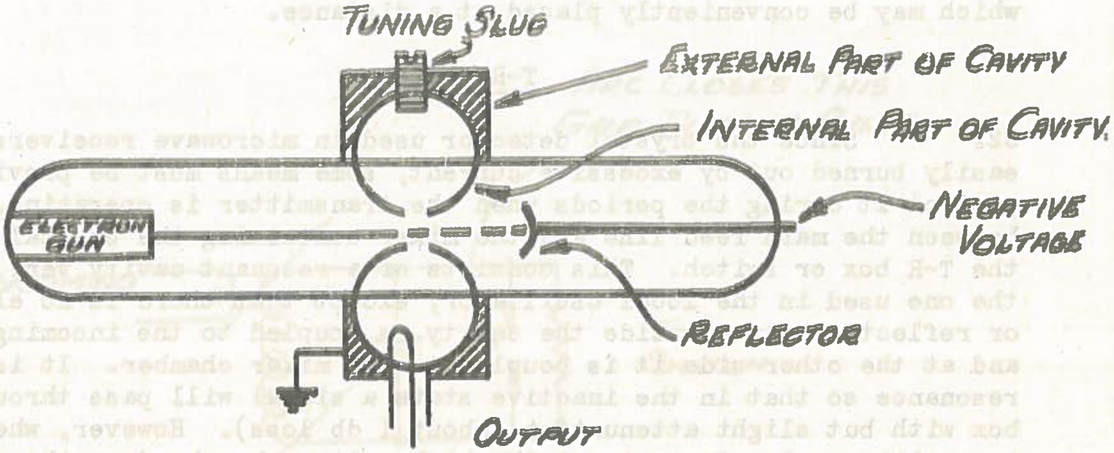
56. The magnetron is essentially a pulse generator. The voltages required for oscillation in the desired mode are of the order of 15 to 25 KV, and the magnetic field needed is in the neighbourhood of 2000 gauss. The peak current during the pulse may be as high as 40 to 50 amperes. Power output efficiencies vary from 25% to 50%. The tube cannot be operated under continuous wave conditions because of the tremendous plate dissipation which would be required, and because the cathode would soon disintegrate. In fact, the duty cycle of the transmitting magnetron is 0.001 or less, that is the magnetron may be turned on for only 1/1000 of the time. Further, the pulse length must not exceed one or two

microseconds, regardless of the recurrence frequency for the same reasons. The duty cycle for the MEW A/S transmitter is approximately 0.0003 since the pulse length is from 0.75 to 1 microsecond and the recurrence frequency about 290 c.p.s.

Local Oscillator

57. The local oscillator should be operated under CW conditions and its power output need not be more than a few milliwatts. A magnetron can be designed for this purpose but it is more convenient to use some of the velocity modulated types of CW oscillators, such as the klystron, the double rhumbatron, or the reflection type cavity resonator used in the MEW A/S receiver.

58. The Sutton tube and McNally-Pierce tube are representatives of this last class. An electron gun focusses a stream of electrons in a narrow beam, through the hole in a doughnut-shaped resonator. If we assume that an oscillating magnetic field has already been set up in this cavity then the alternate positive and negative charges appearing on the inside lips slow up some of the electrons and speed up others, so that the electron stream, after passage through the doughnut cavity, becomes bunched in density. Energy is taken from the cavity in this bunching process.



McNally or Sutton Tube

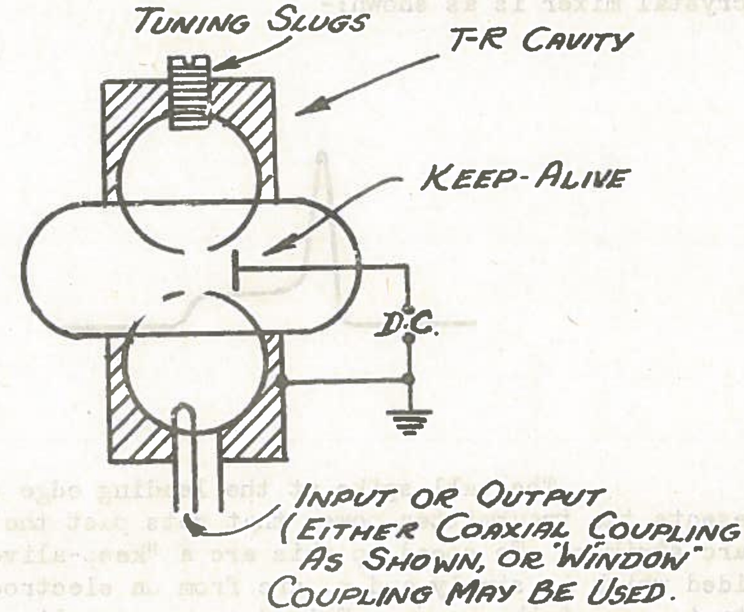
59. If a reflector is placed as shown, with a negative potential on it, the electron stream will be turned back and will pass through the cavity in the opposite direction. If the phase of the returning bunches of electrons is properly controlled by both the spacing of the reflector from the cavity and the potential difference between the reflector and the cavity, then the returning bunches will give up energy to the cavity, thus maintaining its oscillation, with some excess energy for external use. Several discrete values of reflector voltage may be used to set up proper conditions for oscillation, of which one value will permit the tube to oscillate with maximum output. Passing from one to another of these special values of reflector voltage is sometimes described rather loosely as changing the mode of oscillation, whereas it is really the transit angle of the electron stream that has been changed; the mode of oscillation of the cavity is unaltered.

60. A small loop is inserted into the cavity to couple the power into a coaxial line. Angular orientation of the loop determines the amount of power removed.

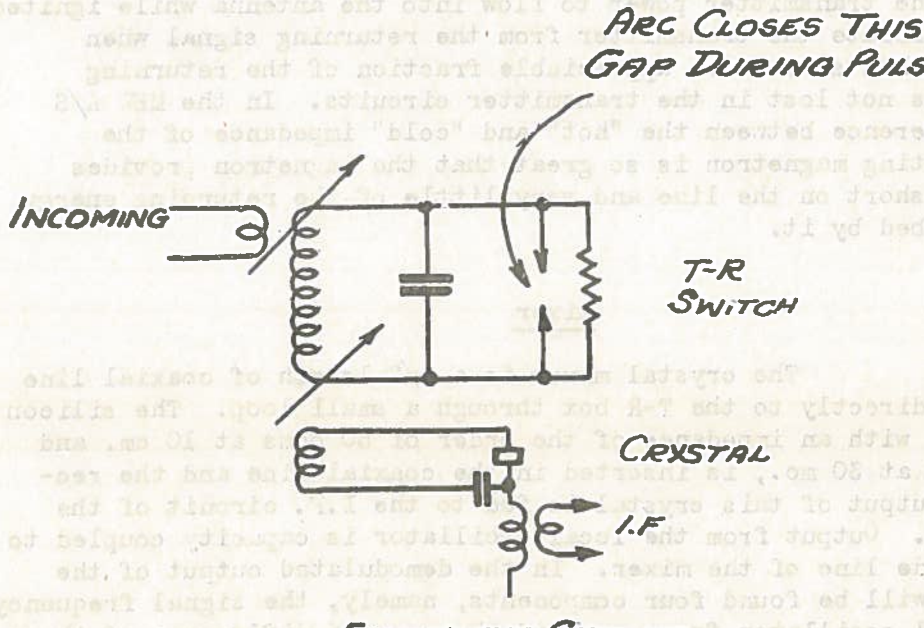
61. In practice this oscillator must be tuned, so that it is convenient to put a portion of the doughnut cavity in a vacuum, sealed in a glass tube while the remainder is open to the air. Several large "tuning slugs" may be screwed into the cavity to adjust its dimensions for the desired frequency. This is true of both the Sutton and the McNally tubes. In addition, however, the McNally tube is tunable over a 10 to 15 megacycle band by varying the reflector voltage slightly about the optimum point for a given transit angle. In the MEW A/S set the coarse tuning is done by the mechanical slugs and the fine tuning by the electrical control which may be conveniently placed at a distance.

T-R Switch

62. Since the crystal detector used in microwave receivers is easily burned out by excessive current, some means must be provided to protect it during the periods when the transmitter is operating. In between the main feed line and the mixer containing the crystal is inserted the T-R box or switch. This consists of a resonant cavity very similar to the one used in the local oscillator, except that there is no electron gun or reflector. At one side the cavity is coupled to the incoming waveguide and at the other side it is coupled to the mixer chamber. It is tuned to resonance so that in the inactive state a signal will pass through the T-R box with but slight attenuation (about 1 db loss). However, when the transmitter pulse is sent out the high voltage breaks down the gap across the two inside cones of the cavity. This discharge effectively shorts the cavity and the resultant change in resonant frequency applies a short to the waveguide coupled to the cavity. This will mean that very little energy will be received by the cavity to be coupled to the mixer circuit. Misadjustment of the T-R switch tuning will cause crystal burnout, however. The equivalent circuit of the T-R switch is shown (see page 19).

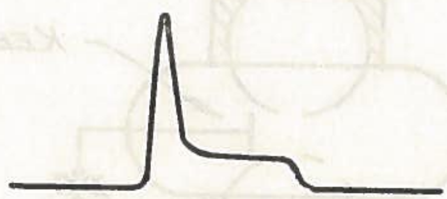


T-R SWITCH



EQUIVALENT CIRCUIT

63. The waveform of the transmitter pulse as seen by the crystal mixer is as shown:-



64. The tall spike at the leading edge of the wave represents the transmitter power that gets past the T-R box before the arc strikes. To speed up this arc a "keep-alive" circuit is provided which is simply a d.c. arc from an electrode outside the cavity to one of the cones. This d.c. arc supplies enough ionized particles to hasten the striking of the main discharge, thus providing some extra protection. A certain amount of water vapor and hydrogen is introduced into the glass portion of the T-R switch to provide enough ions to permit the gap to break down easily and to clean up the arc quickly after the transmitter pulse has finished.

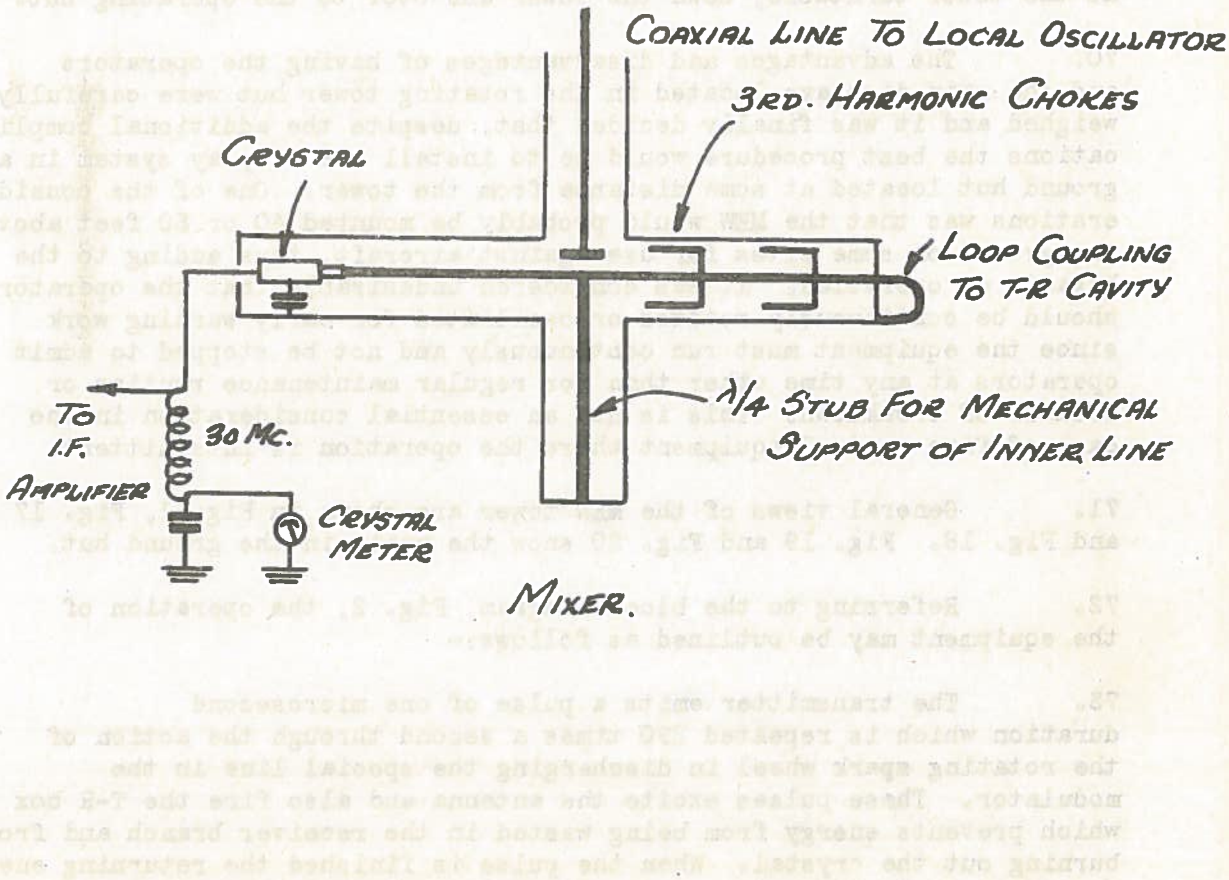
65. In low frequency r.f. equipment a second gap is usually employed, called the anti-T-R gap. Its function is to permit the transmitter power to flow into the antenna while ignited and to isolate the transmitter from the returning signal when extinguished so that an appreciable fraction of the returning energy is not lost in the transmitter circuits. In the MEW A/S the difference between the "hot" and "cold" impedance of the transmitting magnetron is so great that the magnetron provides its own short on the line and very little of the returning energy is absorbed by it.

Mixer

66. The crystal mixer is a $\lambda/2$ length of coaxial line coupled directly to the T-R box through a small loop. The silicon crystal, with an impedance of the order of 50 ohms at 10 cm. and 300 ohms at 30 mc., is inserted in the coaxial line and the rectified output of this crystal is fed to the I.F. circuit of the receiver. Output from the local oscillator is capacity coupled to the inside line of the mixer. In the demodulated output of the crystal will be found four components, namely, the signal frequency, the local oscillator frequency and the sum and difference of these two frequencies.

67. Since the last frequency is the only one of interest a by-passing capacity is inserted at the base of the crystal to short out all the higher frequencies.

68. Small cups are attached to the centre coaxial line of the mixer as shown. Their function is to choke off the passage of 3 cm. energy. The T-R switch by itself does not attenuate the third harmonic of the transmitter very much. It is thought that the crystals are sometimes burnt out by the third harmonic energy unless this additional protection is added to the mixer.



MIXER.

CHAPTER III - MEW A/S GENERAL DESCRIPTION

69. Because it is essential that the overall efficiency of the system should be as high as possible to obtain the maximum range, all losses in the r.f. components must be reduced to a minimum. This is accomplished by mounting the transmitter and receiver close to the antenna without using a rotating coupling joint. In fact the complete transmitter, modulator and power supply, and the complete receiver, including the local oscillator, I.F. and video, are mounted in the tower hut so that the overall waveguide feed from the transmitter to the antenna is not more than 6 or 7 feet. The attenuation of the standard 1.5 x 3 inch waveguide is 4 db per 100 meters, each way, so that it is desirable to avoid running a long waveguide through a rotating joint at the tower turntable, down the tower and over to the operating hut.

70. The advantages and disadvantages of having the operators and the main displays located in the rotating tower hut were carefully weighed and it was finally decided that, despite the additional complications the best procedure would be to install the display system in a ground hut located at some distance from the tower. One of the considerations was that the MEW would probably be mounted 40 or 50 feet above the ground on some sites for use against aircraft, thus adding to the hazards of operation. It was considered undesirable that the operators should be continuously rotated or oscillated for early warning work since the equipment must run continuously and not be stopped to admit operators at any time other than for regular maintenance routine or because of breakdown. This is not an essential consideration in the case of fire control equipment where the operation is intermittent.

71. General views of the MEW tower are shown in Fig. 1, Fig. 17 and Fig. 18. Fig. 19 and Fig. 20 show the units in the ground hut.

72. Referring to the block diagram, Fig. 2, the operation of the equipment may be outlined as follows:-

73. The transmitter emits a pulse of one microsecond duration which is repeated 290 times a second through the action of the rotating spark wheel in discharging the special line in the modulator. These pulses excite the antenna and also fire the T-R box which prevents energy from being wasted in the receiver branch and from burning out the crystal. When the pulse is finished the returning energy is picked up by the antenna and passed through the T-R box, and is heterodyned to the 30 megacycle I.F. frequency by the McNally local oscillator. Nine stages of 30 megacycle I.F. amplification are used with a band width of about 10 megacycles and an overall gain of

approximately one million. The second detector and one stage of the video provide the output necessary to feed the video line supplying signal to the ground equipment. The pros and cons of passing down the signal information at the 30 megacycle I.F. frequency versus the video frequency were weighed and it was considered that the video system would be more satisfactory in practice and would require less care and design. If the I.F. were fed through the slip-rings the voltage level would have to be fairly high, and feedback difficulties would be encountered. Then too, interference from powerful 30 megacycle communication stations is sometimes picked up with such a system. The monitor scope, located in the tower hut is also tied into this video output.

74. The control rack includes all the controls necessary for local operation of the equipment independent of the ground hut. Switches are provided to change from local to remote control, once the equipment has been lined up. An inter-communication system is also included to enable an operator in the tower to direct an operator downstairs when it is desired to orient the antenna on a particular fixed echo for test purposes.

75. The magnetron with its associated blower and magnet is mounted in a small cabinet in such a way that a 90° twist has had to be inserted in the waveguide feed. This twist is inserted chiefly for convenience in attaching the T-R box to the wide side of the guide. At some future time the T-R box may be attached to the narrow side of the guide and the twist may be omitted. Fig. 5 and Fig. 22 show the R.F. assembly. The high tension power supply and modulator are included in a common rack.

76. All of the signal, power and control circuits pass through the slip-ring assembly located in the centre of the standard CHL/GCI turntable. This assembly is not a CHL/GCI slip-ring but is one taken from a GL set. The video output is passed through telcothene cable type AS48 wherever possible except for the unavoidable discontinuity at the slip-ring. The heating and lighting circuits for the tower hut also pass through this slip-ring assembly.

77. The turntable is driven through a gear box and a belt and pulley system by a 3 H.P. d.c. motor which is in turn controlled from the ground hut either by a Ward Leonard motor generator type speed control or by a CHL/GCI thyratron speed control. In either case the control potentiometer is mounted conveniently near the operator's hand in the ground hut. For straight PPI display continuous rotation is desirable. The maximum speed is about 4 r.p.m. and the recommended speed between 1 and 2 r.p.m. for the best signal-to-noise ratio on the display tube.

However, for "searchlighting" or for sector scan it may be desirable to oscillate the array back and forth over a certain sector. Actually, at 3 r.p.m., tests have shown that no time is saved by scanning a 90° quadrant back and forth as compared with continuous rotation. As continuous rotation is very much easier on the mechanical system it is highly recommended that the array be set at a constant speed. If it is desirable to pay special attention to a particular echo then it is sometimes advantageous to oscillate back and forth over a sector not greater than 60°. However, it is not recommended that the operator try to hold the array on the target as the types of displays used are not designed for this procedure.

78. Mounted under the turntable will be found the gear box assembly which supplies the PPI selsyn sweep, the sector B sweeps, and the azimuth markers. A junction box is located on the first level of the tower through which pass all the wires and cables from the slip-ring assembly and from the gear box.

79. In the ground hut will be found three large racks. (Fig. 19 and Fig. 20) The first rack contains all the control equipment necessary for operating the station from the ground location. Meters are provided for remote observation of essential voltages and current in the equipment in the tower. A system of interlocks ensures that no damage will ensue if an incorrect procedure is used in starting up the equipment. Time delays are included in the high tension circuits to hold off the high voltage until the filaments are heated.

80. The PPI display is presented on a twelve-inch long-delay 12DP7 cathode ray tube located in the centre rack (Fig. 20). The sweep circuit used with this display is rather different from that employed in the usual PPI receiver, such as the CHL/GCI, and will be described in detail later. As will be evident from the discussion in Chapter II some difficulty is encountered in identifying echoes because the signal received on the PPI tube has approximately the same dimensions as a spot of random noise, unless the signal is sufficiently strong to differentiate it immediately against the general noise background. This difficulty does not arise on a PPI display coupled to a system operating on the longer wavelengths, such as the CHL/GCI or the LREW-PPI, where the antenna patterns are several degrees wide, since a very weak echo may be distinguished in the noise because of its physical shape, that is, because it appears as an arc several degrees long.

81. Therefore it is necessary to employ an auxiliary display tube to assist in resolving echoes which have definitely been received but which are not clearly distinguishable from the surrounding noise spots which have

the same shape and characteristics. This is accomplished by feeding the video to a sector B display, which is located in the third rack, Fig. 19. In this display the range is shown as the y-axis and the azimuthal angle is introduced by moving the sweep horizontally across the tube. For example, 90° of the PPI tube may be presented across eight to ten inches of the sector B display, so that the received echo is now drawn out and appears as a streak on the tube which is appreciably longer than the diameter of the surrounding noise pulses and hence may be recognized as a signal, even though its intensity is of the same order as the noise background. It so happens that for a beam width of the order of 1° to 1 1/2° the average signal on the PPI tube has the same diameter as the focus spot of the cathode ray beam. This focus spot size is constant for both the PPI and B tubes so that by lengthening out the echo to several spot diameters the contrast is immediately apparent, because random noise pulses still appear as individual spots the size of the focus spot.

82. Three separate ranges are provided on the two display tubes and a given range may be selected simultaneously on both by means of a single control switch. The ranges are pre-set to cover the requirements of the particular installation, i.e., 20, 40 and 80 miles, or 40, 80 and 160 miles, etc. Calibration pips are provided at 20-mile intervals which appear as rings on the PPI tube and as straight lines across the B display.

83. The B display sector may be selected from anyone of four quadrants and by adjustment of the angle sweep the particular sector under observation may be made to cover from less than 90° to nearly 180°, if so desired. It is possible to switch the B sectors in sequence while the array rotates continuously to present the sectors as they appear on the PPI tube, but this is not recommended as it takes time to wipe off the picture already painted on the B display, and confusion of echoes will result. If an angle greater than 120° is to be observed in detail, it is recommended that one or more additional sector B displays be added. Provision is made in the video output circuits to accommodate additional displays. One B display only is furnished with each equipment as it is assumed that for the special application of anti-submarine work a small sector only will be under critical examination, and the PPI tube should be adequate to supply general all-round looking information.

84. Some consideration was given to the problem of controlling the rotation of the tower and array from the tower hut as well as from the ground hut to assist the operator in lining up an echo for tune-up purposes. It was decided that the same function could be accomplished very easily by means of an intercommunication system which is a

necessity in any case. The line-up procedure will be given in more detail later, but in substance it requires that the array be stopped and that one operator enter the tower hut to tune up the equipment. He verbally directs the ground hut operator to rotate the array until a suitable echo appears on the monitor scope.

85. It was originally planned also to duplicate in the ground hut all the meters located at the tower position, but it has been found in practice that several meters, such as crystal current meters, were unnecessary at the remote control rack and only added to the complications of wiring, because of interaction with the other circuits. There appears to be little point in monitoring crystal current continuously because it is uncritical over a wide range and the best evidence of failure in this part of the circuit is given by the disappearance of the echoes on the display tubes. On the other hand, the magnetron operation may become faulty without seriously affecting the echoes, and damage might result if the fluctuation of the magnetron current were not observed so that this circuit is remotely metered.

86. An I.F. gain control is incorporated as it is useful in the preliminary line-up procedure and it may also be required for following very strong echoes at close range. Normally, the gain control is not touched since the video circuits are adjusted for best efficiency at a pre-set I.F. gain.

87. In the sections that follow all the elements and circuits of the MEW A/S system will be considered in detail sufficient enough to provide an understanding of their functions. All power supplies have been omitted and all wiring, cabling, circuit values, etc. that are not considered essential to a comprehension of the principles involved will be left for Book B. While it might be possible for an experienced operator to put the station on the air from the information contained in Book A, full and complete operating instructions will be found in Book B and it is not recommended that the operators or the maintenance crew should use Book A for this purpose.

CHAPTER IV - TRANSMITTING SYSTEM

Oscillator

88. The schematic diagram of the magnetron transmitter is shown in Fig. 3. This unit contains the magnetron with its associated permanent magnet and cooling blower, and also the pulse transformer. Fig. 21 is a photograph of the oscillator and modulator racks. The modulator and power supply are housed in a second unit which includes the charging choke and condenser, the pulse line, the spark wheel and motor and the hold-off diode, as well as the high tension power supply.

89. The assembly of the r.f. system and magnetron is shown in Fig. 5. In order to keep the shell of the magnetron at ground potential and thus avoid insulation difficulties, a negative pulse is applied to the cathode which is insulated from ground through the low capacity filament transformer. In practice, it may be found that once the set has been warmed up and transmitting, the filament current may be cut off since the cathode is then heated by positive ion bombardment. If the pulse recurrence frequency is high it is common practice to so disconnect the filament after a few moments of operation in order to cut down the heat dissipation. However, at a low recurrence frequency, such as used in the MEW A/S the operation tends to become erratic with the heater cut off and so the filament remains lit continuously.

90. The sweep synchronizing voltage is obtained across a very small inductance connected in the ground lead of the pulse transformer. The impedance of this source is very low and no trouble is encountered in transferring the voltage to the remote displays. Also, connected in the ground lead of the pulse transformer will be found the two magnetron current meters together with suitable filters.

Modulator

91. The high tension power supply (Fig. 4) provides 10 KV at 100 ma. d.c. by means of the full wave rectifier using type 253 tubes and a brute force filter. The power supply is equipped with over-load relay protection, suitable current and voltage meters and variacs for varying the d.c. voltage, one of which is located in the tower for local operation and the other at the ground hut for remote control.

92. The modulator section consists of the charging inductance L_2, the charging capacity C_3, the pulse shaping network and the rotary spark

gap. A type 253 diode is connected in series with the high voltage to act as a hold-off diode to hold the voltage on the line at its maximum value until the spark gap fires. If the recurrence frequency were higher this diode would not be required since there would not be time for the voltage to drop between charges. The rotary spark gap serves to discharge the network at about 290 times per second. Five spokes on the rotating wheel driven by the induction motor determine this recurrence frequency.

93. Assume that the spark gap has just finished firing and condenser C_3 is completely discharged. C_3 will now receive a charge through L_2 from the power supply and in doing so the voltage on C_3 builds up to 1.8 times the power supply voltage due to the oscillation produced by the series resonance of C_3 and L_2. When the next spoke of the spark gap wheel comes into position at the contact point, the gap fires and discharges the condenser C_3 through the three tank circuits and the series coil of the pulse forming network. Each of the three tank circuits oscillate at its resonate frequency during the discharge of C_3. The first tank circuit is tuned to give one complete cycle during the pulse, the second tank circuit goes through two oscillations during the pulse and the third tank circuit produces three oscillations. The voltage across each tank circuit is inversely proportional to its frequency. The voltages across each of the tank circuits plus the voltage across the series coil when added to the discharge of C sum up to produce a negative square wave across the primary of the pulse autotransformer (Fig. 3).

94. The pulse transformer distorts the pulse to a small extent only but because a certain percentage of the power is stored up in magnetizing the core, a transient oscillation may be produced which lasts several microseconds after the pulse. This oscillation is damped by making the pulse transformer with lossy characteristics. The step-up ratio of the pulse transformer is approximately 3:1. The pulse shaping line is adjusted for a nominal pulse width of 1 microsecond, but due to the time taken by the rise and fall of the pulse through the stray capacities of the shaping network, the pulse transformer, and the magnetron itself, the effective pulse width is about 0.8 microseconds.

95. The normal operating voltage for the magnetron is from 20 to 24 KV at approximately 40 amps. The magnetron current is a function of the magnetic field as well as of the d.c. pulse voltage. The field of the permanent magnet is set at 2150 gauss which is the optimum field for the 3BX magnetron.

CHAPTER V - ANTENNA

General Description

96. The present MEW A/S antenna consists of a linear waveguide array flooding an 8' x 32' parabolic cylinder. The linear array contains 68 elements spaced $\lambda_g/2$ - 3.18", giving an overall array length of approximately 18'3". This array will be replaced by a new one having 110 slots in a length of about 26 feet. A 96-dipole array has been used in the mirror quite successfully as far as the radiation pattern was concerned, but the load characteristics of this antenna were such that only a few specially selected magnetrons could be used to excite it. The 68-element slot array is shown diagrammatically in Fig. 6(a) and a view mounted in the mirror is shown in Fig. 18. As shown, the feeder guide is connected to the antenna by an E-type T-junction, and both ends are terminated in short circuits approximately $\lambda_g/4$ from centre of the last element.

97. The radiating elements are resonant slots cut longitudinally in the broad face of the guide (see Fig. 6(b)). The impedance is controlled by the distance of the centre of the slot to the centre line of the guide. This impedance varies as $\operatorname{cosec}^2(\pi x/a)$ and remains substantially a pure resistance over the range of displacement used. Phase reversal is secured by alternating the displacements from one side of centre to the other. The gabling function used, from centre to end is given by the expression,

$$A = 0.6 + 0.4 \cos^2 \frac{\pi}{2} \cdot \frac{x}{\ell}$$

where:

A = amplitude
x = distance from centre
2ℓ = length of array
a = wide dimension of waveguide

giving an impedance variation of 0.36:1 from centre to end. However, due to the negligible difference in antenna pattern and the simplification in machining, future antennas will have a linear power taper.

98. Since the E-type junction gives a series feed, each half of the array was designed to have an input admittance at the centre of 2 (normalized units). This was accomplished as follows:

let Y_n be admittance of Nth element from centre (total number of elements = 2N),

then for a 4:1 linear power taper, the first element will have an admittance = 4K, where K is some constant, and the last element will have an admittance = K.

For matching:

$$\sum_{n=1}^{N} Y_n = 2$$

but

$$\sum_{n=1}^{N} Y_n = 34 \frac{(K+4K)}{2} = 85K = 2 \text{ (from above)}$$

$$\therefore \quad Y_N = K = 2/85 = \frac{1}{42.5}$$

$$Y_1 = 4K = \frac{1}{10.625}$$

$$Y_n = \frac{1}{10.625} - \frac{n-1}{33}\left(\frac{1}{10.625} - \frac{1}{42.5}\right)$$

99. For convenience in machining the elements were divided into groups of five, with the same impedance. The required displacements were then taken from the curve of Dr. W. H. Watson in N.R.C. Report PRA-84.

Antenna Patterns

100. Due to the resonant nature of this antenna, the horizontal radiation pattern maintains its desired shape only over a limited frequency band -- in this case from approximately 10.66 to 10.75 cm., -- and these patterns are shown in Fig. 7. The pattern begins to deteriorate at the band edges due to the deterioration of both phase and amplitude distribution along the array and a little further beyond

these limits. The pattern is then split into two peaks by the phase distribution caused by the centre feed.

101. Vertical plane patterns have not yet been studied since these are not important in the MEW A/S application, but these will be examined in detail in the near future.

Antenna Matching

102. Fig. 8 shows the standing wave ratio versus frequency curve of the input matching as seen through the T-junction, after a corrective inductive iris had been inserted. The iris was chosen to maintain a constant match over the frequency band, rather than the best match at λ_a = 10.70 cm.

103. The matching standing wave ratio was increased from about 1.3:1 to 1.45:1 by putting the antenna into the dish and by some other slight adjustments. It has been found that with a mismatch of this order it is not difficult to choose magnetrons that will operate satisfactorily into the load. Double moding is practically absent and frequency pulling is not serious provided magnetrons are chosen whose wavelengths when operating into a matched sand load are inside the band. If magnetrons are chosen outside these limits, they will transmit on a frequency outside the antenna frequency band with resultant poor performance from radiation pattern view point.

104. A wider frequency band may be obtained if the antenna is fed from one end and if the slots are spaced slightly more or less than $\lambda_g/2$ apart. With this type of feed the energy travels down the antenna guide once only and means must be provided to absorb or exhaust from ten to twenty percent of the power at the end since a standing wave cannot be tolerated within this type of antenna. The radiation pattern swings in angle relative to the antenna as the frequency is changed. The waste of power and the changing beam angle of the end-fed antenna are disadvantages to be weighed against the broad frequency characteristics.

105. If the spread of frequency of production magnetrons were very broad then there is no question but that the MEW A/S would use the end-fed antenna. However, Canadian production 3BX magnetrons fall within a band from 10.60 cm. to 10.80 cm. so that a high percentage falls within the MEW A/S band of 10.65 cm. to 10.75 cm. Magnetrons for MEW A/S will undergo a selection test at the N.R.C. until such time as either the R.C.A.F. or the manufacturer set up suitable test equipment.

CHAPTER VI - RECEIVING SYSTEM

T-R Switch

106. Fig. 9 is a schematic diagram of the entire receiving system. In order to get the circuits on one sheet of paper several irrelevant details have been omitted and the I.F. section of the receiver drastically condensed. The sequence of events in this system is as follows.

107. When the transmitter fires, a portion of the energy passing down the waveguide is fed into the T-R switch and a high voltage is developed across the gap in the resonant cavity. Since the cavity is filled with low pressure gas a d.c. "keep-alive" arc may be maintained just outside the gap, so that ionization takes place very rapidly and the gap breaks down, causing the cavity to be effectively short-circuited. This presents a very high impedance at the mouth of the receiver side branch so that a very small fraction of the transmitter output is coupled to the mixer. It will be noticed that small 3 cm. chokes are included in the crystal mixer in order to attenuate third harmonic emission from the magnetron which is thought to have a bad effect on the crystal in some cases.

108. The returning energy from the target is collected by the antenna system and passes down the feed waveguide to the T-R switch. See also Fig. 5 and Fig. 22. The gap extinguishes within a very few microseconds after the transmitter pulse is completed so that this branch of the waveguide now represents a matched impedance to the main feeder. On the other hand, the non-oscillating magnetron has an impedance which differs from its impedance during oscillation, and this change of impedance is sufficient to prevent all but a small amount of the received energy from being fed back into the magnetron. Consequently no anti-T-R switch is required.

Mixer

109. The r.f. voltage arriving at the mixer is fed to a crystal as shown in Fig. 9. A few millivolts of local oscillator voltage is capacitively coupled to the mixer. The local oscillator voltage is rectified by the crystal and the coupling is adjusted to provide optimum crystal current, (about 600 microamperes) in order to obtain the best conversion conductance in the crystal. The crystal also rectifies the signal voltage, and the demodulated output contains alternating current components of the signal frequency, local oscillator frequency, and the sum and difference of these two components, as well as harmonics and higher cross-modulation terms. A capacity of a few micro-microfarads

at the base of the crystal by-passes to ground all but the steady d.c. current and the difference frequency. The direct current and the difference frequency which is normally called the intermediate frequency (in this case 30 mc.) is coupled through a low capacity cable to the transformer T_3 in the I.F. amplifier. The 30 mc. component is applied to the grid of V_8 and the d.c. component is filtered and applied to a current meter and the reading used to adjust the local oscillator coupling as mentioned above.

Local Oscillator

110. The reflection type velocity modulated oscillator has its own special regulated power supply and the chief reason for showing it in the diagram (Fig. 9) is because the fine tuning of the oscillator is accomplished by varying the d.c. reflector potential. The rectifier system has a voltage output of about 1000 volts which is applied to three VR-105 and one VR-150 regulator tubes in series, V_2, V_3, V_4 and V_5. A constant potential of 255 volts developed across V_4 and V_5 is fed through a 50 ma. meter to the cathode of the McNally oscillator. The 210 volts of negative potential developed across V_2 and V_3 is applied to an adjustable divider network R_4 and R_1. R_4 is the coarse adjustment of reflector potential which permits the correct transit angle potential to be selected for optimum output and is so adjusted while R_1 is set at mid-range. The coarse tuning is done by the mechanical slugs located in the cavity of the McNally tube. The frequency of oscillation of the McNally tube can be tuned over approximately 15 mc. for a given setting of R_4 (that is for a given transit angle) by varying the rheostat R_1 which is located at the display racks in order to provide remote tuning of the local oscillator. Normally the oscillator is allowed to warm up for a half-hour before the set is tuned up; any subsequent drift in frequency due to temperature variations can be corrected from the operating position by adjustment of R_1.

111. For reasons which will appear in the discussion of the video system the receiver band width was made approximately 10 mc. wide with a substantially flat top response curve, thereby eliminating the necessity for automatic frequency control of the McNally tube local oscillator since the latter can drift two or three megacycles without harmful effect on the signal. In practice it is found that R_1 is rarely touched.

I.F. Amplifier

112. Fig. 23 is a photograph of the I.F. amplifier with the bottom removed. Nine stages of feedback amplification are built in line on one chassis to form the broad band I.F. amplifier as shown in condensed form in Fig. 9. The mid-point of the band pass is 34 mc. and the band width 10 mc.

between the half-voltage points on either side. Each stage is adequately decoupled from the next by means of series resistors and de-coupling condensers in the plate leads, and chokes and condensers in the filament leads. This de-coupling performs two functions; first, to ensure that all the feed back from one stage to the next is controllable so as to give a symmetrical flat-top response curve, and second, to isolate the first stages of the receiver from extraneous 30 mc. signals which may be picked up in the power leads. Since all the de-coupling filter networks are in series and terminate at the output end of the I.F. chassis these interfering signals are attenuated stage-by-stage so that the interference amplitude at a given stage is negligible in comparison with the desired signal amplitude. For the same reasons several filter networks are inserted in series with the crystal current lead from transformer T_3.

113. The second detector consists of a double triode 6J6 connected as a diode whose cathode feeds an RC combination, R_{22} C_{16}, which forms the detector load. The video output from the cathodes is coupled through a 30 mc. filter to the grid of a cathode follower, V_{11}, which serves as a low impedance source to feed the video amplifier.

114. The I.F. gain is controlled by varying the plate and screen voltages of the whole I.F. amplifier. The change in response curve of the amplifier as the gain is varied in this manner is not as great as when the gain is changed by varying the bias on one or more stages of the amplifier. In addition, no further de-coupling filters are required as would be necessary for grid bias control. The actual control is effected by a potentiometer located at the ground hut which varies the grid voltage on a pair of 2A3's connected as cathode followers, which in turn supply the 150 volts required for the entire receiver plate and screen potentials.

Video Circuits

115. As mentioned above, the overall response of the receiver system up to the cathode of V_{12} is approximately 10 mc. between half-voltage points. With this bandwidth the noise generated at the input of the receiver will appear at the video as very short positive pulses of random amplitude and duration. When the cathode of V_{12} is driven positive by a signal or a noise pulse, it is cut off and the voltage across C_{17} rises at a relatively slow rate determined by the time constant of R_{24} and C_{17} and also by the applied voltage. When the voltage on the cathode of V_{12} decreases towards zero, V_{12} will conduct and C_{17} is discharged very rapidly through the diode and its cathode load. It can be shown that the most probable time duration of a noise pulse delivered by such an amplifier is

considerably less than 1 microsecond. Through the use of this slow-rise and rapid-fall distorting circuit it is evident that the amplitude of a noise pulse will be greatly decreased in comparison to signal pulses which are of the order of a microsecond in time duration. Semi-quantitative measurements on this distorter circuit in actual operational use indicate that the broad band amplifier together with the distorter provide a considerable improvement in signal-to-noise ratio over a narrow band amplifier and conventional video when applied to PPI or sector B displays.

116. The video output from the cathode follower V_{11} is fed through a low capacity cable to the diode of V_{12}. The output of V_{12} is coupled directly to the grid of the cathode follower V_{13} which in turn is connected through 100-ohm AS48 cable to the slip rings. From the slip rings the video output passes through an 80-foot length of AS48 cable, and is then fed directly to the cathode of V_{14}, which is located in the A rack of the ground hut equipment.

117. The output of V_{14} is coupled through a high pass filter to the grids of two cathode followers formed by the double triode tube V_{16} (Fig. 9). One of the cathode follower outputs leads to the PPI display and the other to the sector B display. The cathode of V_{16} is also connected through a low capacity cable to the cathode of the last video amplifier, V_{20}. The bias on V_{20} can be regulated by R_{47} so that the limiting level of the video may be pre-set before being applied to the c.r. tube grid. The plate of V_{20} is direct-coupled to the c.r. tube grid, and back-trace blanking is accomplished by connecting V_{21} in parallel with the video amplifier V_{20}. Normally V_{21} is conducting but during the sweep time it is cut off by a negative pulse applied from V_{19}. The bias on the cathode of the c.r. tube V_{23} is adjusted for proper brilliancy while V_{21} is cut off.

118. Calibrator pips and azimuth markers are injected into the video circuit through the cathode of the double triode V_{18}. The calibrator pips are fed through C_{28} to one grid of V_{18}, and with S_2 in the closed position the bias is adjusted by means of R_{33} so that the positive peaks of the incoming pips cause an increase in the cathode voltage of V_{20} due to V_{18} conducting. When S_2 is open the bias is increased to -300 volts so that calibrator pips are cut off. Azimuth markers are injected through the other grid of V_{18} in a similar manner. When S_3 is in position 1 the grid of V_{18} is normally biased beyond cut-off by adjustment of R_{37}. In the gear box located under the turntable are two micro-switches actuated by cams, one of which operates four times per revolution of the array and the other thirty-six times. That is, for every 10° rotation of the array a micro-switch is closed which grounds one end of R_{39}. This causes a momentary decrease in potential at the junction of R_{38} and R_{39} which decreases the

bias on the grid of V_{18}. This in turn causes current to flow through V_{18} and thus raises the potential of the cathode of V_{20} during the time the micro-switch S_4 or S_5 is closed. When S_3 is switched to position 2 the change in bias is now so small that V_{18} remains cut off and the azimuth markers are not passed on to the video system.

119. The video amplifier used to drive the PPI display tube is identical in every respect to that used in the sector B display. However, in the PPI application the suppressor of V_{19} is grounded externally to the chassis, whereas in the sector B circuits the suppressor is keyed on and off by the B sweep sine wave to provide back-trace blanking of the azimuth sweep. The RC combination in series with the grids of V_{19} and V_{21} is to ensure a sharp rise on the leading edge of the back-trace blanking pulse. With this arrangement the c.r. tube beam is turned on within a fraction of a microsecond after the transmitter pulse.

Keying Circuits, Back-Trace Blanking and Range Calibrator

120. The key link in the sweep circuit chain is the Kipp relay V_2 (Fig. 10). This Kipp may be fired internally from a fixed frequency multivibrator, V_1, for testing purposes, but in operational use it is fired from a negative pulse supplied through the d.c. restorer V_3. This negative pulse comes directly from the spark gap modulator as outlined in Chapter IV. The delay time of V_2 is controlled by C_4 and a resistor connected to +300 volts through the switch S_2. Between sweeps the first half of V_2 is cut off and the other half is conducting maximum current. By returning the two cathodes of V_2 to -300 volts through R_6 the total current is maintained at a substantially constant value through the two halves of the tube. Between sweeps the diode V_3 is conducting, and the current flowing through the resistors R_{12} and R_{13} holds the second grid to a positive bias determined by R_{34} and R_{35}. The negative synchronizing pulse which is applied to the first cathode of V_3 is sufficient to cut off the second half of V_2. Because the total current through V_2 remains constant, the first half of V_2 is turned on and its plate potential falls to about 50 volts. Since C_4 couples the first plate of V_2 to the second grid, this negative-going pulse drives the second grid negative to approximately -250 volts. V_3 at this time is cut off so that the current through R_{12} and R_{13} discharges C_4, causing the grid voltage to rise at a rate determined by the resistance and capacity in series. When the grid voltage rises to cut-off the second half of V_2 starts to conduct and the resulting increase in bias on the first half of V_2 causes the second grid to be driven positively. The circuit is thus restored to its initial condition very rapidly and remains there until the arrival of the next synchronizing pulse. For the long range setting of 160 miles the delay time of the Kipp relay is approximately 1600 microseconds. The usual Kipp relay of this type is very unstable for hold-offs of this time interval with the result that the delay time will

vary ± 25 microseconds. In the MEW A/S keying circuits, however, some of the calibrator sine wave voltage is coupled back into the grid of V_2 through C_7 so that this variation is reduced to about 2 or 3 microseconds.

121. The negative-going square wave from the first plate of V_2 is fed to the grid of calibrator keying tube V_5. Immediately before the synchronizing pulse, time t_o, V_5 is conducting its maximum current (approximately 20 ma.). When V_5 is cut off a damped train of oscillations is generated in the tank circuit L_2, C_8. C_9 and L_3 connected in series across the output of V_5 are resonant at a frequency somewhat higher than L_2 C_8, so that they present a capacitive reactance to the applied voltage. Under this condition the current through this branch of the circuit will lead the applied voltage by approximately 90°. The voltage developed across L_3, however, leads the current by approximately 90° and hence leads the applied voltage by 180°.

122. Therefore the voltage developed across the load, L_2 C_8, due to the output of V_6, will be in phase with the initial voltage, producing a regenerative action which is controlled by variation of the effective G_m of V_6 when R_{20} is adjusted. The regeneration is normally adjusted to a value sufficient to maintain the oscillations at a constant amplitude. When the grid of V_5 is driven positive at the end of the Kipp relay delay time the feedback through C_7 from the plate to grid causes a degenerative action which kills the oscillations in one or two cycles.

123. The blocks of sine wave oscillations produced by V_5 and V_6 are applied to the grid of a distorting amplifier V_7. The cathodes of V_7 are coupled to -300 volts through a resistor, R_{24}. When the grid of V_7 is driven positively the cathode tends to go positive also, reaching a value sufficient to cut off the second half of V_7. When the grid goes negative the second grid of V_7 holds the cathode potential up, causing the first half of the tube to be cut off. The distorted waveforms on the plates of V_7 are 180° out of phase and are capacity coupled to V_8 which is a distorting amplifier similar to V_7 except that it is driven in push-pull. The output of V_8 is taken from the first plate and differentiated by C_{15} and R_{32}. The cathode follower, V_9, acts as an impedance transformer feeding the resulting calibrator pips into a low impedance line where they are distributed to the two display video amplifiers.

124. At time t_o the second plate of V_2 goes positive and the resulting positive square wave is applied to the grid of cathode follower V_4. One half of V_3 is used as a d.c. restorer in the grid of V_4 ensuring a constant amplitude positive square wave output. A low impedance line distributes this positive square wave to the display circuits where it serves to initiate the sweeps and to key the back-trace blanking circuits on the video amplifiers.

Monitor Oscilloscope

125. A monitor oscilloscope is located conveniently with respect to the transmitter and receiver in the tower hut. This oscilloscope is used to line up the receiver by facilitating the adjustment of the T-R cavity, and McNally tube cavity slug tuning and the reflector voltage adjustment.

The unit consists of a 5-inch c.r. tube, sweep voltage generator and video amplifier built into one chassis.

126. The sweep and back-trace blanking circuits are keyed by the Kipp relay V_2, Fig. 11, which can be triggered internally by multivibrator V_1 or from the negative-going synchronizing pulse delivered by the spark gap modulator. The positive-going square wave output from V_2 is used to key on the grid of c.r. tube V_{10}. The negative-going square wave output with a time duration of approximately 1000 microseconds is fed to the grid of the phase inverter amplifier V_4. The positive-going output from the plate of V_4 keys the suppressor grid of V_5, which is a Miller type sweep voltage generator. The principles of operation of this sweep generator are discussed in some detail in Chapter VII in connection with the PPI sweep circuit. The sweep speed is adjustable in four steps to give 12, 24, 48, 96 miles respectively by means of a selector switch S_2. V_6 operates as a phase inverter amplifier delivering a positive-going sweep waveform. A centre-tapped resistor network coupled between the plates of V_5 and V_6 is connected directly to the control grid of V_6. The proper bias is adjusted by varying a series resistor between the grid of V6 and the -300 volt terminal. The resulting coupling from the plate of V_5 to the grid of V_6 and the feedback from the plate to grid of V_6 automatically regulates the waveform, so that the shape and amplitude are very nearly the same as the output from V_5, but with the opposite polarity. The combined output of V_5 and V_6 applied to the horizontal deflection plates of the c.r. tube V_{10} is sufficient to supply a sweep the full width of the c.r. tube screen.

127. Video voltage of positive polarity is fed from a cathode follower in the I.F. amplifier to the cathode of diode V_7. V_7 and V_8, together with the associated RC distorting circuits, have previously been described in the section on Video Circuits. The distorter circuits are actually located in the monitor chassis for convenience though they were described in the above section in order to complete the chain of the receiver system. A resistor in the plate of V_8 develops negative-going video which is coupled to the grid of the video amplifier, V_9. In turn, V_9 supplies the video deflection voltage to one of the vertical deflection plates of the c.r. tube, V_{10}. The cathode of V_8 delivers the video to the AS48 cable feeding through the slip rings to the display equipmont in the ground hut. The 2000-volt power supply for the c.r. tube is located in the same rack as the monitor scope.

CHAPTER VII - PPI SWEEP AND DISPLAY

128. In the CHL/GCI sweep system a Selsyn generator is used to transfer the rotation of the antenna system to a Selsyn receiver at the display position. The Selsyn receiver drives a deflection coil system around the neck of the PPI tube in approximate synchronism with the motion of the antenna. Unfortunately there is an angular lag between the generator and receiver Selsyns because of friction in the system which may vary from time to time, thus causing an angular error in the azimuth indication. To overcome this, as well as to avoid other complexities of the mechanical rotating sweep, a PPI Selsyn sweep system has been developed which uses a rotating electromagnetic field to produce the sweep on the c.r. tube and no mechanical moving parts are used at the display unit.

129. A suitable current waveform is fed into the rotor of a Selsyn located in a gear box and geared 1:1 with the antenna. The output current from three stator coils of this Selsyn will be three-phase modulated at the frequency of the antenna rotation and these coils are connected to the corresponding coils of a Selsyn stator which is mounted on the neck of the 12-inch long-delay c.r. tube as shown in Fig. 12.

130. The problem of maintaining sweep centering while the recurrence frequency is varied (not of vital importance in MEW A/S where the recurrence frequency is fixed by the spark wheel) is solved by developing a special current waveform to feed into the Selsyn. This waveform is built up from a sawtooth which produces the desired sweep, followed by a square wave of the same peak amplitude but of opposite polarity. The length of the square wave is controllable and is so adjusted that the positive area of the final waveform is equal to the negative area. When this condition is met the current throughout the Selsyn network is zero at the conclusion of the centering square wave and remains at zero until the next sweep waveform is applied. Since the spot on the c.r. tube is centered when no current is flowing in the deflection coils the frequency of recurrence of the sweep does not affect the centering.

131. The output of the cathode follower, V_4, (Fig. 10) is coupled through a buffer amplifier V_1 (Fig. 12) to key the sweep generator V_2. When the waveform on the suppressor grid of V_2 goes negative the plate current is cut off and the grid is driven slightly positive by the positive voltage supplied by R_9, R_{10} or R_{11}. Due to the low impedance of the grid while drawing grid current the grid voltage is only a fraction of a volt. When the waveforms supplied to the suppressor go positive the suppressor draws current and plate current begins to flow. C_8 is coupled from the plate to the grid so that when the plate current begins to flow the grid is driven negative thus tending to cut off the plate current. The condenser C_8 is discharged, however, due to the current flowing through one of the resistor networks connected to switch S_1. As this current flows the grid voltage of V_2 increases in the positive direction until grid current again starts to flow. That is, as the grid voltage decreases the plate current increases and the resultant change in plate potential coupled back to the grid tends

to keep the grid voltage constant. Since the total change in grid voltage is only of the order of 3 volts, the total change in current flow through the resistor network is very small, therefore during the time that the grid is in the negative region, C_8 is being discharged with a substantially constant current flow which in turn produces a constant voltage change at the plate.

132. The resulting sawtooth wave shape is applied to one grid of the mixer tube V_3. At the time that the suppressor of V_2 is cut off the same waveform is differentiated by the resistance capacitance circuit C_5 and R_{23}, R_{24} or R_{25}, depending on the position of the selector switch S_1. The negative part of this differentiated waveform cuts off V_4 which produces a positive square wave in the plate circuit, the time duration of which is determined by the RC combination in the grid. The resulting positive centering square wave is applied to the second grid of the mixer V_3. By means of R_{16} the peak amplitude of the sawtooth is limited to approximately 135 volts and the amplitude of the centering square wave is limited to approximately 280 volts by R_{19}. Since the cathode of V_3 will follow the most positive grid the resulting waveform at the junction of R_{17} and R_{18} is the complete sweep and centering waveform necessary for the Selsyn sweep.

133. This waveform is fed onto the grid of phase inverter amplifier, V_6, which in turn drives the grids of V_7 and V_8 as a push-pull amplifier. Cathode degeneration is produced by T_2 and R_{35} and the value of R_{35} is adjusted so that the resulting RL combination compensates for low frequency attenuation in the following transformer and Selsyn network. Another purpose of this cathode degeneration is effectively to raise the plate impedance of the push-pull amplifier in order to produce sufficient mismatch between the amplifier and the load to cause the output amplifier to act as a constant current source. The current under this condition will vary almost directly with the grid voltage change regardless of the change of load impedance throughout the sweep waveform. Transformer T_4 couples the plates of V_7 and V_8 through a low capacity line to the PPI Selsyn rotor mounted under the array turntable. The Selsyn stator is then coupled back to the deflection coil through a balanced three-wire line.

CHAPTER VIII - SECTOR B DISPLAY SYSTEM

134. Due to the narrow beam width of the MEW array the echoes displayed on the PPI tube are very short, and near the centre of the tube they are approximately one spot diameter in size. Since noise pulses are one spot diameter in size it becomes very difficult to select the echoes from the noise. To overcome this difficulty a pre-selected section of the PPI picture is expanded and displayed on the "B" tube.

135. Two sweep systems are used to produce this display. The range sweep occurring at the pulse recurrence frequency of the system starts at the bottom and moves vertically with range. The azimuth sweep system causes this trace to move horizontally with array rotation. The resulting picture is a rectangular display of range and azimuth, range being measured vertically and azimuth horizontally. The circuits involved are illustrated in Fig. 13.

136. Approximately 20 volts, 2000 c.p.s. is applied from the phase-shift oscillator, V_1 and V_2, through the step-down transformer T_1, Fig. 13, to the rotor of a Selsyn geared 1:1 to the array. If the voltage applied to the rotor is represented by $E \sin \omega T$ then the output of one winding of the Selsyn stator will be $E_1 \sin \omega T \cdot \sin \Theta$. Θ is the angle of the array with respect to north, say. The output of the other two coils will be $E_1 \sin \omega T \cdot \sin(\Theta + 120°)$ and $E_1 \sin \omega T \cdot \sin(\Theta + 240°)$ respectively. E, the input voltage, equals 20 volts. E_1, the peak output voltage, equals 10 volts approximately. This three-phase-modulated 2000 c.p.s. sine wave output is fed to the display racks where it is applied to a resistor network, which changes the modulation to two-phase. The output of this network is now $E_2 \sin \omega T \cdot \sin(\Theta - 15°)$ and $E_2 \sin \omega T \cdot \sin(\Theta - 105°)$ to ground, therefore these two voltages are modulated by terms 90° out of phase. $\left(E_2 = \dfrac{E_1 \sin 120°}{\sin 45°}.\right)$ The vector diagram illustrates this change from three-phase to two-phase modulation.

137. The output from each side of the resistor network is fed to the centre taps of resistors across two identical windings on a transformer T_2. The output voltage of each of these windings is approximately 20 volts and these voltages are fed to the plates of four diode peak rectifiers. Since the voltage from transformer T_2 is in phase with the voltage to the Selsyn system, the voltage on the plates of the diodes will be:

$$E_2 \sin \omega T \cdot \sin (\theta - 15°) + E_3 \sin \omega T$$

$$E_2 \sin \omega T \cdot \sin (\theta - 15°) + E_3 \sin (\omega T + 180°)$$

$$E_2 \sin \omega T \cdot \sin (\theta - 105°) + E_3 \sin \omega T$$

$$E_2 \sin \omega T \cdot \sin (\theta - 105°) + E_3 \sin (\omega T + 180°)$$

where $E_3 = 1/2$ secondary voltage of T_2

Examining these four voltages it is apparent that they are carrier frequencies of 2000 c.p.s. amplitude modulated with a sine wave of the frequency of rotation of the array and there is no phase reversal as long as $E_3 > E_2$. Therefore the output of the peak rectifier and filtering network will be a sine wave of the frequency of array rotation. By selecting the proper combination of voltages to the amplifiers, V_5 and V_6, and to the grid of the back-trace blanking keyer, V_7, the resulting sweep can be made to cover each of the four quadrants represented on the PPI display. Referring to the wave-form diagram, if waves A and B are applied to the grids of V_5 and V_6 and wave C applied to the grid of V_7, then the sweep on the B tube will be represented by the portion of the curve marked A_1. During this period of time waveform C on grid of V_7 causes the output to go positive, thus turning on the suppressor of the back-trace blanking amplifier located on the video chassis, Fig. 9. This results in the sweep appearing while C is positive. During the remainder of the cycle C is negative cutting off the back-trace blanking amplifier. It will be seen that nearly 180° is available on the Sector B tube for any setting of the quadrant switch so that considerable overlap may be obtained. However, it is desirable to use not more than 120° of this sweep due to the non-linearity at the ends, and it is preferable to expand the sweep, as mentioned below, so that 90° covers about nine inches on the 12" C.R.T.

138. The vertical range sweep is generated by V_8, V_9 and V_{10} feeding into the horizontal coils of the deflection yoke. The back-trace blanking pulse is fed from the keying chassis to the grid of V_8 which amplifies and inverts the phase of this square wave and applies it to the second grid of V_8. When the second half of V_8 is cut off, condenser C_{17} starts to charge positively through the diode V_9 and the series resistor R_{42}. This rise in potential is applied to the grid of V_{10} which, with R_{46} in its cathode, acts as a cathode follower coupled through C_{16} and raises the potential at the junction of V_9 and R_{42}. This cuts off V_9 and keeps an almost constant potential drop across R_{42} thereby producing a constant current charging C_{17}. The resulting sawtooth waveform is quite linear. The plate current of V_{10} is fed through the deflection coils producing a beam shift proportional to V_{10} plate current. Sweep length is adjusted by varying the potential on the plate of diode V_9. Sweep time is determined by the length of the back-trace blanking pulse delivered from the keying chassis.

CHAPTER IX - CONTROL SYSTEM

A. C. Control System

139. The a.c. control system shown in Fig. 14 for MEW A/S is designed to give the maximum of flexibility in control with the minimum of operation. At the same time the operational sequence is so arranged as to make it virtually impossible for the operator to damage any of the equipment by throwing the wrong switch at the wrong time. The transmitting and receiving equipment located in the tower hut can be controlled from either the remote or the local operating positions. The 110/220 volt mains enter the A rack (ground hut distribution rack) at terminals 1, 2 and 3, Terminal 1 being the grounded neutral. To place the set in operation from the "local" or tower hut position the main switch S_1 and the tower switch S_3 are first closed, energizing relay RE_3. This applies 110 volts to the cables 1AJ and 3AJ, and pilot light PL_3 indicates that power is applied to the transmitting equipment. At the same time the hour meter M_3 begins to total the operating time of the magnetron filaments.

140. The switch S_8 is closed in order to energize relays RE_{10} and RE_{11}, (insufficient contacts available on a single relay) which, in the energized position, closes the contacts for local operation. After forty-five seconds from the time S_3 is closed, relay RE_7 closes and applies 110 volts through switch S_9, through the contacts of the over-load relay RE_8, across the pilot light PL_6, and to the micro-switch S_6. The power variac for controlling the high voltage power supply is manually rotated to zero and in the zero position the micro-switch S_6 is closed, thus applying 110 volts to the relay RE_6. When this relay is energized the line voltage is applied to the variac and to the spark wheel and blower motors. As the variac is turned up manually, switch S_6 opens but the hold-on contact on RE_6 keeps the relay energized. If the variac is turned too high the excess power supply current passing through relay RE_8 opens the pilot circuit so that the contacts of RE_6 are broken and the line voltage is removed from the variac. To re-cycle, it is necessary to rotate the variac back to zero in order to close the micro-switch S_6 again. Switch S_7 is a manual control to apply line voltage to the high voltage receiver power supplies.

141. To set up the system for remote operation, the switch S_8 is turned to the "remote" position so that the double relay RE_{10}, RE_{11} is de-energized, and at the same time S_7 and S_9 are left closed. The operator in the ground hut now closes S_1 to apply pilot voltage to S_2 and S_3. With S_3 closed the operating sequence is the same as described above for "local" operation except that the remote variac and the relay RE_5 now control the high voltage to the transmitter. The pilot light PL_5 indicates when the time delay relay RE_7 is closed. Filament voltage is applied to

the display racks when relay RE_2 is energized by closing switch S_2. The time delay relay RE_4 holds off the application of high voltage to the display racks for forty-five seconds. The switch S_4 allows the high voltage to be removed from the racks independently for test purposes. The pilot light PL_2 shows when the display rack filaments are on and the pilot light PL_4 indicates that the high voltage has been applied to the displays.

142. The meters M_4 and M_5, located in the ground hut and the tower hut respectively are connected in series to indicate the high voltage of the transmitter power supply. Similarly, the meters M_7 and M_8 indicate the average magnetron current.

143. A separate 110/220 volt service is run directly to the tower for lighting and heating purposes. The heating is automatically controlled by thermostats. Due to the large variation in power consumption of the motor control system, the motor control is supplied by a separate power plant, to avoid difficulties in regulation of the voltages in the radio equipment.

Slip Ring Assembly

144. Fig. 24 illustrates the slip ring assembly coupling the cable from the display equipment to the transmitter and receiver gear located in the tower hut. The inner drum is bolted to the turntable mount while the outer frame is secured to the turntable by means of a U-clamp. The cables running from the slip rings to the radio gear in the tower hut are connected to the terminals located on the top of the assembly. The rings on the drum connect internally to weather-proof cables which are fed out through bushings at the bottom end of the drum. The lower six rings are used to couple the 110 volt power and are capable of handling up to 30 amperes each. There are thirty-six smaller rings capable of handling only a few amperes each which are used to couple pilot circuits, meters, etc., and there are also four rings located on a smaller drum at the very top which terminate in low loss coaxial lines. Two of these rings are used for inter-communication, one for video and the fourth is tied to the shields of the coaxial line. In MEW A/S all of the power rings are used but several of the smaller rings are not needed, since the assembly was not designed specifically for this particular application.

145. When bolted in position the assembly is housed in a weather-proof well and the top is covered over with a sheet metal cap.

Azimuth Marker System

146. The azimuth markers mentioned in connection with the video amplifier system are generated by rotating cams and micro-switches

indicated on Fig. 15. V_1 is the marker injector tube located on the video amplifier chassis associated with each display. The resistor combination R_6, R_7, R_8, R_4 and R_5 comprise the bias network which is keyed by micro-switches S_5 and S_6.

147. Fig. 25 indicates the position of the azimuth marker switches mounted on the gear train. The power take-off from the turntable, turning 8:1 with the array, drives the gear train shown in the photograph. The right-hand cam operating a micro-switch turns 36:1 with the array producing an azimuth marker every 10° of array rotation. The left-hand cam turns 4:1 with the array producing a wider marker on the display tubes to indicate north, south, east and west. The last gear in the train travels 1:1 with the array and rotates the two Selsyns used to produce the PPI sweep and the sector B azimuthal displacement respectively. The gear box completely assembled has a brass shield screwed in place to protect the gears from foreign matter, and a sheet metal housing clamps over the whole assembly making the unit completely weather-proof.

CHAPTER X - WARD LEONARD CONTROL

148. For the plan position indication type of display the antenna should rotate at a uniform speed continuously. The optimum speed of rotation will depend on the various factors of recurrence frequency, antenna pattern beam width, cathode ray tube build-up, etc. as explained in CHAPTER II, and may be determined experimentally. In the case of the MEW A/S PPI it has been found that 2 to 3 r.p.m. is about the greatest angular velocity that can be used without any lessening of signal-to-noise on the PPI tubes.

149. When attention is transferred to the B scope it is found that, for a spread of 90° across the tube, the best signal-to-noise is obtained at rotational speeds of not much greater than 1 r.p.m.

150. For straight PPI operation it will be seen that a constant speed a.c. induction motor might be used to drive the array and this could also apply to the sector B scan if one were willing to wait until the antenna came back to the desired sector. In point of fact, continuous rotation might well be best in the case of the sector B scan from the view-point of saving wear and tear on the turntable, gear box, and all the tower equipment during the periods of reversing at the end of the scan. However, if this reversing is done gradually no serious damage will result. It then becomes a question of whether the time taken to reverse the structure is comparable to the time taken for the structure to come around again to the sector while being rotated continuously.

151. Since the operational requirements of this new set are not clearly defined yet it has been considered desirable to include a speed control with the first few models at least. This control may be used to determine the optimum rotational speed for the particular equipment when used for PPI display, or it may be used for sector scan in cases where a sector of from 90° to 120° only is required to be examined. For this latter application a special motor-driven reversing potentiometer may be supplied which is automatically actuated by pre-set micro-switches. In no case, however, should the speed control be used for "search-lighting". That is, no attempt should be made to hold the antenna on a target as this technique is satisfactory only for the earlier types of RDF equipment in which the A scope was the sole display. For the PPI and B scopes the best signal-to-noise results if the antenna continuously scans at an optimum speed. Further, if the antenna is scanning continuously there will be no danger of missing other targets due to concentration on one.

152. Two types of speed control have been used with MEW A/S. The first one was a thyratron control designed to operate the GCI antenna.

In this control a pair of FG-105 thyratrons is used to control the armature current through the turntable d.c. motor. One thyratron only operates at a given time and as the maximum continuous rating of the thyratron is 6.5 amperes, the total power that can be handled is of the order of 1 1/2 H.P. This is adequate for operation of the GCI antenna under most conditions but there is some doubt that the thyratron control will provide sufficient power to drive the MEW array with its greater wind loading in winds of the order of 50 miles per hour.

153. The Ward Leonard control system supplies more power than the thyratron control and should be more rugged. It is built up from three moving machines, (See Fig. 16). The first is a 5 H.P. a.c. motor, 220 volts, single phase, 60 cycles input rotating at 1720 r.p.m. This motor drives a d.c. generator through a direct coupling. This generator is rated at 3 KW output at 260 volts. On the same shaft as the main generator is a small d.c. generator or exciter of 1/2 KW rating, 2 amperes at 230 volts.

154. The output from the exciter unit is connected across a double potentiometer, P_1 P_2 located at the control desk of the MEW A/S equipment. The two moving arms of this potentiometer are connected to the field of the main d.c. generator so that when the arms are in the central position there is no voltage on the generator field. By rotating the controls to either side of centre the polarity and magnitude of the generator field voltage may be changed. The d.c. output of the generator varies with its field voltage so that a very smooth control of d.c. power is obtained. The generator output is fed to the armature of the tower motor, usually through a small resistance to minimize the effect of surges. The tower motor is a 3 H.P., 220 volt d.c. motor of similar construction to the main d.c. generator. The field voltage of the tower motor is supplied directly from the exciter unit. The d.c. motor is belted to the gear box reducing unit which in turn drives the ring gear of the CHL/GCI turntable.

155. The advantage of the Ward Leonard type of control is that the generator output is always at a very low impedance, of the order of 1 ohm or so, regardless of the output voltage so that a good torque is obtained from the tower driving motor, even at low speeds. When the field is on the driving motor but zero field is on the generator so that the d.c. generator has no output the armature of the generator constitutes a practical short circuit across the tower motor so that a "static torque" is developed which is a very effective brake. Two or three ohms of resistance are usually inserted in the leads between the generator armature and the driving motor armature to minimize the effects of a sudden surge of current in the driving motor when the control potentiometer is suddenly turned up from the zero position by an inexperienced operator. Serious damage to the generator, motor, and gear train may result if the control is quickly spun full on or reversed suddenly. The equipment in the tower hut may also be damaged.

OTTAWA
September, 1943

H. A. FERRIS
D.W.R. McKINLEY

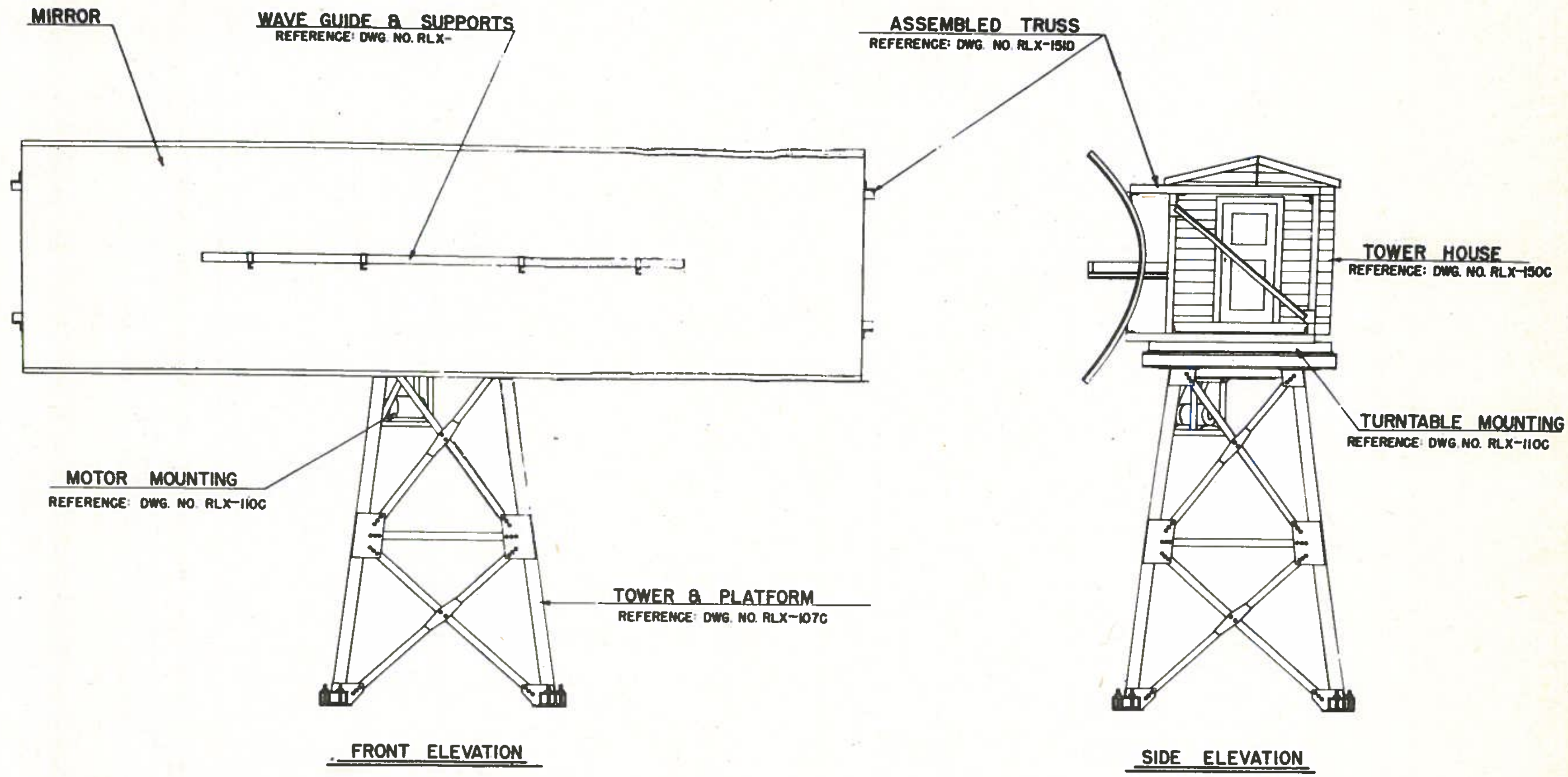


FIG. 1

PRA-92

FHB.	OCT 3, 43	
NATIONAL RESEARCH COUNCIL-RADIO SECTION		
MEW A/S ASSEMBLY		RLX-152D

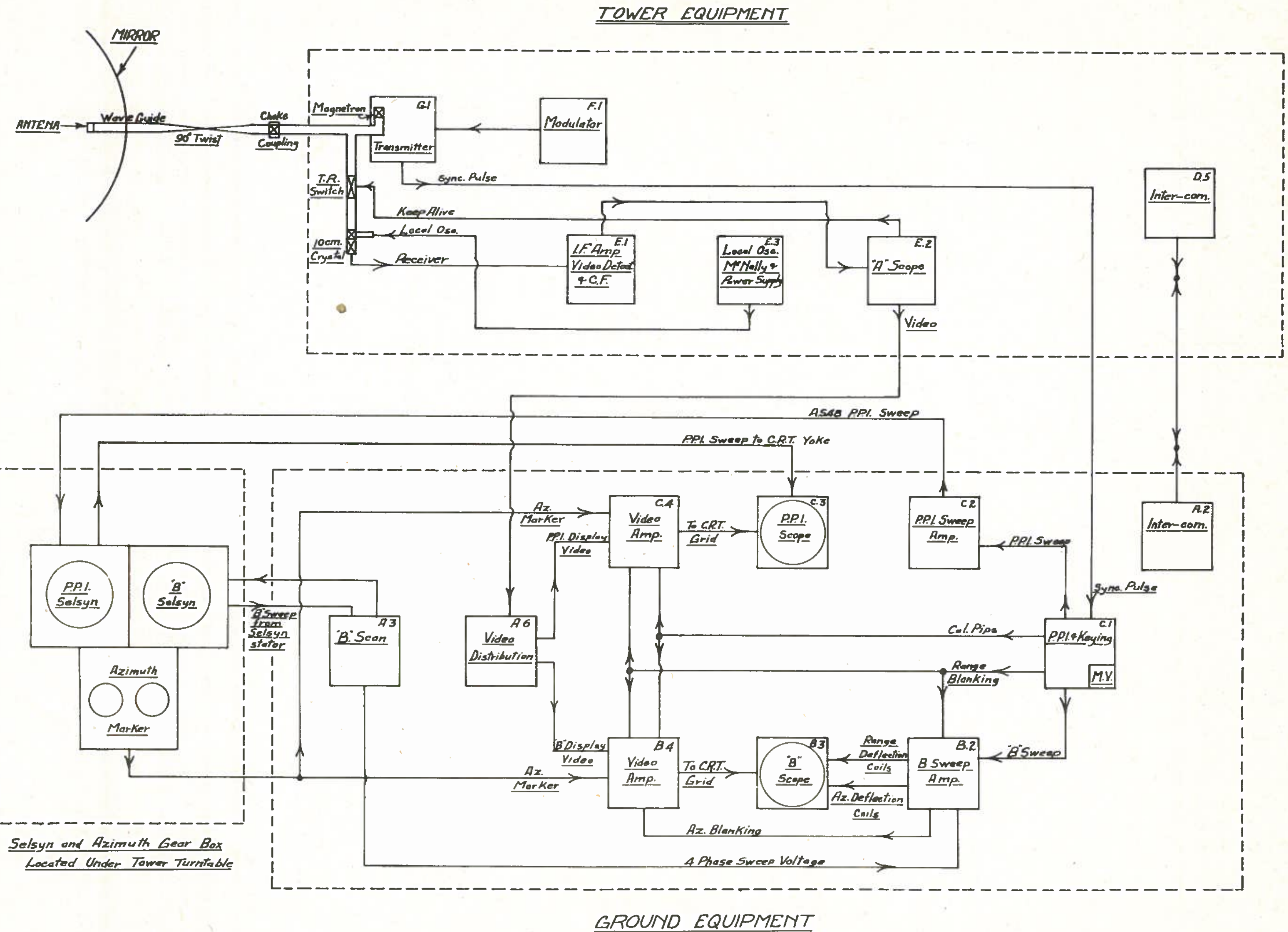


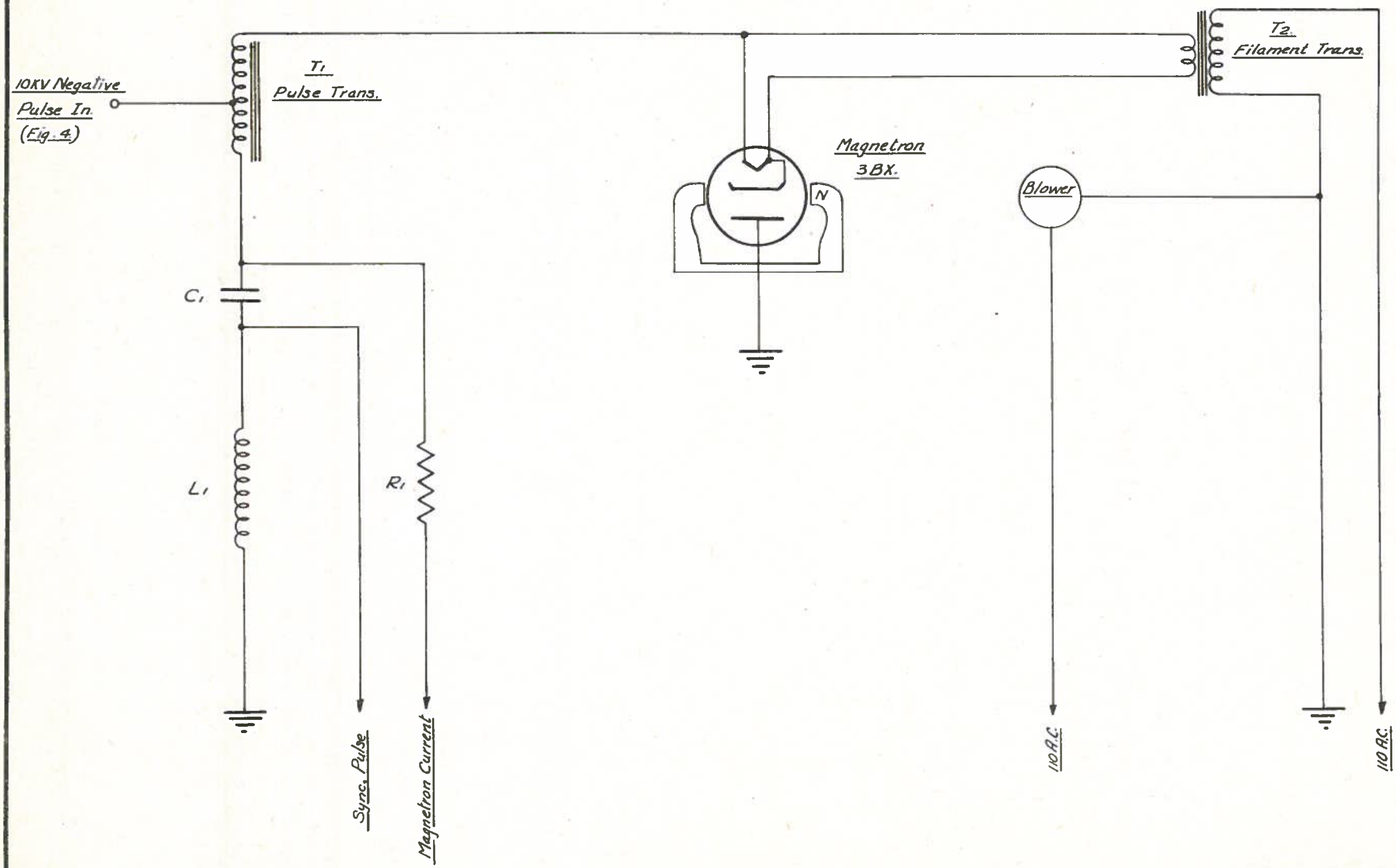
FIG. 2

PRA-92

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION
DRAWN BY		DATE		SUPERSEDES
CHECKED		DATE		SCALE
ENG. APPROV. BMSK		DATE		FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME: BLOCK DIAGRAM of MEW A/S — DWG. NO. RLX-189C



PRA-92

Fig. 3

ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION

DRAWN BY D. Seymour	DATE Nov. 23-43	SUPERSEDES
CHECKED E.H.B.	DATE Dec. 4, 43	SCALE
ENG. APPROV. P. Lewis	DATE	FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME R.F. TRANSMITTER — DWG. NO. PRA-190C

PRA-92

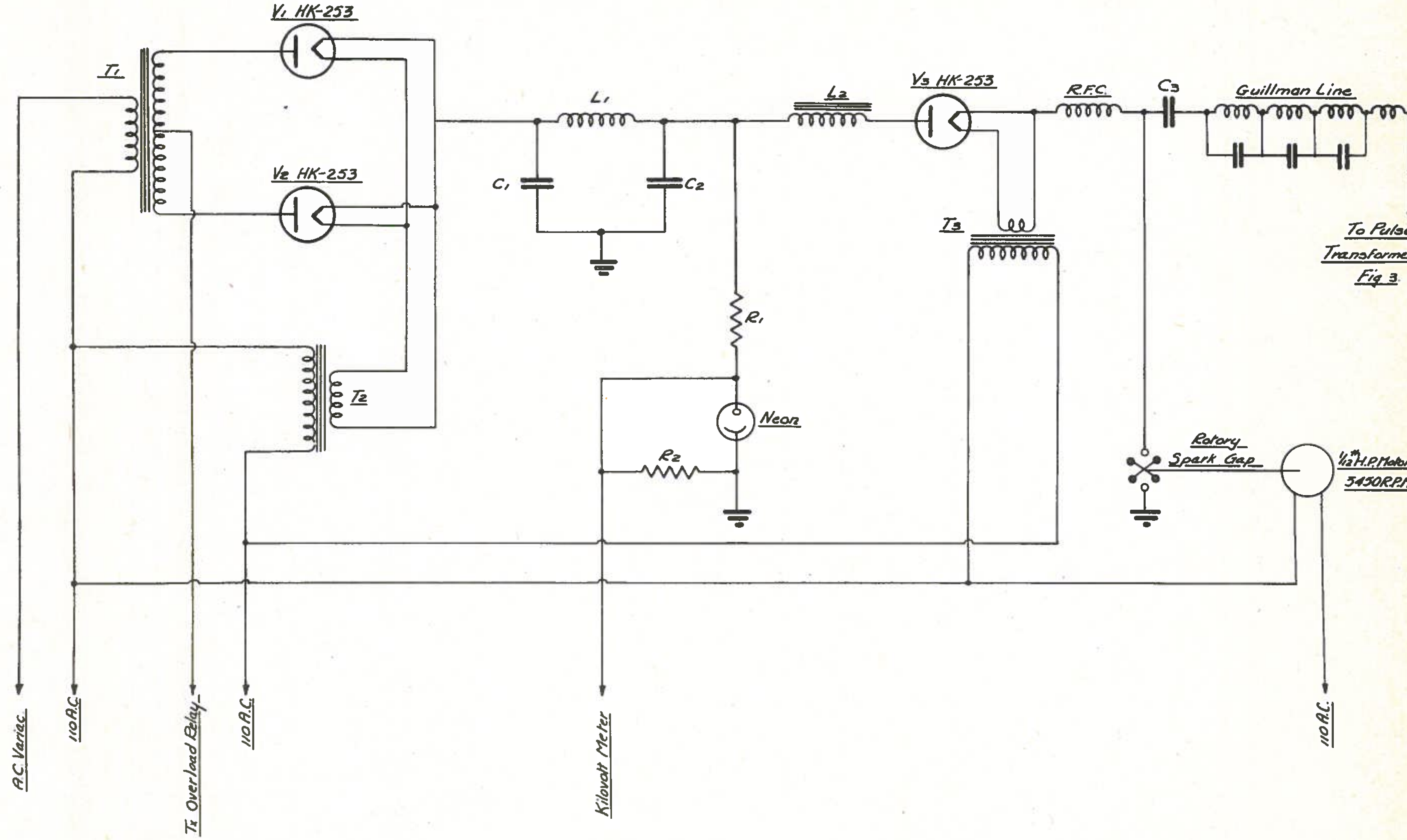
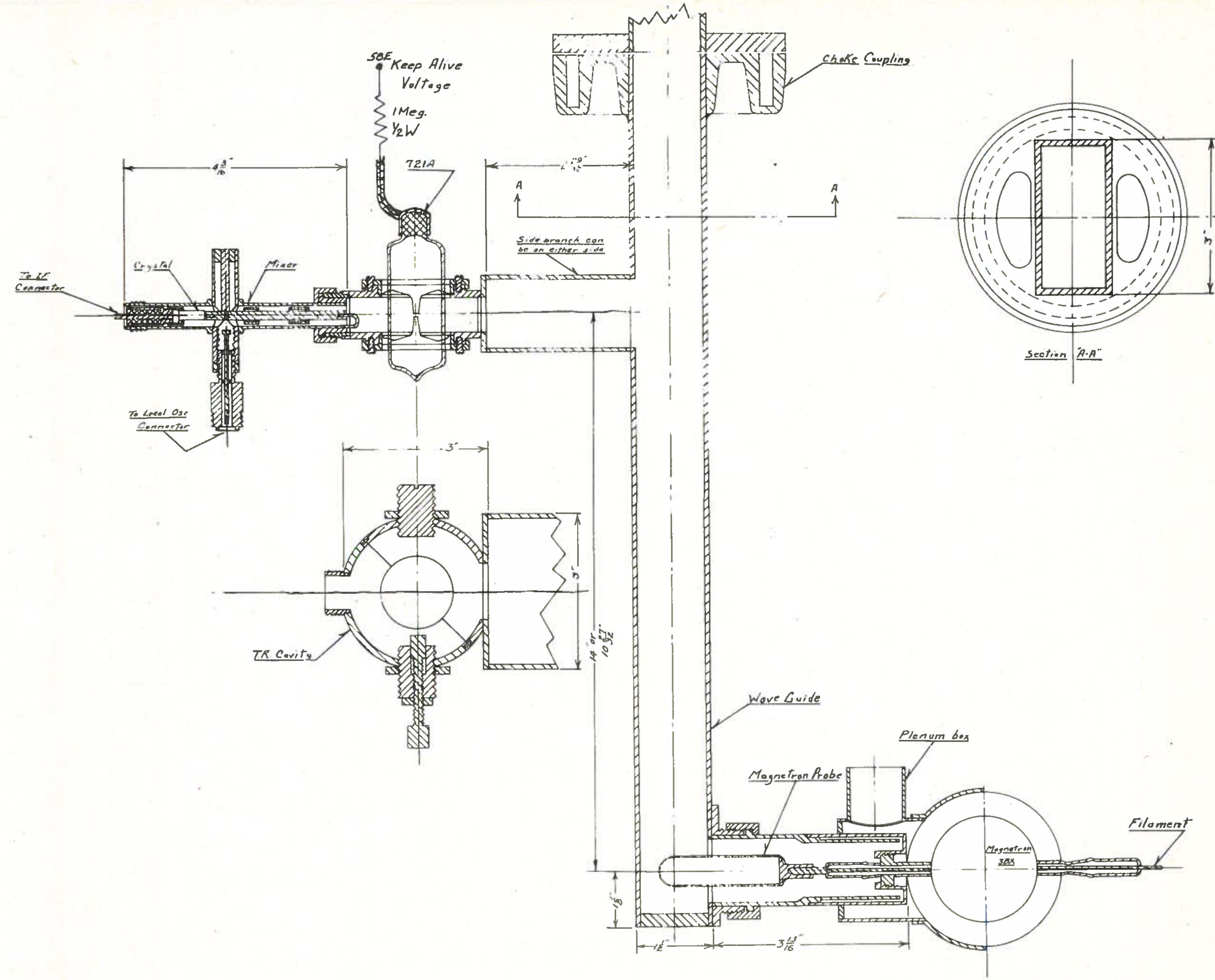


FIG. 4

ITEM	PART No.	QUAN	MAT'L	DESCRIPTION
DRAWN BY D. Seymour	DATE Nov. 22-43	SUPERSEDES		
CHECKED E.N.B.	DATE DEC 1,'43	SCALE		
ENG. APPROV [illegible]	DATE	FINISH		

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME MODULATOR AND P.S. DWG. NO. PRA-191C



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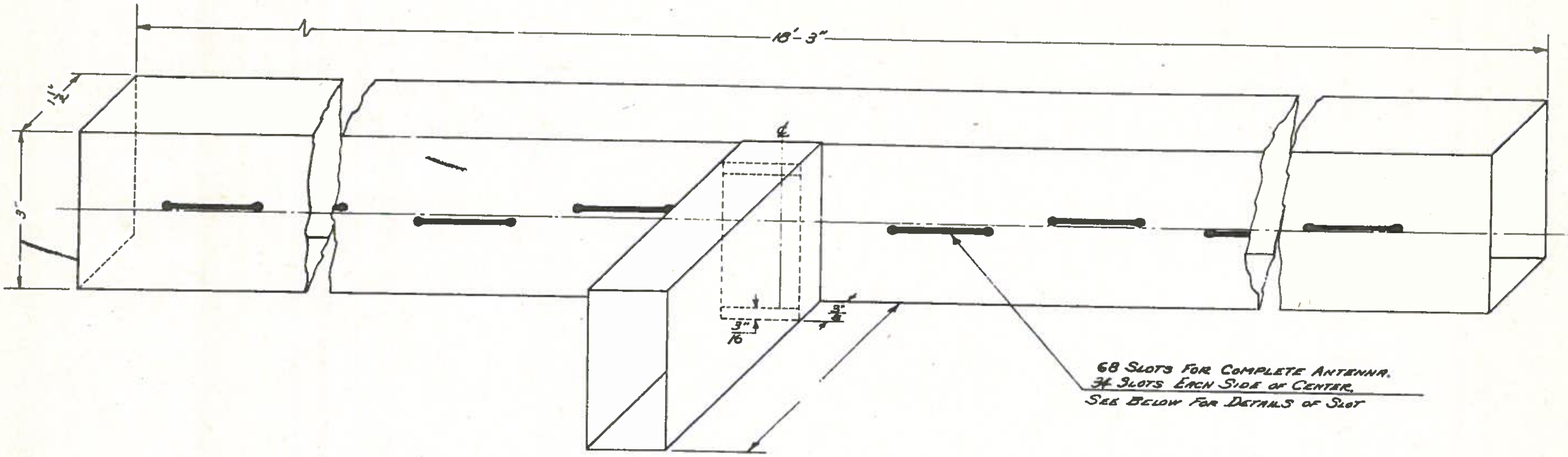
ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION
DRAWN BY F.McMillan		DATE 13-10-43		SUPERSEDES
CHECKED		DATE		SCALE
ENG. APP. H.Ferris		DATE		FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME: R.F. SYSTEM MEW A/S

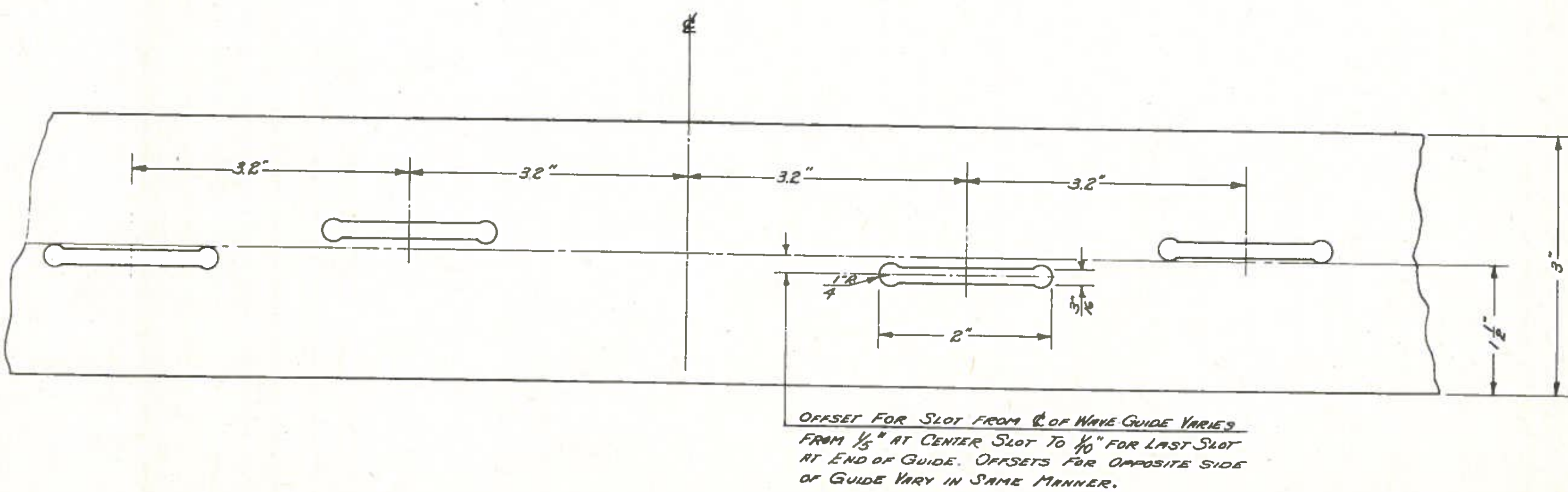
DWG. NO. RLX-160-C

FIG. 5



ANTENNA ASSEMBLY - FIGURE 6A

NOTE:
ALL DIMENSIONS ARE FOR DIAGRAMMATICAL PURPOSES ONLY AND NOT NECESSARILY EXACT.



SLOT DETAIL - FIGURE 6B

FIG. 6

PRA-92

ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION
DRAWN BY E.H.B.		DATE OCT. 1943		SUPERSEDES
CHECKED		DATE		SCALE
ENG. APPROV. [signature]		DATE		FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME: M.E.W. A/S ANTENNA ARRAY — DWG. NO. PRA-192C

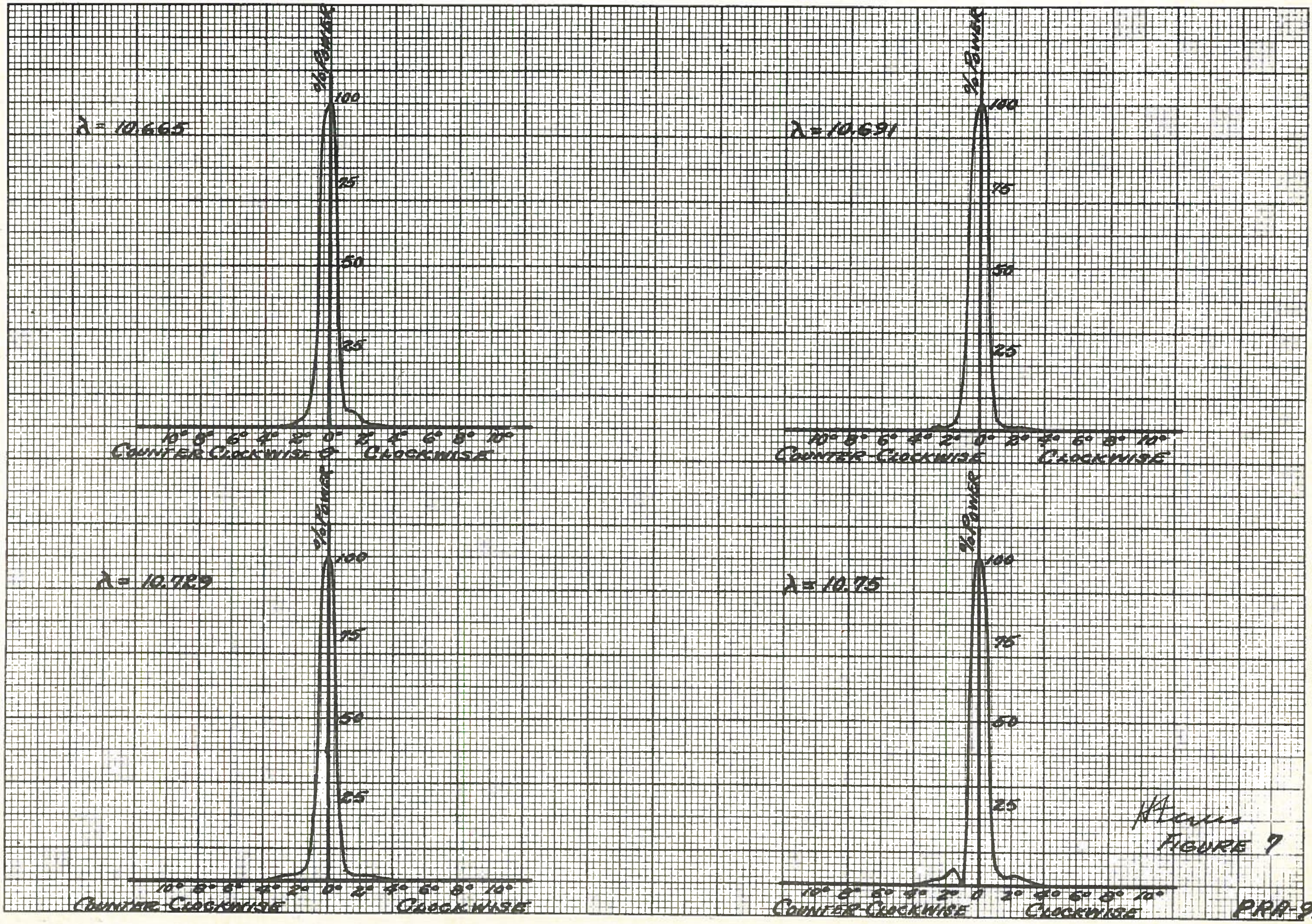
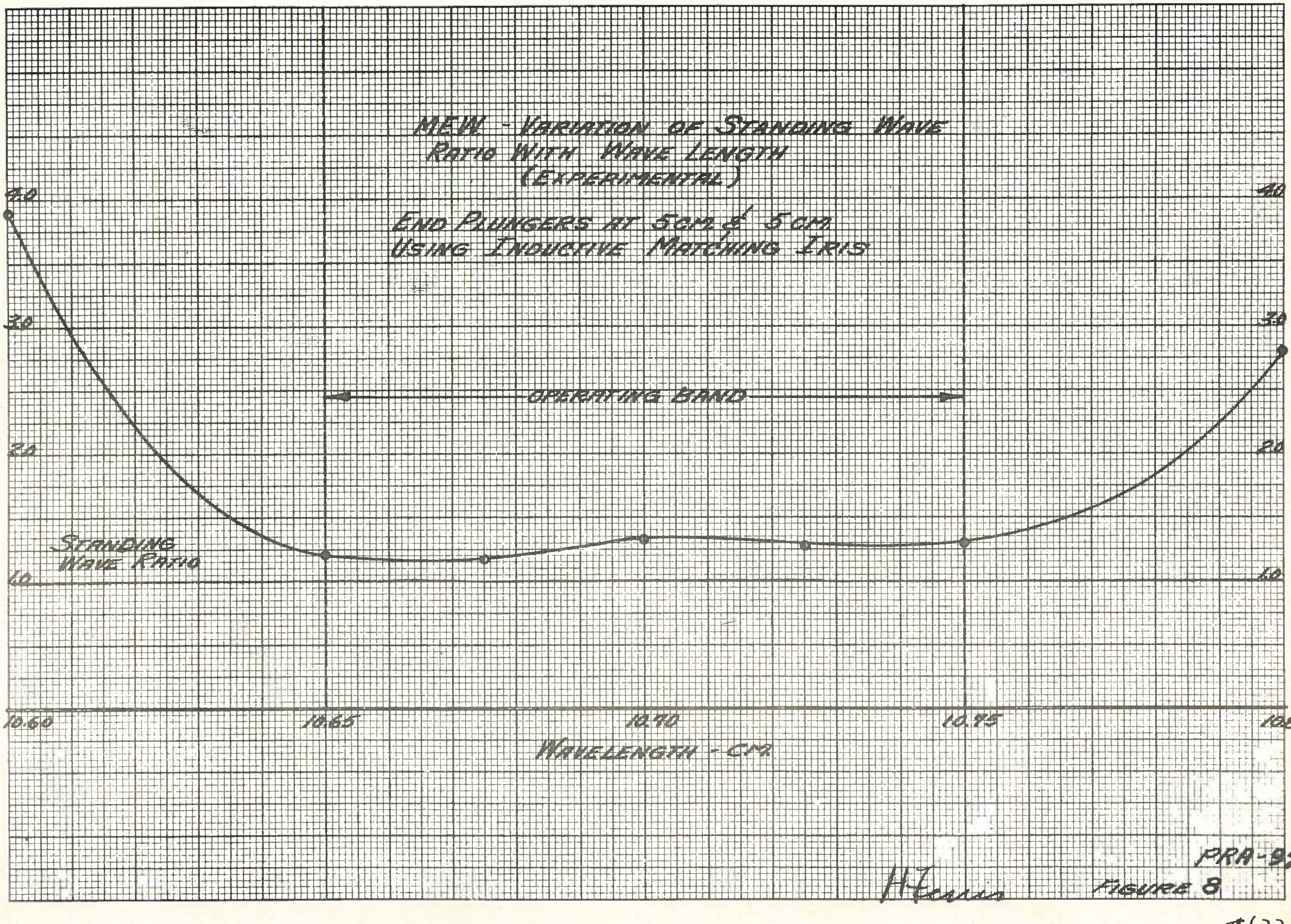


FIGURE 7

PRR-92

#621


MEW - Variation of Standing Wave
Ratio With Wave Length
(Experimental)
End Plungers at 5cm & 5cm
Using Inductive Matching Iris
Operating Band
Standing
Wave Ratio
4.0
3.0
2.0
1.0
10.60
10.65
10.70
10.75
10.80
Wavelength - Cm
PRA-92
Figure 8

#622

PRA-92

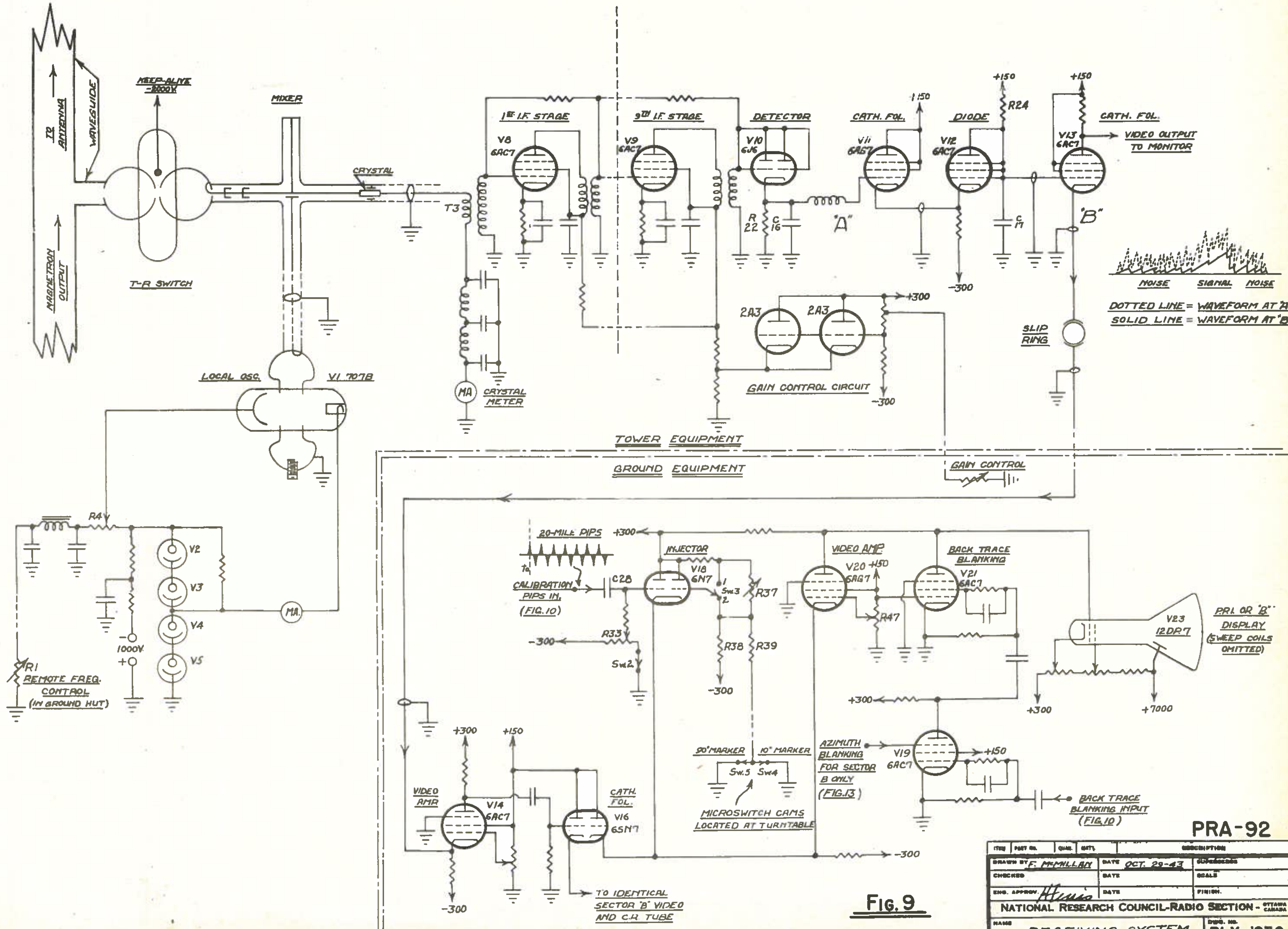
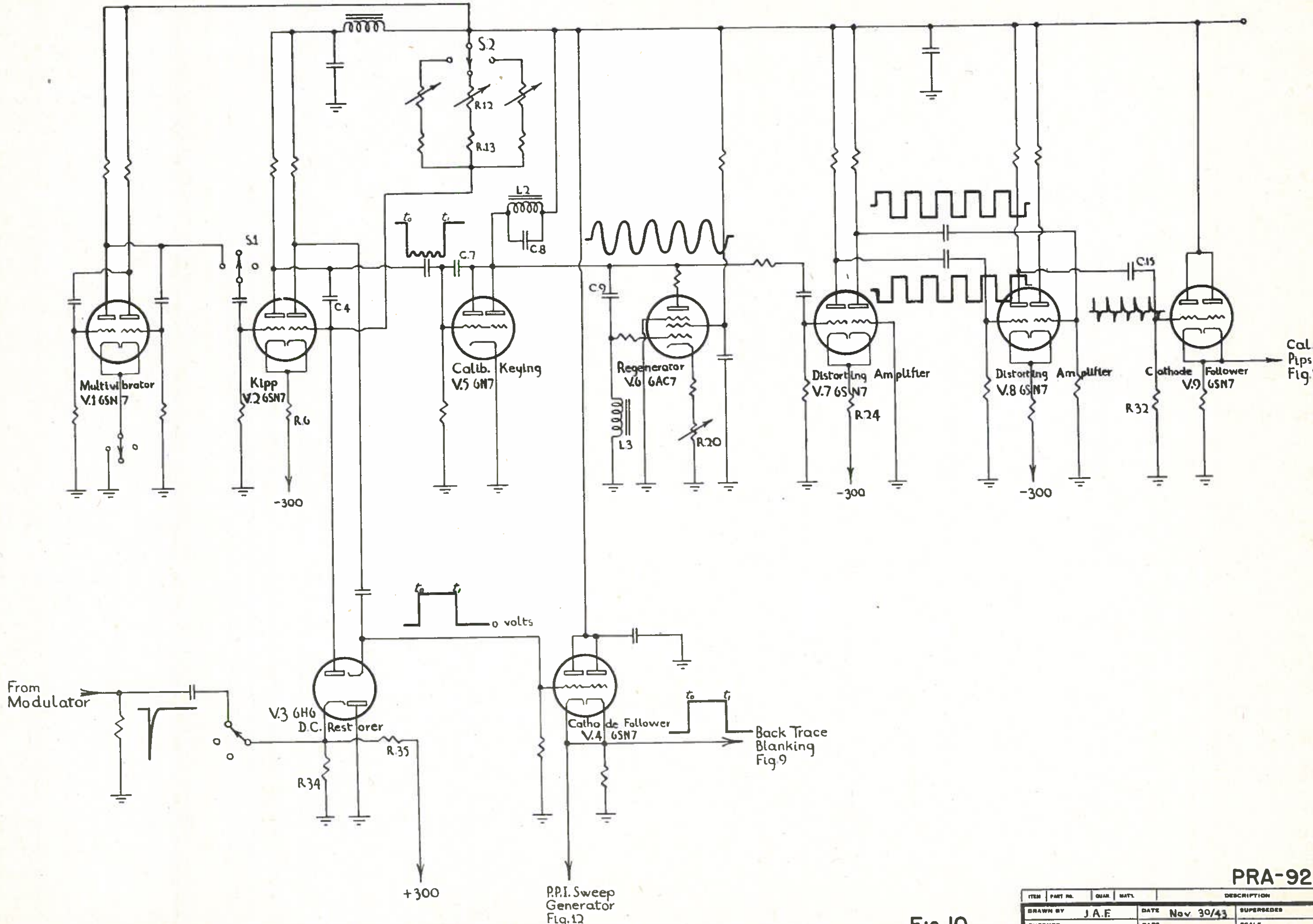


FIG. 9

ITEM	PART NO.	QUAN.	MATL.	DESCRIPTION
DRAWN BY F. McMILLAN	DATE OCT. 29-43	SUPERSEDES		
CHECKED	DATE	SCALE		
ENG. APPROV.	DATE	FINISH.		

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME RECEIVING SYSTEM — DWG. NO. RLX-193C



PRA-92

FIG. 10

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION
DRAWN BY	J.A.F.	DATE	Nov 30/43	SUPERSEDES
CHECKED		DATE		SCALE
ENG. APPROV.	(signature)	DATE		FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME: Cal. Pips & Back Trace Blanking — DWG. NO. RLX-194C

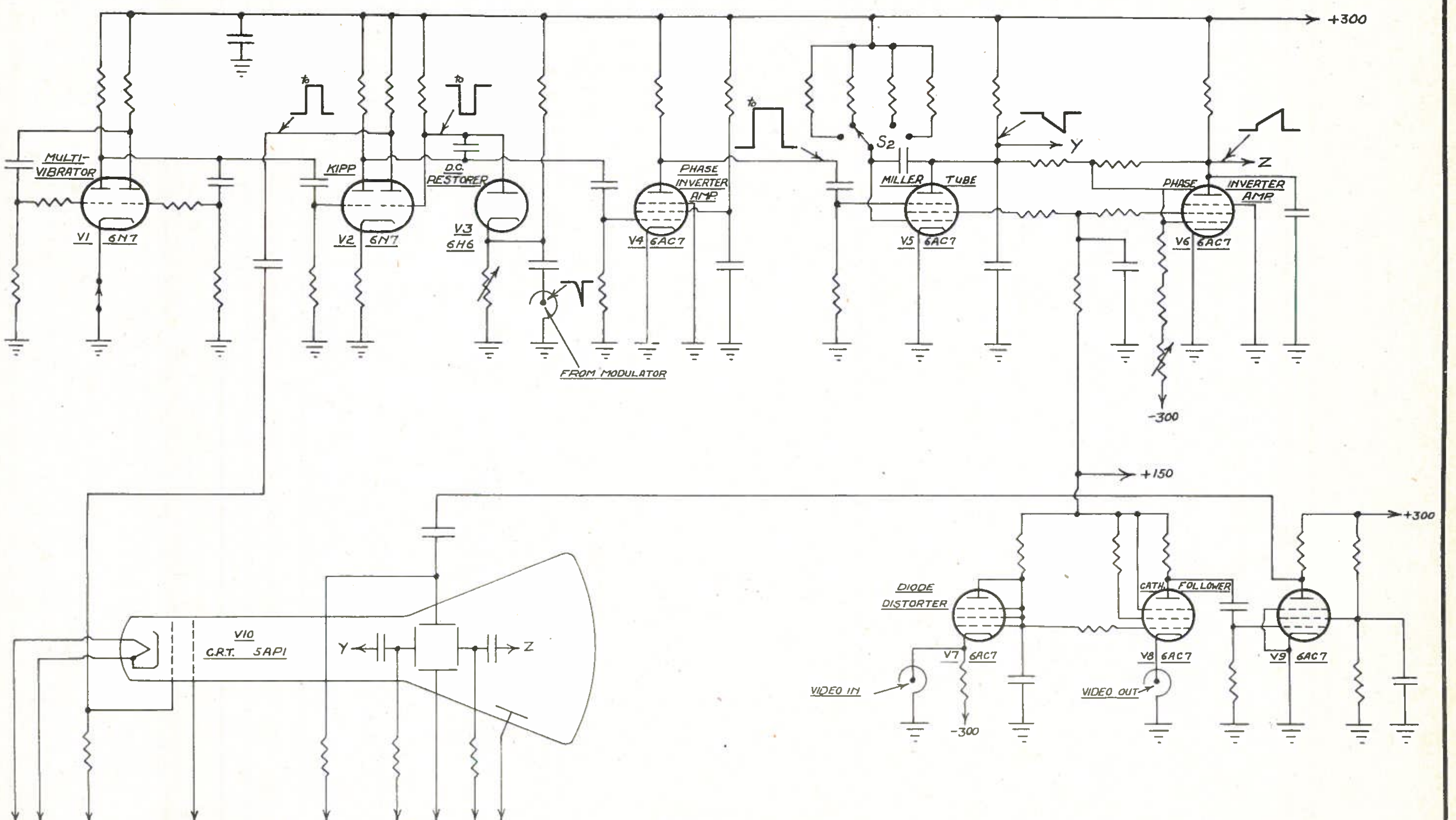


FIG. 11

PRA-92

ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION
DRAWN BY F. McMILLAN	DATE NOV. 16-43	SUPERSEDES		
CHECKED	DATE	SCALE		
ENG. APPROV.	DATE	FINISH		

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME: MONITOR SCOPE — DWG. NO. RLX-195C

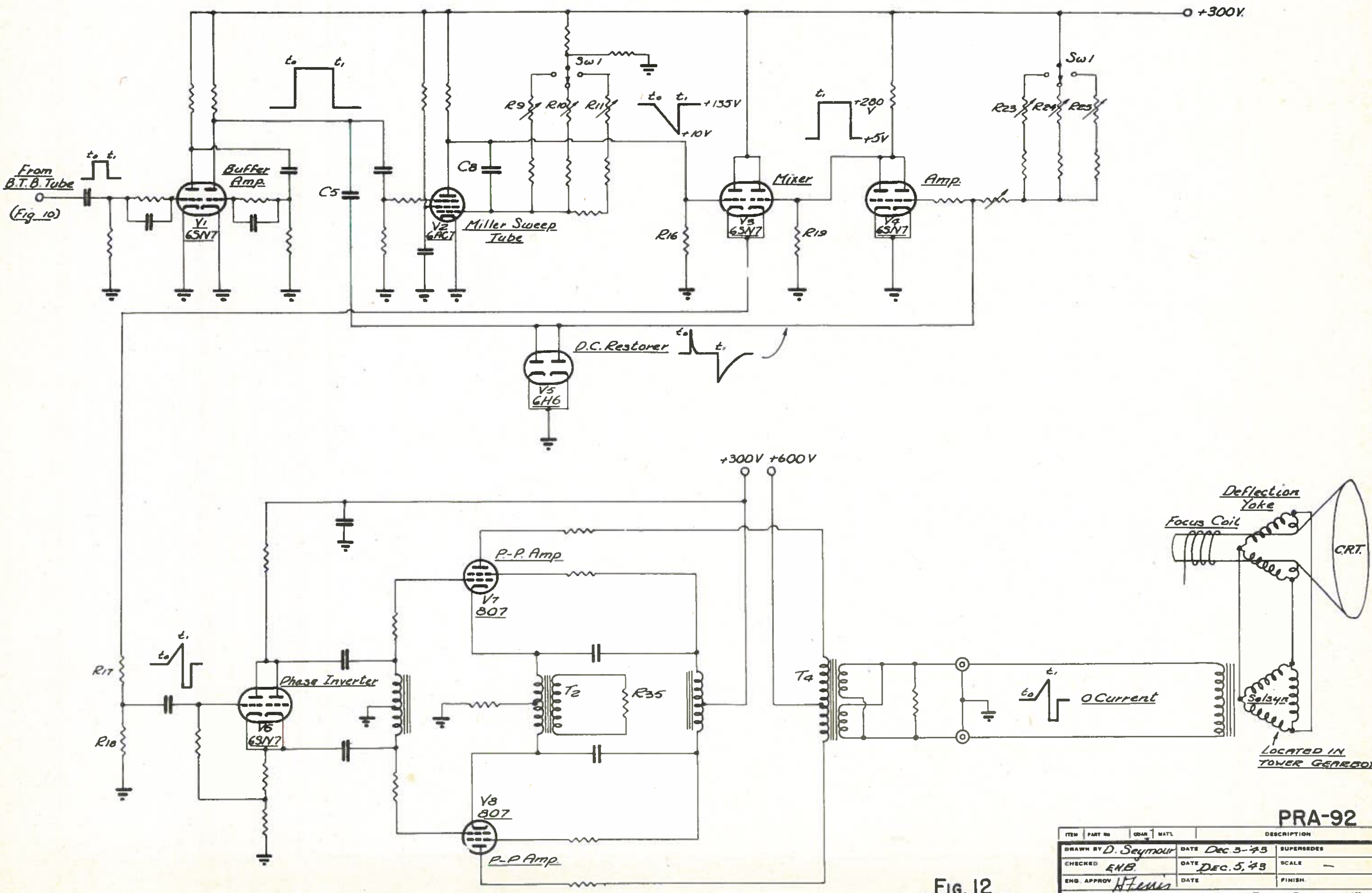


Fig. 12

PRA-92

ITEM	PART NO		MAT'L	DESCRIPTION
DRAWN BY D. Seymour	DATE Dec 5-'43	SUPERSEDES		
CHECKED E.K.B.	DATE Dec. 5, '43	SCALE —		
ENG. APPROV H. Lewis	DATE	FINISH		

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME P.P.I. SWEEP SYSTEM — DWG. NO RLX-196C

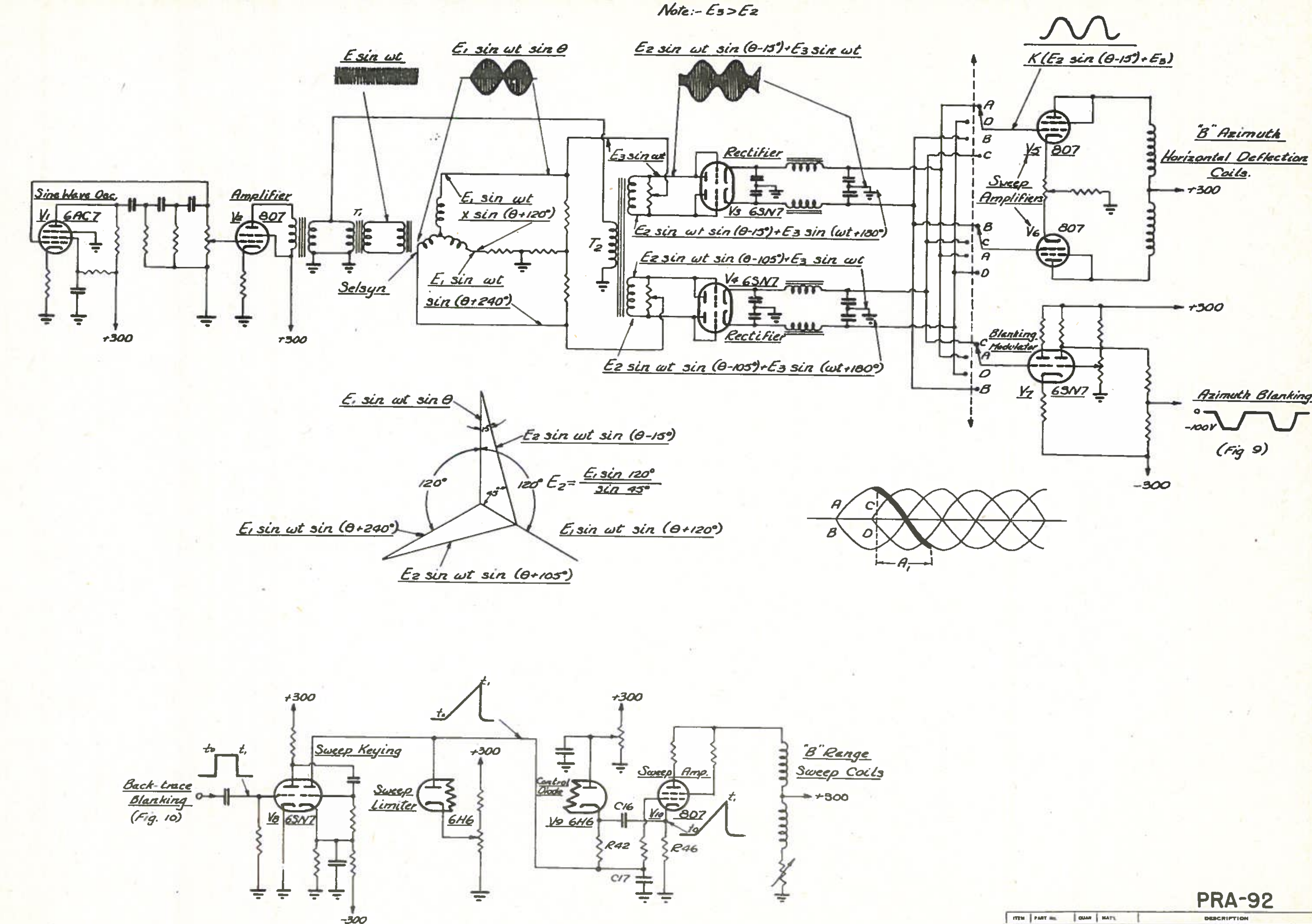


Fig. 13

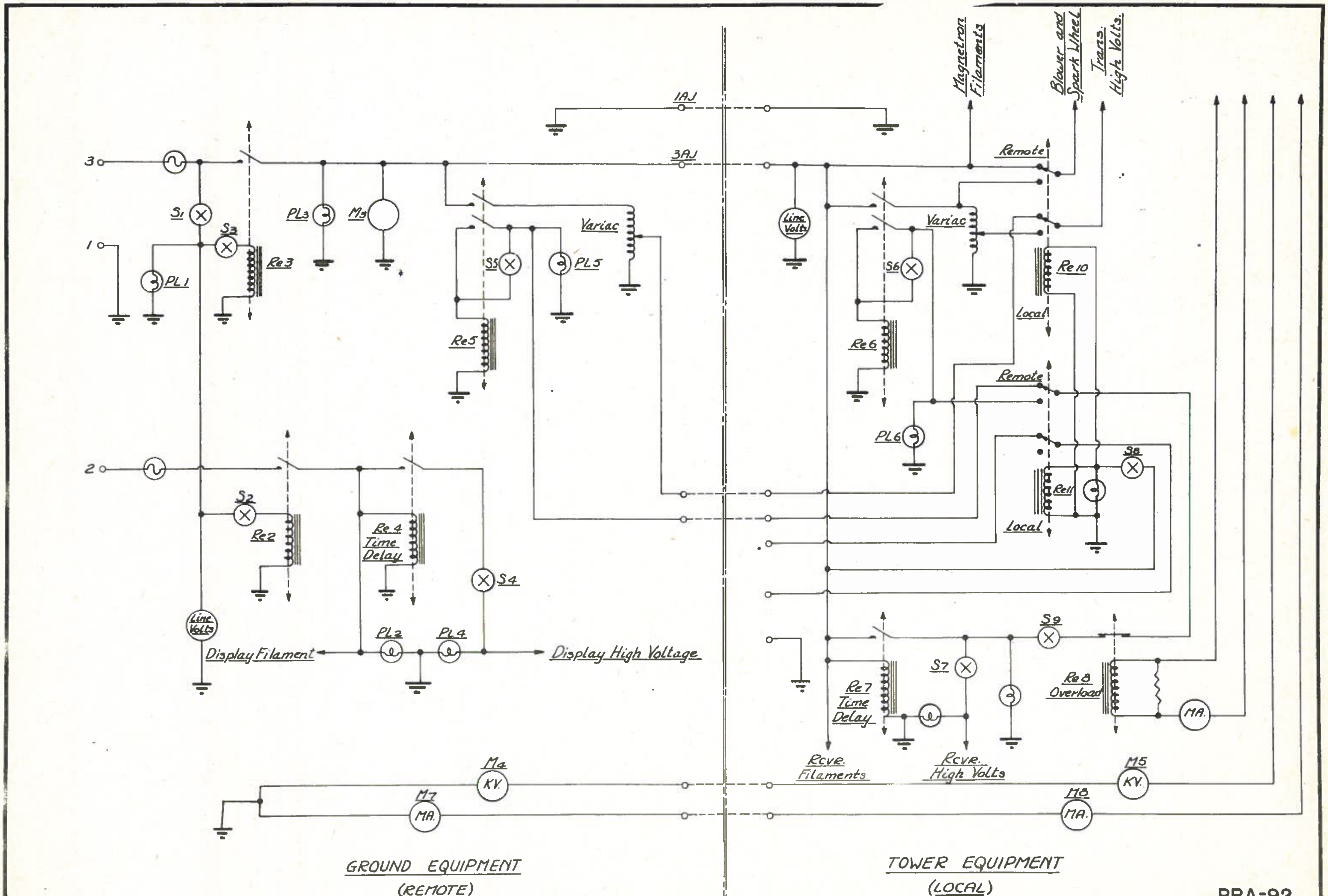
PRA-92

ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION

DRAWN BY D. Seymour	DATE Nov 11 - 43.	SUPERSEDES	
CHECKED E.H.B.	DATE Dec 6, 1943	SCALE	
ENG. APPROV. [signature]	DATE	FINISH	

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME "B" SWEEP SYSTEM — DWG. NO. RLX-197C



PRA-92

FIG. 14

ITEM	PART NO.	QUAN.	MAT'L	DESCRIPTION

DRAWN BY D. Seymour	DATE Dec. 4-'43	SUPERSEDES	
CHECKED E.H.B.	DATE Dec. 5, '43	SCALE	
ENG. APPROV. H Teiner	DATE	FINISH	

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME A.C. CONTROL — DWG. NO. RLX-198C

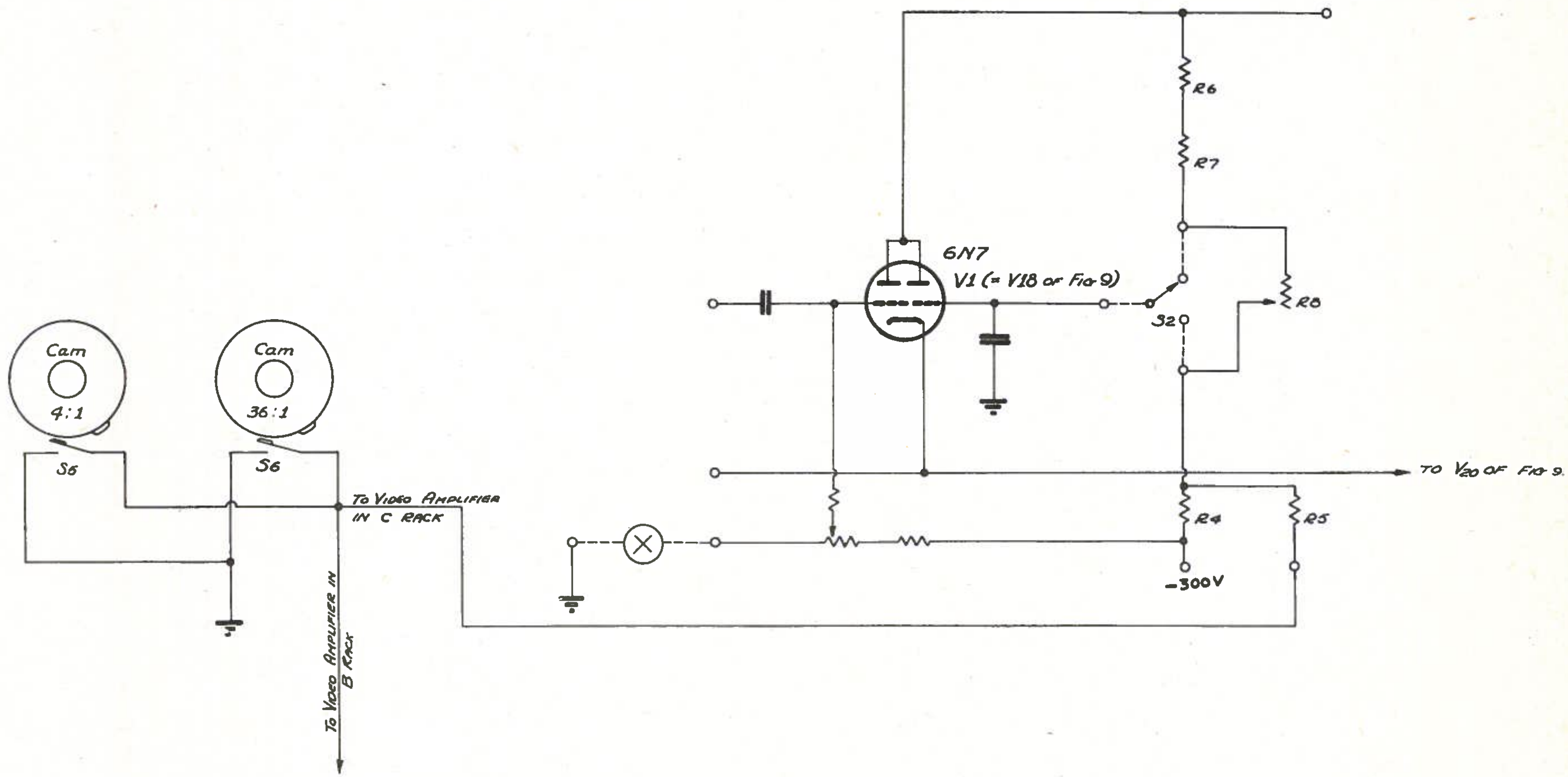


FIG. 15

PRA-92

ITEM	PART NO.	QUAN	MAT'L	DESCRIPTION
DRAWN BY D. Seymour		DATE Dec. 4-43		SUPERSEDES
CHECKED E.H.B.		DATE Dec. 4-43		SCALE
ENG. APPROV.		DATE		FINISH

NATIONAL RESEARCH COUNCIL-RADIO SECTION - OTTAWA CANADA

NAME AZIMUTH MARKER SYSTEM — DWG. NO. RLX-199C

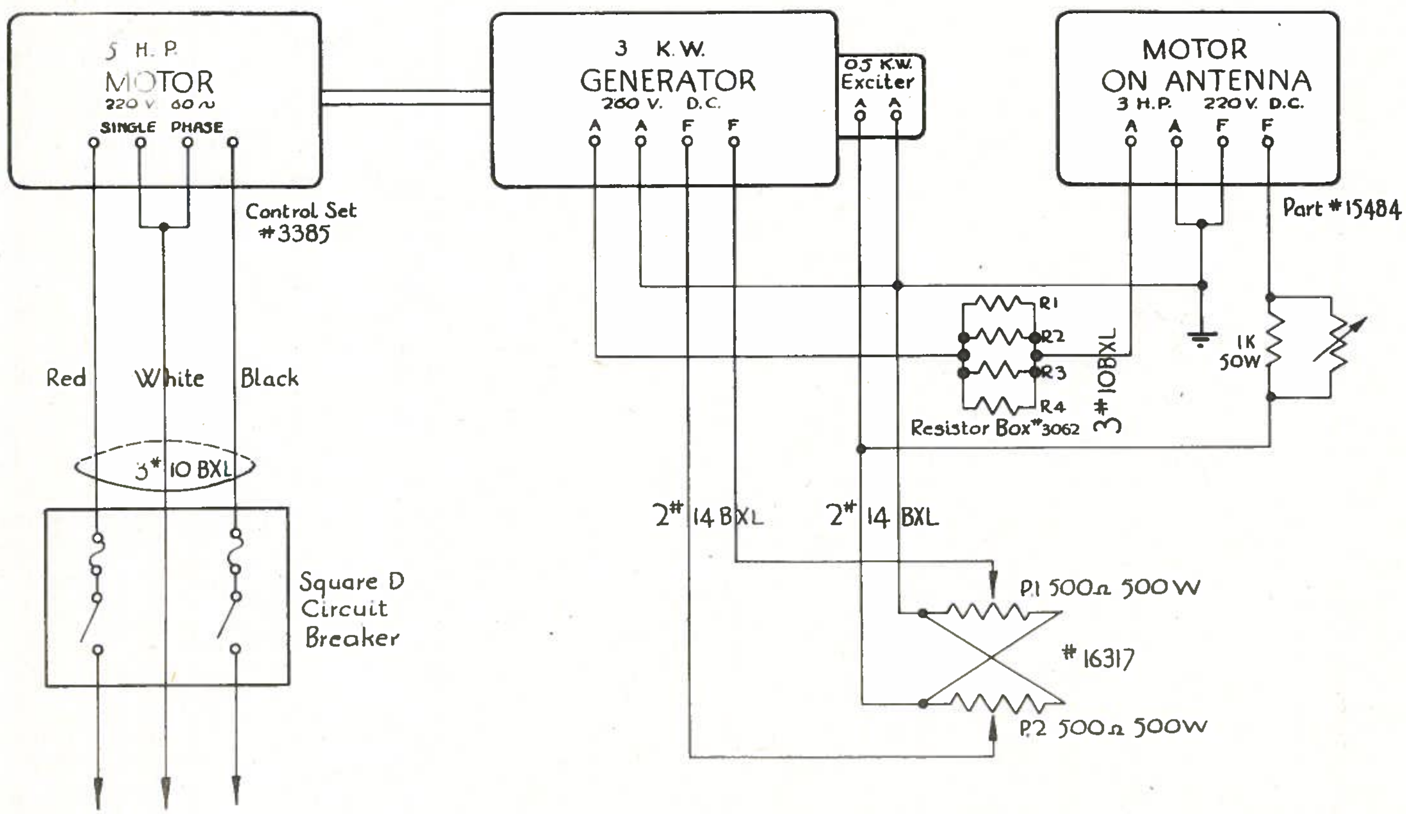


FIG. 16

PRA-92

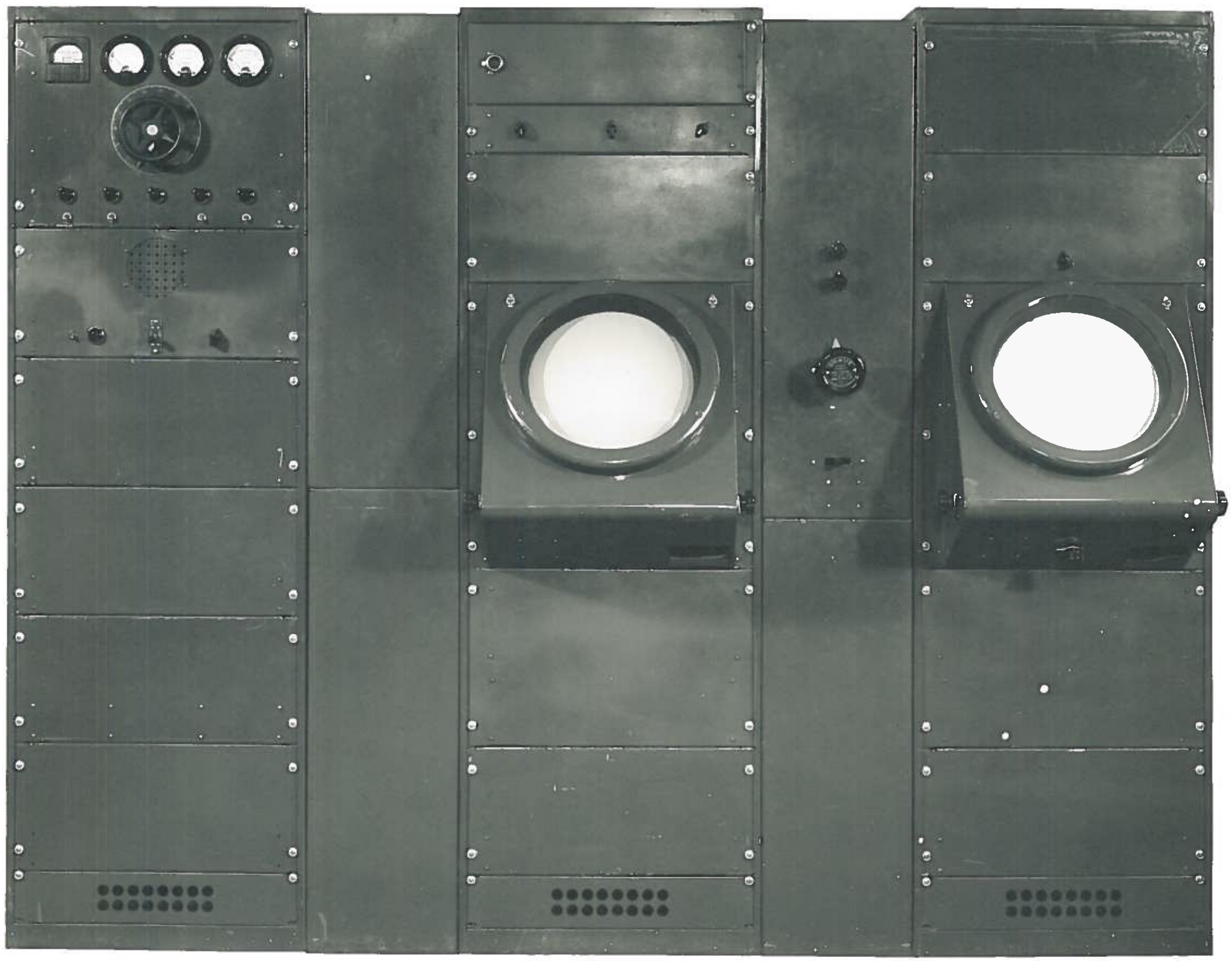
DRAWN BY D. Seymour	DATE Dec 3-'43	SUPERSEDES
CHECKED E.H.B.	DATE Dec 5,'43	SCALE
ENG. APPROV. H. Lewis	DATE	FINISH

NATIONAL RESEARCH COUNCIL - RADIO SECTION - OTTAWA CANADA

NAME: Ward-Leonard Control — DWG. NO. RLX-200C

N.R.C. PHOTO
FIG. 17

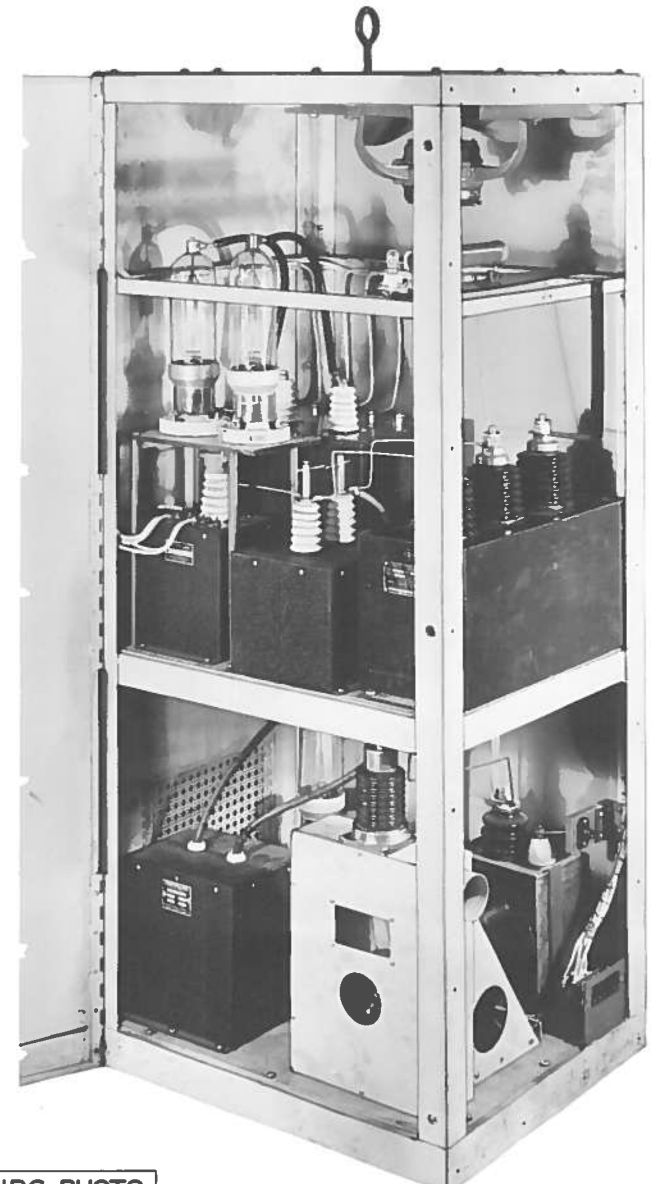
N.R.C. PHOTO
FIG.18



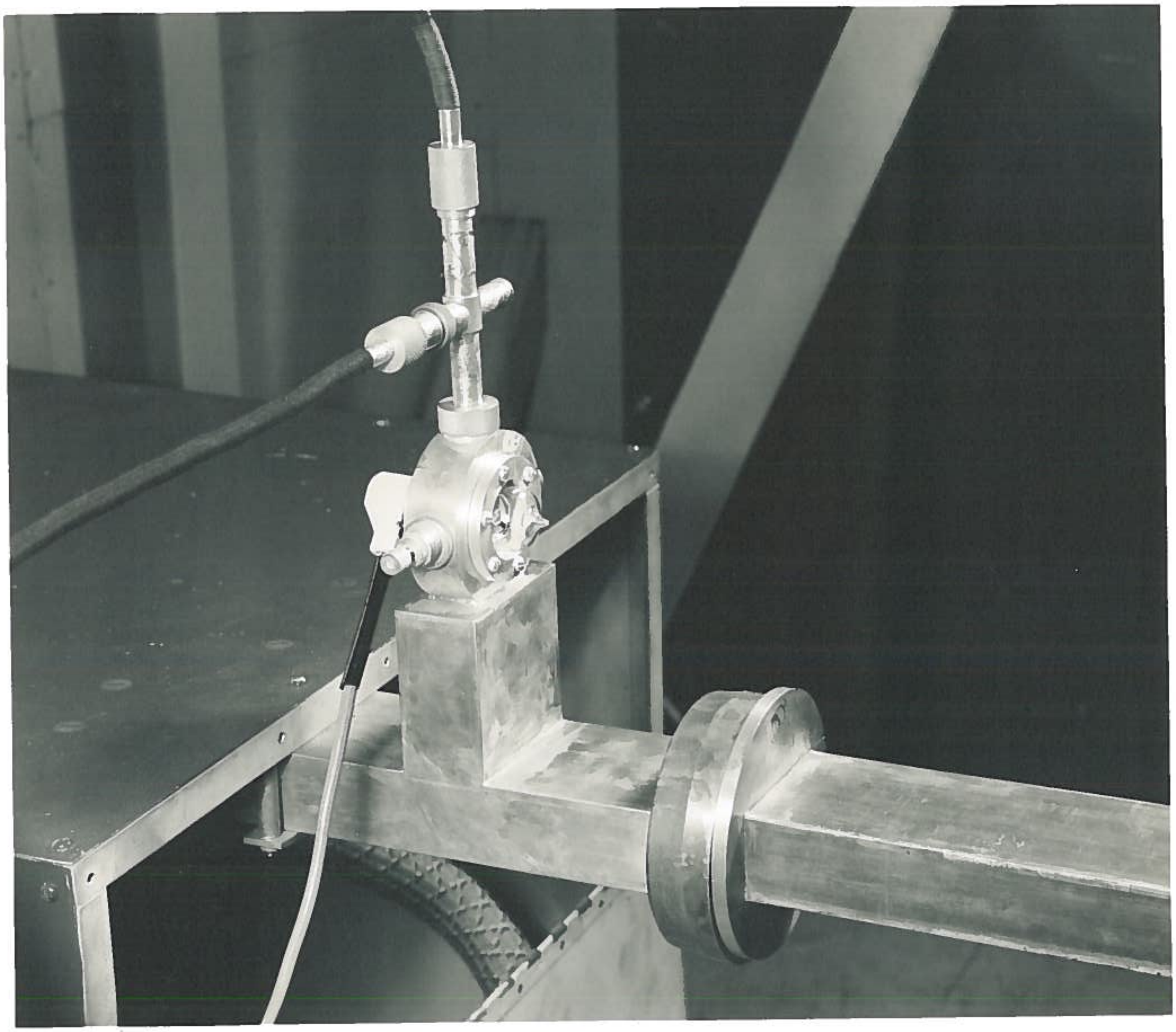
N.R.C. PHOTO
FIG. 19

N.R.C. PHOTO
FIG. 20

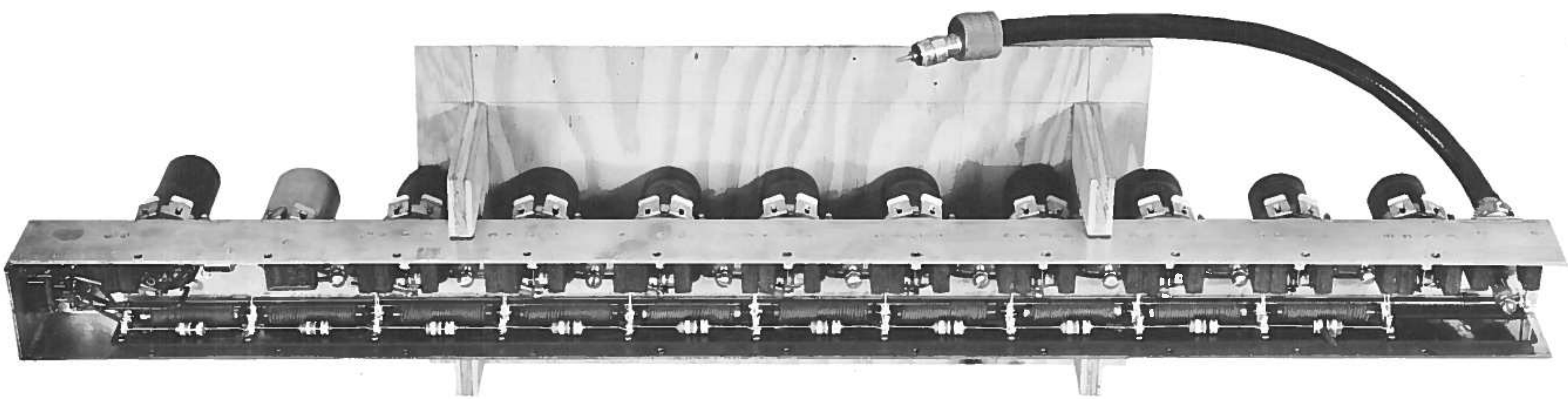
N.R.C. PHOTO
FIG. 21



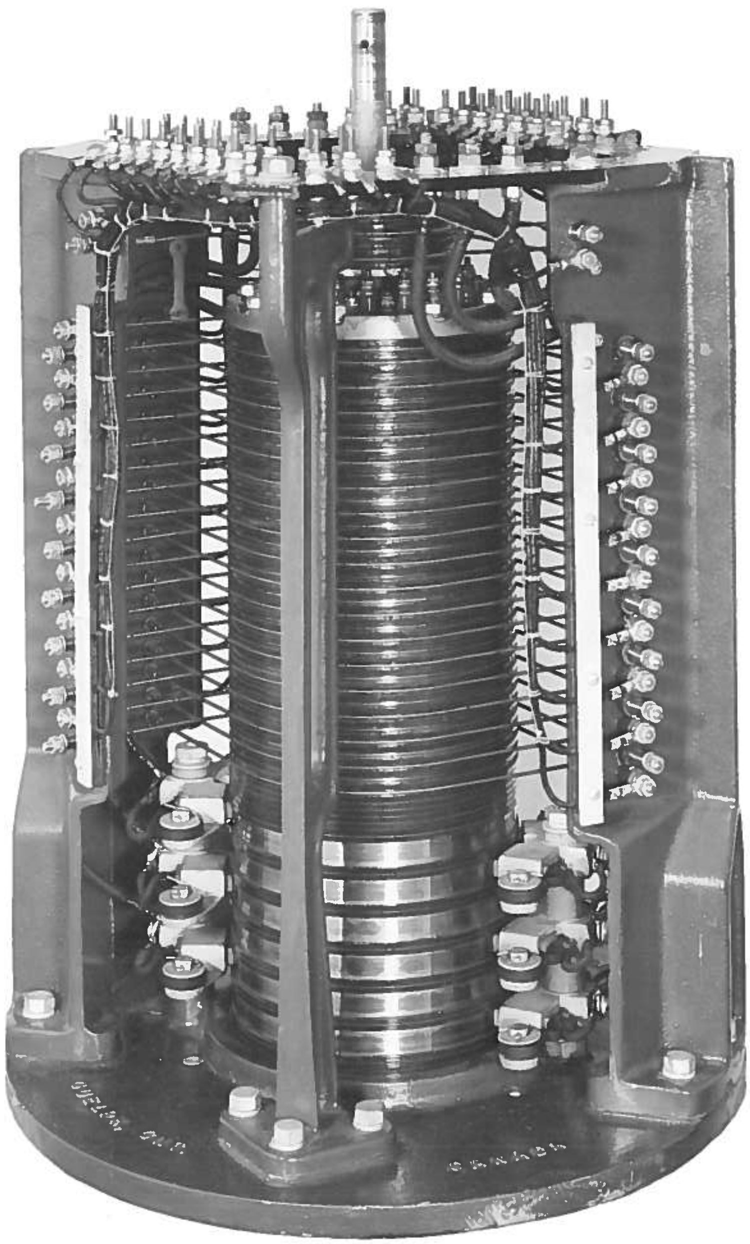
N.R.C. PHOTO
FIG. 21A



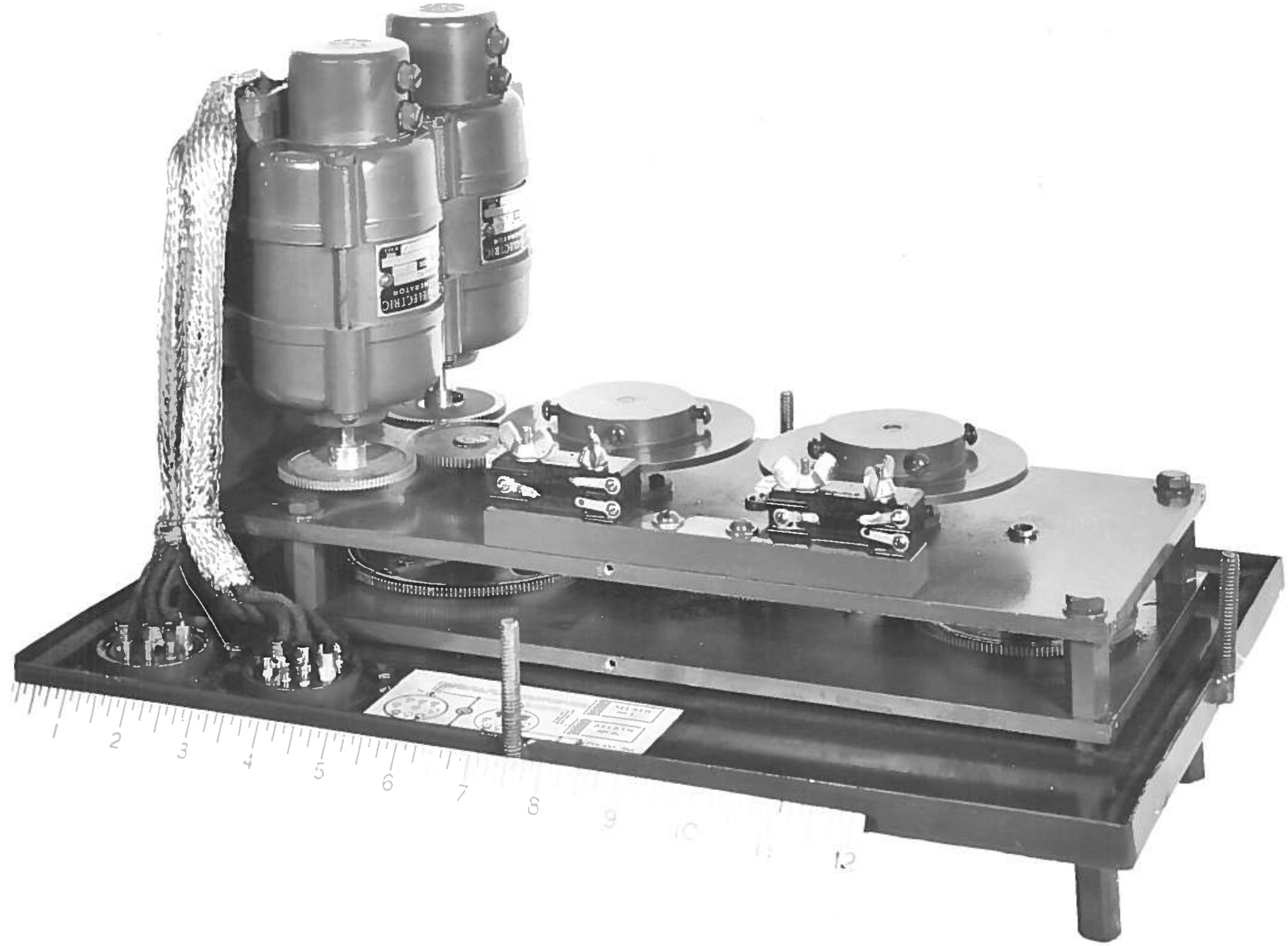
N.R.C. PHOTO
FIG. 22



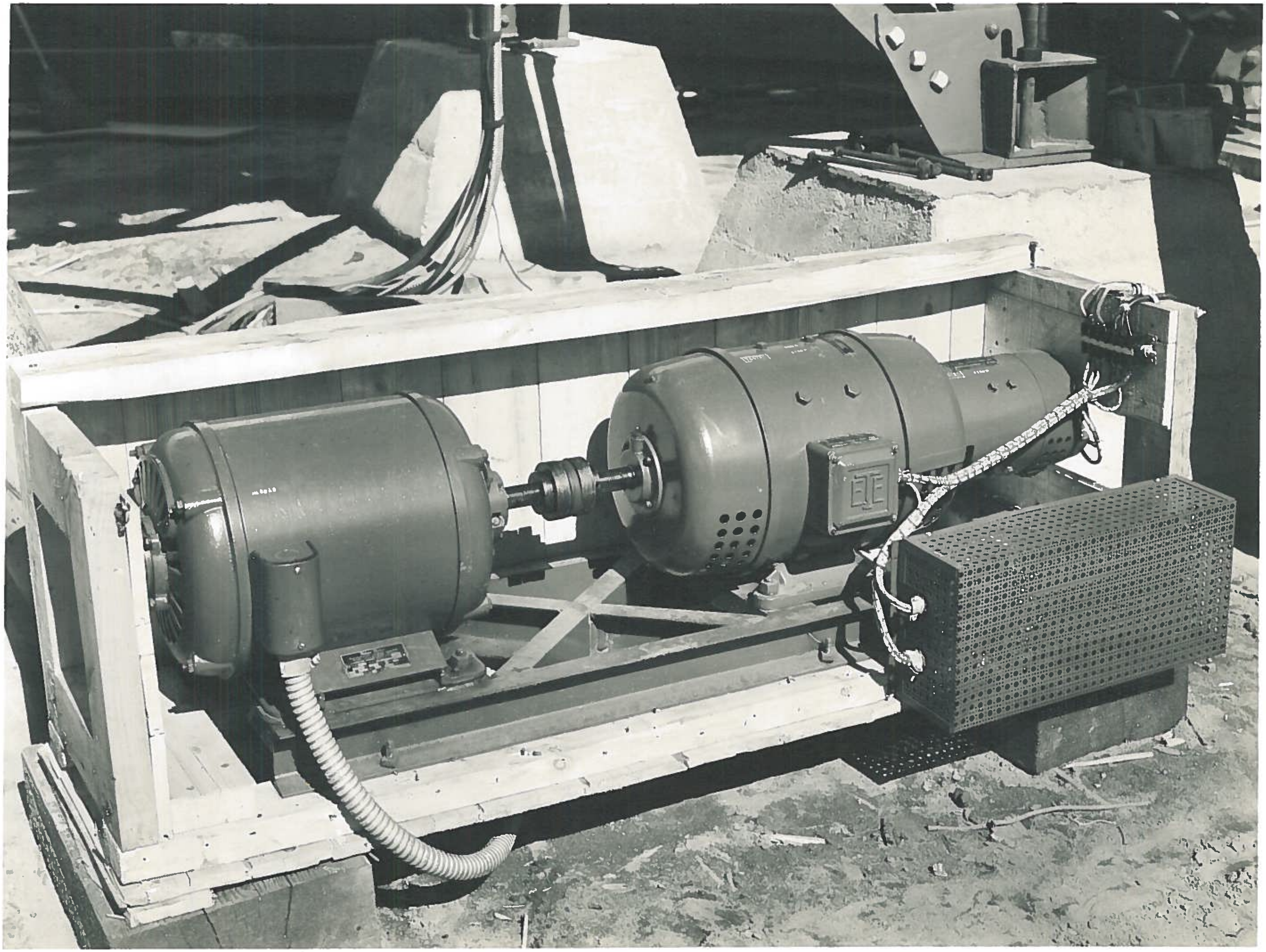
N.R.C. PHOTO
FIG. 23



N.R.C. PHOTO
FIG. 24

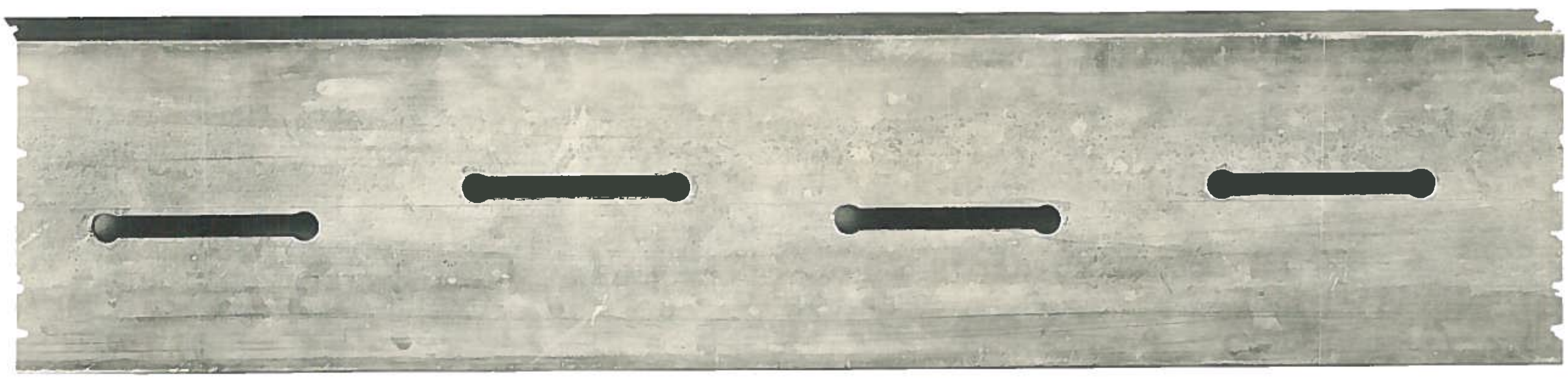


N.R.C. PHOTO
FIG.25



N.R.C. PHOTO
FIG.26

N.R.C. PHOTO
FIG. 27



N.R.C. PHOTO
FIG. 27A