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Report on Present Day Technique
for
Radio Transmission and Reception
in the
Micro-Ray Frequency Band

DEPARTMENT OF THE NAVY BUREAU OF ENGINEERING

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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on Present Day Technique
for
Radio Transmission and Reception
in the
Micro-Ray Frequency Band
(300-3000 megacycles)
with
Suggested Applications for Naval Purposes

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ABSTRACT

This report gives a summary of existing technique for radio transmission and reception in the micro-ray band of frequencies (300-3000 megacycles per second). Following the historical portion, several applications of circuits in this frequency band for Naval purposes are suggested, and a systematic program for investigation and development outlined.

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I HISTORICAL INTRODUCTION

Experimental Investigations

1. The micro-ray band of frequencies as defined in this report covers the range from 300 to 3000 megacycles per second. Experimental investigations of continuous wave oscillations in this frequency band may be considered to date from the discovery by Barkhausen and Kurz (1) of a technique for the production of such oscillations. Their method consisted in placing the grid of a triode at a high positive potential, and adjusting the plate potential to such a negative value that the electrons passing through the grid would tend to oscillate around it until they are eventually captured to form part of the d.c. grid current. Sometime after this work. Gill and Morrell (2 and 3) made a careful study of the phenomenon, and deduced relationships between the electron transit times and the periods of oscillations corresponding to maximum output. There persisted in the literature for some time following this work a tendency to distinguish between Barkhausen-Kurz oscillations, whose frequency was determined chiefly by the voltages placed on the tube electrodes; and Gill-Morrell oscillations, whose frequency was correlated with the natural period of the Lecher frame which was attached to the plate and grid electrodes. Wundt (4) has shown that the system electron stream - Lecher frame should be regarded as two coupled circuits, the coupling taking place through the grid plate impedance. From this point of view, the variation of wavelength with external circuit adjustments and with electrode voltages may be given a complete and satisfactory explanation. It should be remarked here that the power developed by these earlier tubes was extremely small, and the phenomena were of interest chiefly to physicists. Oscillations have been produced recently with conventional feed-back circuits as high as 1200 megacycles per second (5). The tubes were of a special design and will be considered in detail later. Another method for the production of electronic oscillations in the micro-ray band depends on the properties of the magnetron oscillator formerly utilized for oscillations of longer wavelength. Originally produced by Zacek (6), such oscillations have been further studied by Yagi (7) and Okabe (8). In the Japanese type of tube, the plate is split and the tuned Lecher frame attached to each of the anode segments. The magnetic field is parallel to the axis of the filament of the tube. The mechanism of electron oscillation in the magnetron has been clearly outlined by Hollmann (9).

Mathematical Theory

2. In this section are given briefly the equations relating the wavelength of the micro-ray oscillations to the voltages impressed on the electrodes, and the electrode spacings.

(a) Barkhausen oscillations: plane electrodes (10).

$$\lambda = 4\, v_0 \, \frac{1}{\sqrt{2 \frac{e}{m} E_g}} \; \frac{r_2 E_g - r_1 E_a}{E_g - E_a} \qquad (1)$$

where E_a, r_2 = potential of plate re filament, spacing of plate re filament,

E_g, r_1 = potential of grid re filament, spacing of grid re filament,

v_o = velocity of light,

e/m = specific charge of the electron

If E_a and E_g are in volts, and r_2 and r_1 in centimeters

$$\lambda = \frac{2000}{\sqrt{E_g}} \quad \frac{r_2 E_g - r_1 E_a}{E_g - E_a} \quad \text{cm.} \tag{2}$$

(b) Barkhausen oscillations: cylindrical electrodes (10).

It will be assumed here that in the principal mode of oscillation, the flight time from cathode to reversal point near the plate is half the period of oscillation.

$$\lambda = c \cdot \tau = \frac{4 c r_1}{\sqrt{2 \frac{e}{m} E_g \cdot 10^8}} \left\{ f\left(\sqrt{\log \frac{r_1}{r_o}}\right) + g\left(\sqrt{\frac{E_g}{E_g - E_a} \log \frac{r_2}{r_1}}\right) \right\} \text{cm} \tag{3}$$

The functions f and g have the form:

$$f(x) = x\, e^{-x^2} \int_o^x e^{u^2}\, du \qquad\qquad g(x) = x\, e^{x^2} \int_o^x e^{-u^2}\, du$$

Comprehensive tables of these functions covering the range of variables likely to be met in practice are given by Kapzov and Gwosdower (11). If λ is in cm, and the potentials and radial distances are in volts and cm respectively, the expression becomes:

$$\lambda = \frac{2000\, r_1}{\sqrt{E_g}} \left\{ f\left(\sqrt{\log \frac{r_1}{r_o}}\right) + g\left(\sqrt{\frac{E_g}{E_g - E_a} \log \frac{r_2}{r_1}}\right) \right\} \text{cm.} \tag{4}$$

where E_a = potential of plate re filament in volts.

E_g = potential of grid re filament in volts.

r_2 = radius of plate in cm.

r_1 = radius of grid in cm.

r_0 = radius of filament wire in cm.

(c) Magnetron oscillations: cylindrical electrodes (12).

Oscillations are initiated when the plate potential E_a and the magnetic field strength H assume values satisfying the equation:

$$E_a = H^2 \frac{e}{8m} r_a^2 \qquad (5)$$

In practical units: $$E_a = \frac{H^2 d_a^2}{181} \qquad (6)$$

where E_a = plate potential in volts

d_a = plate diameter in cm.

H = magnetic field strength in gauss.

In case the critical conditions are satisfied:

$$\lambda = \frac{12300}{H} \text{ cm. for zero space-charge} \qquad (7)$$

$$\lambda = \frac{16700}{H} \text{ cm. for space charge saturation} \qquad (8)$$

The usual type of oscillation satisfies equation (7) approximately.

II TUBES FOR THE GENERATION OF MICRO-RAY OSCILLATIONS

Conventional Feed-back Oscillators

3. A comprehensive report on tubes intended to operate in conventional circuits for the range of frequencies from 100 - 1000 megacycles was given by Kelly and Samuel (13 and 5). One type of tube mentioned there, when connected in a push-pull combination, gave the following outputs and efficiencies (2 tubes) with 400 volts on the plate:

Frequency (megacycles)	Output (watts)	Efficiency (percent)
300	16	28
400	15	25
500	12	20
600	6	12

The decrease of efficiency with increasing frequency can be attributed largely to the transit time effect; i.e., the development of phase lag between voltage and current in the plate impedance of the tube due to the finite time of flight of the electrons across the filament-plate space. Two small experimental tubes gave the following outputs: 10 watts at 670 megacycles with efficiency of 20 percent, and 1 watt at 1200 megacycles with an efficiency of 10 percent. It should be remarked that these latter tubes were tested at a frequency largely determined by internal structure and connecting wires, and it would not in general be easy to obtain a smooth continuous change of frequency with them by adjustment of tuning elements, as is the case at longer wavelengths. By placing the entire tuning circuit within the glass envelope of the vacuum tube, Kohl (14) has succeeded in producing oscillations of frequency 500 megacycles. A diagram of the tube is shown in the review article of Wagner and Hollmann (15). No power output level is given, but it was probably less than that obtained by Kelly and Samuel. No external adjustment of frequency was possible with this tube. Small tubes, suitable for use at receiver levels, have been constructed and described by Thompson and Rose (16). Oscillations were obtained as high as 1000 megacycles, and the tubes gave appreciable amplification at 400 megacycles.

Barkhausen Oscillators

4. The physics and engineering literature of the past ten years is replete with articles describing experiments with tubes operating in the Barkhausen-Kurz circuit. Inasmuch as Naval interest in such experiments must necessarily be confined to those furnishing reliable data as to power output, transmission, and reception levels, etc., only articles containing such data will be cited. Kelly and Samuel (14) gave power output and efficiency data for several tubes of the so-called "spiral grid" type operating in the Barkhausen Kurz circuit. The efficiency in all cases was about 1%, and the power output varied from 3 or 4 watts for the 500 megacycle tube to about 0.1 watt for the 2500 megacycle one. A type of positive grid oscillator designed to operate over a band of frequencies from 500 to 550 was also cited, the grid being of the "squirrel-cage" type. The output varied from 8.5 watts at 580 megacycles to 4.5 watts at 500 megacycles; the efficiency varying between 5.5 and 6.0 percent. Herriger (17) gave detailed measurements on a tube manufactured by the Telefunken Company for use in the positive grid Barkhausen circuit and probably representative of European design. The tube operated over a frequency range of 400 to 550 megacycles. At 550 megacycles, the power output for optimum adjustment of the operating parameters was about 3.3 watts, and the efficiency 4 percent. Pierret (18) has obtained about 0.1 watt from a French T M C tube with about 10 watts input, the frequency being approximately 1670 megacycles. The micro-ray tube designed by Clavier (19) for use on the 1700 megacycle circuit across the English Channel was of the spiral grid type and was stated (20) to give 0.5 watt output at this frequency, the efficiency being about 2 percent. Kozanowski (21) has reported a circuit using two Type 852 tubes in a type of push-pull circuit with the positive grid connection. He obtained an output of 5 watts at 460 megacycles with an efficiency of 2.5 percent. Marconi (22) reported a similar push-pull circuit operating on a frequency of 600 megacycles, and with comparable power output and efficiency.

Magnetron Oscillators

5. A comprehensive study of the magnetron oscillator has been made by Megaw (23) with citations from contemporary investigators. Kilgore (24) reported the following values for split-anode magnetrons: Tube #1, 7 watts output at 700 megacycles with 8 percent efficiency; Tube #2, 2 watts output at 1500 megacycles. Subsequent to the publication of his paper, a small tube with self-contained tuning circuit was designed to operate at 3120 megacycles, the output being about 0.5 watt. Posthumus (25) reported a new type of split-anode magnetron having 4 plates. The output ranged from 40 watts at 500 megacycles to 80 watts at 200 megacycles with efficiencies approximating 50%. In another mode of oscillation 30 watts power output at 730 megacycles was obtained, also at high efficiency. Ponte (26) reported a split-anode magnetron with a useful power output of 25 watts at 400 megacycles, with efficiency of between 40 and 50 percent.

III TRANSMITTING AND RECEIVING TECHNIQUE FOR MICRO-RAYS

Reflector Theory

6. The physical dimensions of tuned half wave radiators in the microray frequency range are such as to permit very sharp focussing of the energy radiated in the desired direction by means of appropriately situated reflectors or reflecting elements. For radiation in the frequency range 300 to 1000 megacycles, such reflectors would take the form of arrays of half-wave antennae, disposed either in a flat curtain or in a parabolic arrangement. For radiation at frequencies of 2000 megacycles or higher, paraboloidal or cylindrico-parabolic reflectors of sheet metal could be utilized. The gain in energy transfer of a paraboloidal reflector may be approximately doubled by placing a small hemispherical reflector in front of the radiating antenna to direct the forward radiation from the antenna back on the parabolic reflector, whence it is reflected in the desired direction. Some illustrative examples of the gain obtained by the use of reflectors are given below. Theoretical formulae are available only in the cases of paraboloidal reflectors (27) and linear antenna arrays (29). In the other cases, examples representative of those most likely to be encountered in practice have been taken from the experimental work of Köhler (28). The gain factor in field strength is given along the axis of projection, together with its equivalent in decibels. The angle θ' corresponding to the angular width of the beam in the horizontal plane measured from the 50 percent field strength boundary is also recorded. Data for linear arrays were taken from Southworth's article (29).

(1) Paraboloidal Reflector (Sheet Metal) at Transmitting Station: (Fig.1)

(Antenna in aperture plane: optimum condition)

$$G = \frac{\pi R}{\lambda}$$

$$= 20 \log_{10} \frac{\pi R}{\lambda} \text{ decibels}$$

$$\theta' = 1.094 \sin^{-1} \frac{.61\lambda}{R}$$

R = radius in centimeters of circle in aperture plane

λ = wavelength in centimeters of radiation

(2) Paraboloidal and Hemispherical Reflectors at Transmitting Station: (Fig.2)

$$G = \frac{\sqrt{2}\,\pi R}{\lambda}$$

$$= 20 \log_{10} \frac{\sqrt{2}\,\pi R}{\lambda} \text{ decibels}$$

$$\theta' = 1.094 \sin^{-1} \frac{.61\,\lambda}{R}$$

(3) Paraboloidal and Hemispherical Reflectors at Transmitting and Receiving Stations: (Fig.3)

$$G = \left(\frac{\sqrt{2}\,\pi R}{\lambda}\right)^2 = \frac{2\pi^2 R^2}{\lambda^2}$$

$$= 20 \log_{10} \frac{2\pi^2 R^2}{\lambda^2} \quad \text{decibels}$$

$$\theta' = 1.094 \sin^{-1} \frac{.61\lambda}{R}$$

(4) Cylindrico-parabolic Reflector (Sheet Metal) at Transmitting Station: (Fig.4)

(Aperture 2.5 λ, width 3λ)

$G = 5$

$= 14$ decibels

$\theta' = 15^\circ$

(5) Cylindrico-parabolic Reflectors at Transmitting and Receiving Stations: (Fig.5)

(Aperture 2.5 λ, width 3λ)

$G = 5^2 = 25$

$= 28$ decibels

$\theta' = 15^\circ$

(6) Cylindrico-parabolic Array of Untuned Wires at Transmitting Station: (Fig.6)

(Aperture 3λ, width 3 λ)

$G = 4.7$

$= 13.5$ decibels

$\theta' = 15^\circ$

(7) Cylindrico-parabolic Array of Untuned Wires at Transmitting and Receiving Stations: (Fig.7)

(Aperture 3λ, width 3λ)

$G = (4.7)^2 = 22$

$= 26.9$ decibels

$\theta' = 15^\circ$

(8) Cylindrico-parabolic Array of Tuned Wires at Transmitting Station:(Fig.8)

(Aperture 3λ, width 3λ)

$G = 3.3$

$= 10.4$ decibels

$\theta' = 17^\circ$

(9) Cylindrico-parabolic Array of Tuned Wires at Transmitting and Receiving Stations: (Fig.9)

(Aperture 3λ, width 3λ)

$G = (3.3)^2 = 10.9$

$= 20.8$ decibels

$\theta' = 17^\circ$

In the above cases of parabolic wire arrays, the spacing of the wires was about λ/30 for the untuned arrays and λ/8 for the tuned arrays. The antenna at the focus was 3λ/4 from the wire immediately behind it.

(10) Plane Metallic Reflector (Sheet Metal) at Transmitting Station: (Fig.10)

(Reflector 2.5λ square; antenna $\frac{5\lambda}{4}$ in front)

$G = 2.7$

$= 8.6$ decibels

$\theta' = 27^{\circ}$

(11) Plane Metallic Reflector at Transmitting and Receiving Stations: (Fig.11)

(Reflector 2.5 λ square; antenna $\frac{5\lambda}{4}$ in front)

$G = (2.7)^2 = 7.3$

$= 17.2$ decibels

$\theta' = 27^{\circ}$

(12) Array of Two Antennas spaced $\lambda/2$ radiating in phase with Two Reflectors spaced $\lambda/4$ behind at Transmitting Station: (Fig.12)

$G = 2.24$

$= 7$ decibels

$\theta' = 80^{\circ}$ (approx)

(13) Array of Two Antennas and Two Reflectors phased as above at both Transmitting and Receiving Stations: (Fig.13)

$G = (2.24)^2 = 5.0$

$= 14$ decibels

$\theta' = 80^{\circ}$ (approx)

(14) Array of Four Antennas spaced $\lambda/2$ radiating in phase with Four Reflectors spaced $\lambda/4$ behind at Transmitting Station: (Fig.14)

$G = 3.2$

$= 10$ decibels

$\theta' = 30^{\circ}$ (approx)

(15) Array of Four Antennas and Four Reflectors phased as above at both Transmitting and Receiving Stations: (Fig.15)

$G = (3.2)^2 = 10.2$

$= 20$ decibels

$\theta' = 30^{\circ}$ (approx)

Radiation Systems

7. Where a single radiating element is associated with a passive reflector, the antenna is usually of the tuned half-wave type, fed by either a concentric tubing or two-wire transmission line. Since the output impedance of a tube generating micro-ray oscillations is difficult to measure, it is preferable to use a tuned line, with a trombone length adjustment. The line being only two or three wavelengths long, skin effect and radiation losses are small, even for the very high frequencies. There has been a tendency in experimental work on micro-ray communication systems to use identical set-ups for transmission and reception. More thorough study will probably result in specialized receiving tubes differing in structure from those used for transmission, and making possible more compact and portable receiving equipment. In case antenna arrays are used, the proper phase distribution may be obtained by direct feed with straight two-wire tuned transmission lines.

Reception

8. The receiving station of a micro-ray transmission circuit usually has a reflector system identical with that used at the transmitter. The energy is focussed on the receiving antenna, a half-wave doublet, and the consequent voltage transferred by a transmission line to a suitable rectifying device. Detection can be accomplished with a crystal, a diode tube rectifier, a super-regenerative Barkhausen oscillator, or a so-called "Carrara" detector. Crystal rectification is subject to the variation in sensitivity which characterizes its use in other frequency bands. The diode rectifier is relatively insensitive on account of the inability of the electron stream to follow without phase lag the impressed voltage. In the super-regenerative arrangement, a Barkhausen oscillator tube has its electrode potentials adjusted so that it is at the threshold of oscillation on the transmitted frequency. Such a tube is quite sensitive as a detector but requires excellent regulation of its voltage supply for constant sensitivity. The "Carrara" detector consists of a triode having cylindrical symmetry, in which the grid is at a fairly high (non-critical) positive potential, and the plate slightly positive with respect to the filament. The plate current-plate voltage characteristic is curved in this region, and fairly efficient plate rectification takes place if the signal is impressed on the plate. The circuit is more efficient than the ordinary diode, because rectification takes place in the space between the anode and the virtual cathode near the plate, and since this space is very narrow, the phase lag is correspondingly reduced.

IV PROPAGATION OF MICRO-RAYS THROUGH SPACE

Diffraction Effects

9. A concise solution of the problem of the diffraction of micro-rays below the horizon has been given by Epstein (30). His demonstration showed that considerable signal might persist for distances where the receiving point was far below the geometrical horizon for transmission on 550 megacycles. Computed data were given for the conditions existing during Marconi's latest tests on 55 cm wavelength (31) and the agreement with observed readings shown. It may be conservatively stated, however, that, on account

of irregularities in the surface at the horizon, reception in the optical shadow is subject to large variations in signal strength, and that reliable two-way communication is practically limited to the optical horizon. This optical horizon may, however, extend far beyond the geometrical one on account of refraction effects. These are considered in the next section.

Refraction Effects

10. A general examination of the effect of varying atmospheric conditions on the propagation of ultra-short radio waves through space has been made by Jouast (32). Following a general non-mathematical explanation of the phenomena as related to the temperature, pressure, and relative humidity, a detailed study followed of the experimental results obtained on the France-Corsica ultra-short wave radio channel. When a micro-ray beam is projected at a small angle with the horizontal, it follows approximately a circular path, whose radius of curvature is m times that of the earth. Under extreme conditions of temperature and humidity, this constant may vary between wide limits. Jouast gave an average value of 10.5 for some visual tests off the coast of Brittany, although extreme values from 15 to 7 were observed, together with some negative ones. The value for the France-Corsica circuit was about 5. Schelling, Burrows, and Ferrell (33) quoted values from Humphreys (34) which gave an average value of m equal to 4. Quoting from reference (33), p.441:

> "In ultra-short wave work we are almost always concerned with propagation in a nearly horizontal direction. The curvature of the ray is $1/p$ while that of the earth is $1/r_o$. We are interested, however, in the relative curvature, which we shall call $1/r_e$. If, instead of using simple rectangular coordinates, we transform to a coordinate system in which the ray is a straight line, the curvature of the earth will become $1/r_e$, which is $1/r_o - 1/p$. The equivalent radius of the earth would be
>
> $$r_e = r_o \left(\frac{1}{1 - r_o/p} \right)$$
>
> and is therefore greater than the actual radius of the earth by a factor which in this case is 1.33. This fictitious radius is therefore 8500 kilometers instead of 6370 kilometers. Since in the new system of coordinates, the ray is straight, the new equivalent dielectric is to be assumed constant, and equal substantially to unity. "

A table has been computed (Appendix B) giving the variation in effective range with height above ground for $m = 4$.

Absorption Effects

11. No reliable data are at hand regarding attenuation of ultra-short wave signals by absorption or scattering along the path of projection. Scattering phenomena such as are encountered in the attenuation of a light beam are

unlikely, since no atomic or molecular resonances would have periods as large as those of waves in the decimeter region. Potapenko (35) has performed some experiments on the projection of micro-rays through chambers in which artificial fog was created, and stated that large absorption took place at wavelengths below 5 cm. Since communication technique will probably be confined for some time to wavelengths of 10 cm (3000 megacycles) or above, this is of academic interest only. It should be remarked, however, that variations in received signal strength may appear to be due to absorption under certain circumstances, although the true explanation is to be found in refractive effects. It is conceivable, for instance, that a smoke screen would cause some weakening of the received signal, but the explanation would probably lie in the kink produced in the beam axis by the abrupt change in refractive index in the hot gases constituting the screen.

V. APPLICATION OF MICRO-RAYS IN THE NAVAL SERVICE

Limited Range Ship-to-Ship Communication

12. The possibility of confining micro-ray transmission within a very narrow beam by the use of suitable reflectors suggests the utilization of such beams for secret two-way communication and for recognition signal purposes. Since the sharpness of the beam is a direct function of the size of the reflector system, the choice of wavelengths for such transmission is governed chiefly by the space limitations on reflector size imposed by shipboard conditions. On account of the less critical adjustments required for the micro-ray systems of longer wavelength, and the responsibilities imposed on such circuits under battle conditions, operation on wavelengths within the 40 to 80 cm band would be preferable. As such systems may be modulated either with single audio modulation or with double audio and intermediate frequency modulation, any of the various privacy schemes may be employed in the modulation.

Limited Range Ship-to-Shore Communication

13. Applications under this heading include rotating or fixed beacons for homing or danger signals or for hydrographic surveying in foggy weather. By coding the modulation on different stations, it would be possible to provide sharply defined beams for the guidance of ships through mine fields or through shoal water under conditions of poor visibility. The necessity of using automatic volume control on the receiver to compensate for motion of the ship would prevent discrimination between the axis of the beam, and directions slightly off the axis but providing signal strength within the range of the automatic volume control. This fact would in turn necessitate the maintenance of a very sharply directed beam in order to minimize weaving about the axis of projection. Such sharply defined beams are only possible with transmission on 10 to 20 cm wavelength in conjunction with suitable sheet metal paraboloidal reflectors.

Coastal Point-to-Point Communication

14. Under this heading might be suggested emergency channels between coast defense points if regular wire channels are cut. Suitably camouflaged

reflector systems could be made indistinguishable at moderate distances from the fortifications, and maintenance of communication could be effected under smoke and haze conditions where optical signalling was impossible. Privacy considerations would make desirable a sharply focussed beam, requiring operation in the 10 - 20 cm wavelength band.

Detection of Enemy Ships by Reflection or Interception of Beam

15. The Navy has had under consideration for some time the problem of detecting the presence of enemy ships by reflection or interception of a sharply defined radio beam. The quasi-specular character of the reflection of energy transmitted on the shorter wavelengths means that energy from a flat metallic surface would be received back only very near the axis corresponding to geometrical reflection. This in turn would mean that with fixed positions of the transmitter and receiver aboard ship, reflected energy would be incident on the receiving antenna only for particular orientations of the enemy ship. If a wavelength around 60 - 100 cm were used, the reflection would be no longer specular, but would be governed by diffraction considerations. The reflection in general would take place over a wider angle, and would not be so critically dependent on geometrical orientation. Hence the longer micro-ray wavelengths would be more suitable for this purpose.

Aircraft-to-Ground Communication

16. Research is being carried on at the present time at the Naval Research Laboratory on the development of an alti-drift meter for use on Naval aircraft. Due primarily to space limitations on reflector size, work is being concentrated on apparatus intended to function on a frequency of 3260 megacycles. Details regarding the progress of this work may be found in NRL Report No. R-1111, "Micro-Ray Radio Apparatus for Aircraft Alti-Drift Meter Equipment". Beams using coded audio modulation might be used for ground position location or for danger beacons, functioning analogously to present light beam installations, but with the advantage that transmission through clouds and fog would be possible. The wavelengths to be used would depend on the sharpness of beam desired. No definitive recommendations can be made on this point.

VI. A PROGRAM OF MICRO-RAY DEVELOPMENT FOR THE NAVAL SERVICE

General Considerations

17. In the event a general investigation of the applicability of micro-rays in the Naval Service were contemplated, the allocation of priority of projects in the program would be a matter for decision by the Bureau of Engineering. There is no intention in the present report to suggest such a sequence of projects. The aspects of micro-ray circuits in general about which engineering information is at present lacking are pointed out below, together with recommendations for research which will furnish such information.

Detection of Micro-Rays

18. There is urgent need of investigation of detection thresholds for all frequencies in the micro-ray band. Such work could be carried on with transmitter tubes now available, since detection may be studied with trans-

mission over small distances. The reflector sizes should be so chosen as to produce field strengths at the receiver comparable with those produced over longer distances with larger reflectors. It would be desirable to construct several types of detector tubes, and study their relative efficiency. Since these tubes operate at low levels, their size and cost should be moderate. Such a study would be extremely valuable, as it would be possible on the basis of the results obtained to state definitively the point-to-point transmission range possible for a transmitter tube of given power, operating in conjunction with specified reflector systems.

Constant Voltage Power Supply Systems

19. Considerable progress has been made on such systems in connection with the work described in NRL Report No. R-1111, cited in par.16. Further work is desirable to make more exhaustive studies of the relative merits of the various circuits, and to modify the design where possible to provide greater portability and circuit simplification.

Changes in Transmission Efficiency due to Variations in Atmospheric Conditions.

20. Quantitative knowledge of the behavior of a micro-ray point-to-point circuit under varying atmospheric conditions would provide information of the highest importance to the Navy. Such a circuit could be set up along an optically clear path between the Naval Research Laboratory at Bellevue and the Naval Radio Station at Arlington. By using a recording voltmeter on the output of the receiving circuit, a continuous record of the varying transmission efficiency may be obtained. If desired, a small smoke screen could be laid down across the path of the beam and the effect observed.

High Power Transmitter Tubes

21. For certain applications in which reflection of the micro-ray beam is utilized, it is obvious that after detector thresholds have been reached, greater range is possible only by the use of higher power transmission. Progress along this line is being constantly made by foreign experimenters, and could probably be made also by developmental work done on the Naval program.

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Table 1

Micro-Ray Horison Distance vs. Height of Transmitter

Optical horizon computed with radius of curvature of ray equal to four times radius of earth; earth's radius = 6370 km., fictitious radius = 1.33 x 6370 = 8500 km.

Transmitter Height above Sea Level (meters)	Geometrical Horizon (kilometers)	Optical Horizon (kilometers)
10	11.3	13.0
20	16.0	18.4
30	19.6	22.6
40	22.6	26.1
50	25.2	29.1
60	27.6	32.0
70	29.8	34.5
80	31.9	36.9
90	33.8	39.1
100	35.6	41.3
200	50.5	58.4
300	61.9	71.5
400	71.4	82.5
500	79.8	92.3
1000	113.0	130.4

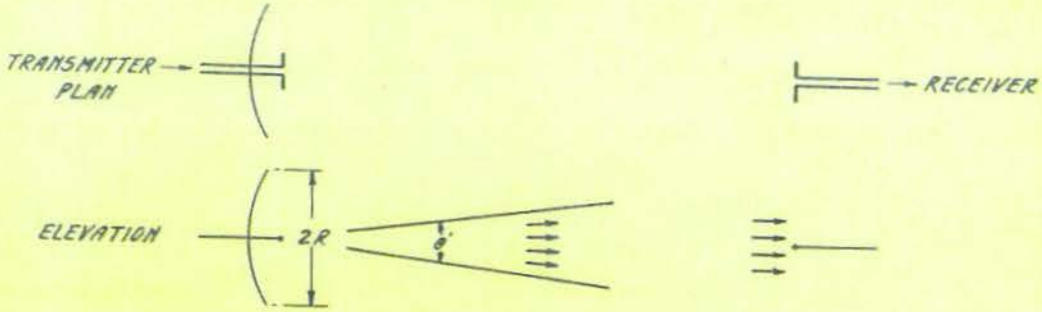


FIG. 1

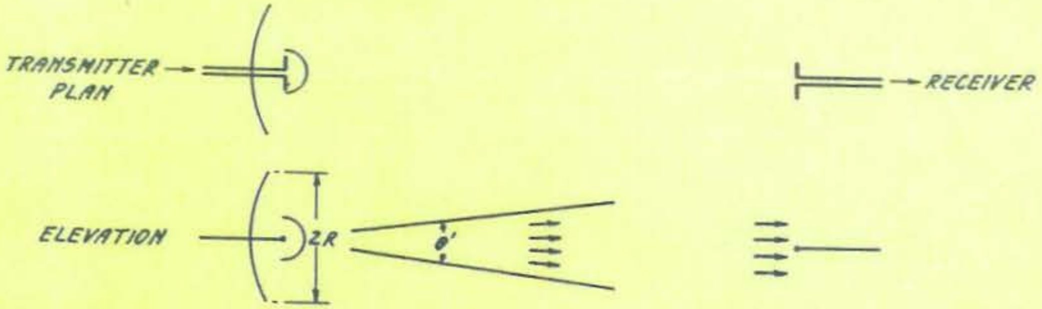


FIG. 2

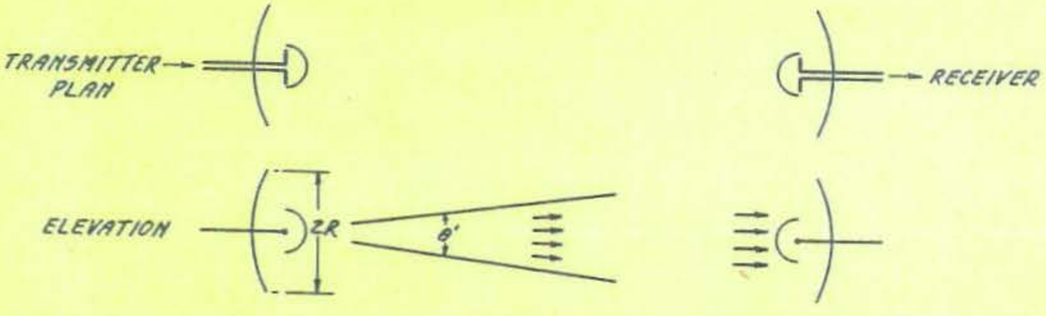


FIG. 3

PLATE I

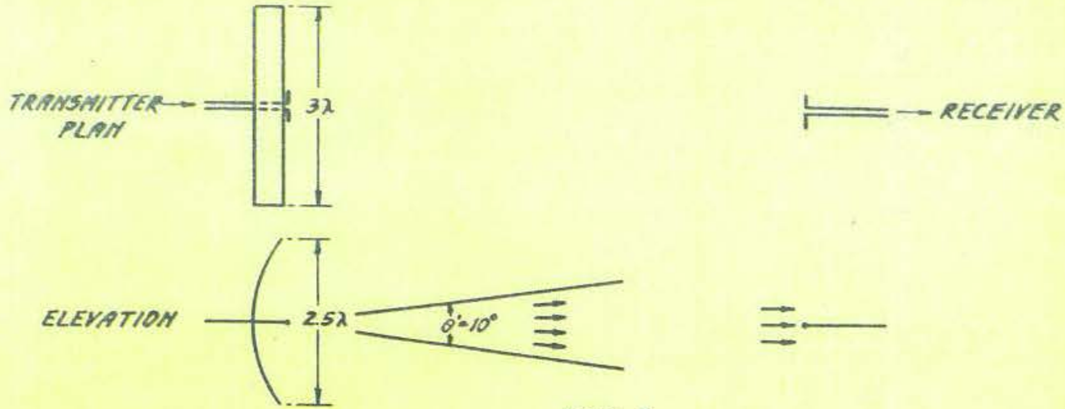
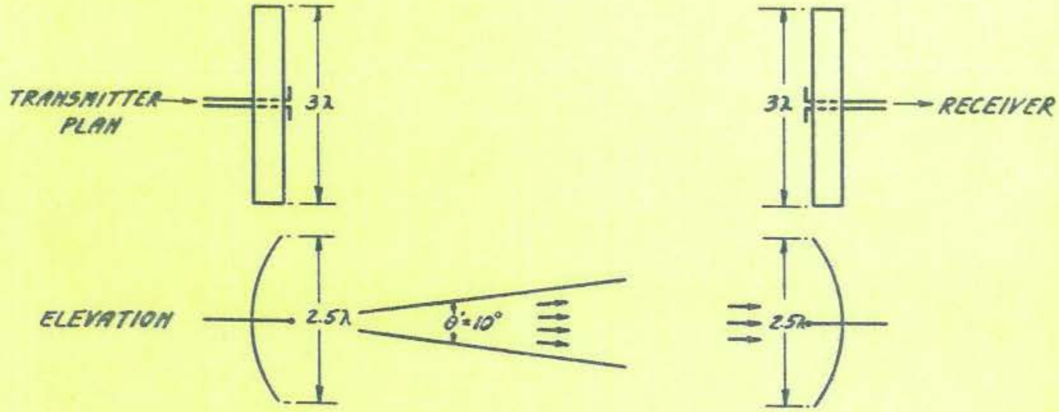


FIG. 4



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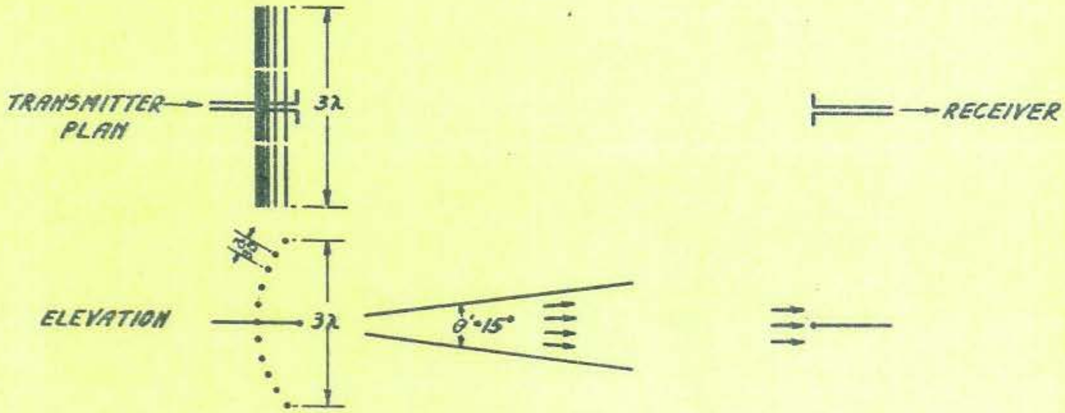
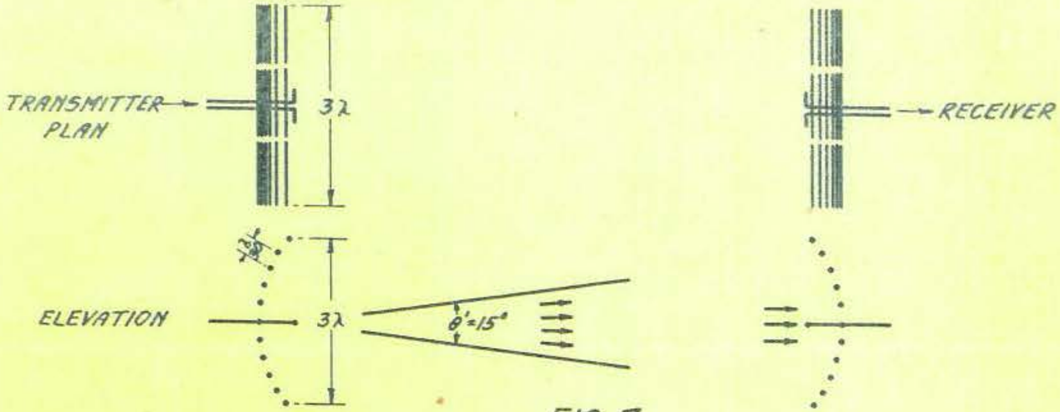


FIG. 6

PLATE 2



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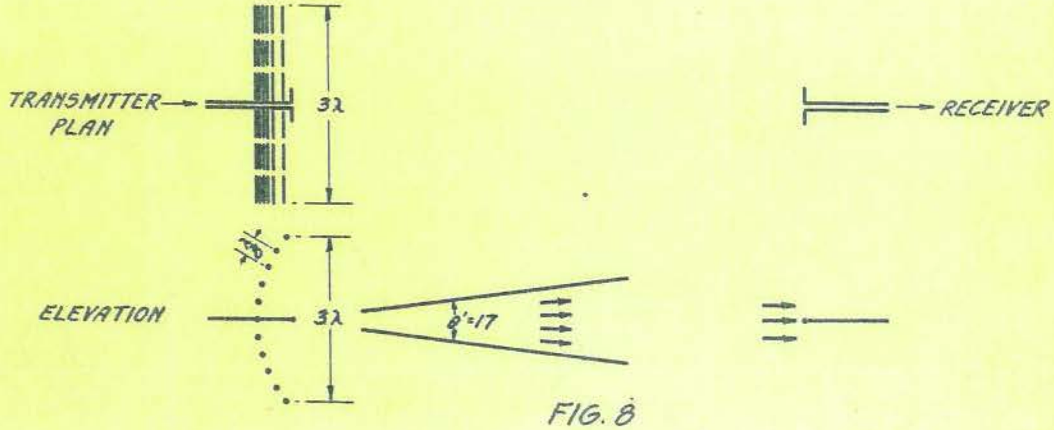

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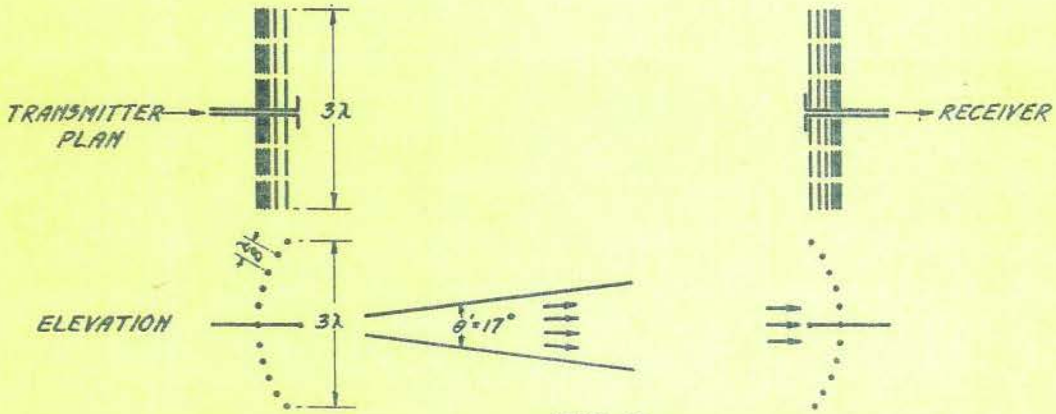

FIG. 9

PLATE 3

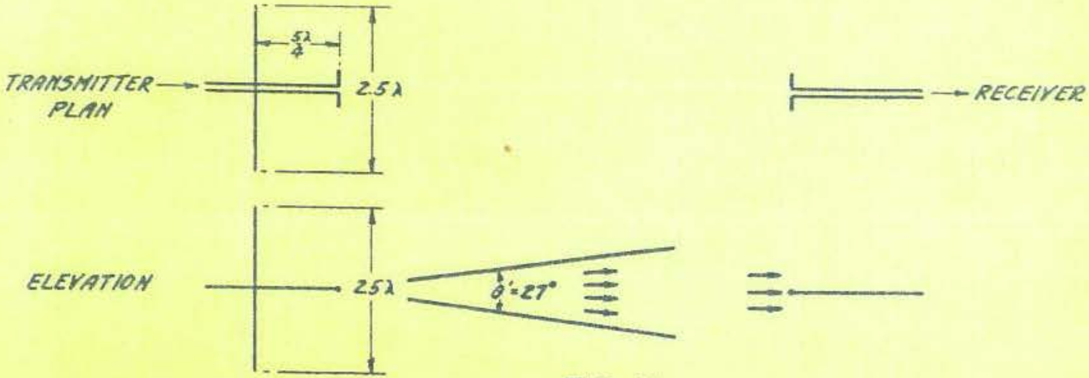

FIG. 10

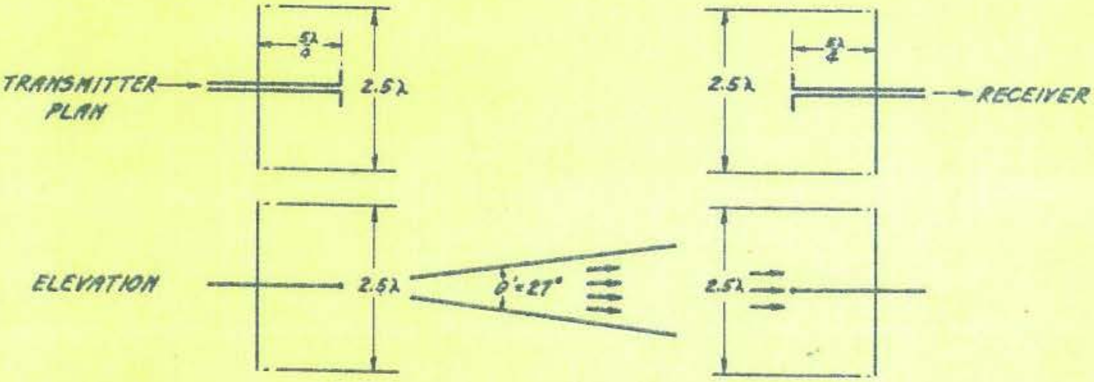

FIG. 11

PLATE 4

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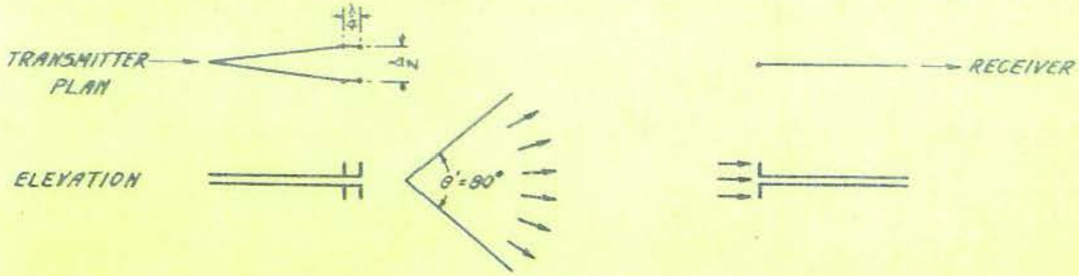

FIG. 12

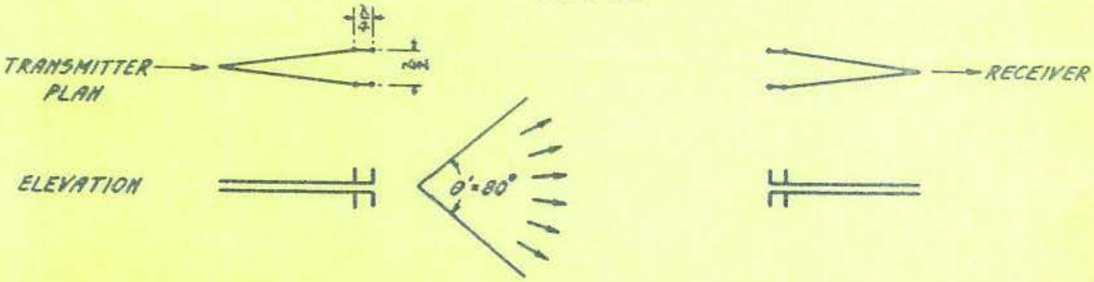

FIG. 13

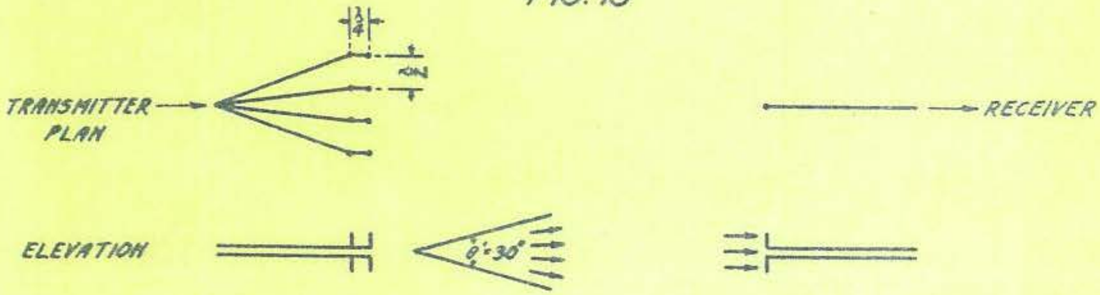

FIG. 14

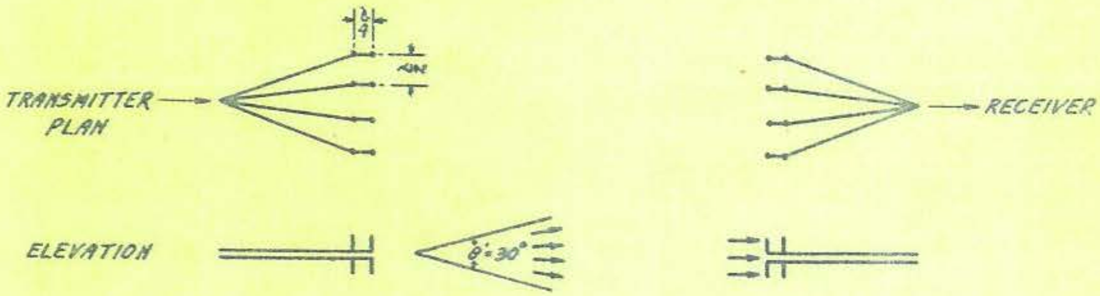

FIG. 15

PLATE 5

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