The National Association of Broadcasters

NATIONAL PRESS BUILDING ★ ★ ★ ★ ★ WASHINGTON, D. C.

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NAB REPORTS ★ ★ ★ ★ ★

Vol. 1 - - No. 22
JULY 26, 1933

ANTENNAS

Increasing agitation for power increases for regional and local stations, and for revision of the Federal Radio Commission quota system, has brought attention to the subject of antenna systems used by broadcasting stations.

While there is much information available, a concise compilation of data pertinent to broadcasting uses has not been available previous to the preparation of a report of a subcommittee (consisting of J. C. McNary, NAB chief engineer, and T. A. M. Craven, Washington consulting engineer) to the Committee Preparing for the North American Conference. Inasmuch as this report is comprehensive in its outline of the effects of antenna configuration, power, and operating frequency, its publication is considered timely.

The report follows:

ASSUMPTIONS

For the purpose of calculations and in order more easily to disclose trends, the following are used as a basis:

(a) Conductivity over the earth's terrain is assumed to be 10^{-13} units as an average. This assumption closely approximates the average to be found in the United States and Europe.

(b) Antenna loss resistance is taken as 10 ohms. This represents a fair average for practical installations of antennas at broadcasting stations.

(c) The height of the Heaviside layer is assumed to have an average of 100 miles with a reflection coefficient of unity. This is considered a close approximation of average conditions encountered in this country during the winter months.

(d) The propagation curves used are those giving distances for 1 KW radiated calculated by the Dellinger Committee for various frequencies. These curves are generally accepted as representing approximate conditions in practice.

(e) Calculations are made for true vertical radiators from .1 to .6 wave length in height. These have representative voltage patterns which have been corroborated in practice and therefore can be used as a basis of comparison for any other type of antenna.

(f) Most of the calculations were confined to heights of antenna less than 1,000 feet, since this maximum height of 1,000 feet is considered the limit of practical mechanical design for antenna structures within reasonably economical costs.

(g) The radiation resistance and voltage distribution formulas of Ballantine are used, since these are accepted as showing a close approximation to actual facts.

(h) Fading is considered objectionable when the ratio between the sky and ground waves exceeds 2. This permits a variation of field intensity at a receiver of 3 to 1.

(i) The attenuation for sky wave radiations is assumed to follow the inverse distance law. This permits a reasonable degree of accuracy in the calculations.

GENERAL EFFECT OF ANTENNA DESIGN

Antenna performance is an important factor in allocation engineering, both from the standpoint of distribution of energy in the vertical plane as well as field intensity in the horizontal plane. The distribution of radiated energy in the vertical plane is an important factor in fading, as well as in useful efficiency. Figure 1 shows the relation between antenna height and frequency, antenna efficiency, radiation efficiency, and the field intensity at 1 mile for various vertical radiators having a 10 ohm loss resistance with 1 KW input power.

An illustration of how this figure may be utilized is as follows: A 500-foot antenna at 1000 kc. is a half-wave radiator, having a radiation efficiency of approximately 99 per cent, and an antenna efficiency of 80 per cent with a field intensity of 235 millivolts at 1 mile. Lowering this height to 250 feet would make the antenna a quarter-wave radiator having a radiation efficiency of 78 per cent, an antenna efficiency of 42 per cent, and a field intensity of 170 millivolts at 1 mile. Decreasing the height to 150 feet would mean a radiation efficiency of 50 per cent, and an antenna efficiency of 22½ per cent, with a field intensity of 135 millivolts at 1 mile. In order to secure the same field intensity at 1 mile from a 150-foot antenna as could be obtained with 1 KW input power on a 500-foot antenna, it is necessary to increase the 1 KW power of the 150-foot antenna to 3 KW.

VOLTAGE PATTERN IN THE VERTICAL PLANE

The actual height of a true vertical radiator also controls the voltage distribution in the vertical plane. In Figure 2 is given various voltage patterns in the vertical plane for different antennas of designated percentages of the wave length in height.

As a general approximation, antennas having a height of .2 wave length or less have a semicircular voltage distribution in the vertical plane.

FADING

Fading is caused by the interaction between the radiations transmitted to the Heaviside layer, where they are reflected back to the earth and then intermingle with the radiations in the horizontal plane.

Fading may also occur by the intermingling of radiations in two vertical angles in the event that they are reflected from different heights of the Heaviside layer.

Figure 3 shows the distances at which objectionable fading commences for various types of antennas and frequencies. In this the fading limit indicated is that of the fading wall nearest the transmitter and is confined to the intermingling of the ground and sky waves when the conductivity of the terrain is 10^{-13} units.

Fading is independent of power input and depends solely upon the design of antenna, upon conditions in the Heaviside layer and upon ground conductivity. Thus, if any one of these factors is changed, the fading distance will likewise be affected.

SERVICE RANGES

The distance to which a specified field intensity can be transmitted over the ground depends primarily upon

(1) Power input.

(2) Design of antenna.

(3) Conductivity of terrain.

(4) Loss resistance in antenna.

The distance to which a specified field intensity can be transmitted without objectionable fading is dependent not only on the foregoing factors but also upon conditions in the Heaviside layer.

Figures 4 (a), (b), etc., indicate the distances at which 10,000, 2,000, 1 000 and 500 microvolts, respectively, will be transmitted with 1 KW input with various heigbts of antennas having 10 ohms loss resistance. These also show approximately the expected service radii for each frequency from 150 to 1700 kc. Figures 4 (a), etc., are intended solely to indicate general trends.

It sbould be noted tbat for a field intensity of 500 microvolts, which naturally is transmitted over the longer distances, the "carrying capacity" of low frequencies over the earth outbalances the loss in initial field intensity caused by inefficient antennas; bowever, as the distance becomes less and the field intensity thus greater, this advantage of the low frequencies becomes less pronounced.

These figures illustrate very clearly the advantage of low frequencies for long distance service, as well as the necessity for having good antenna design to obtain these advantages for low frequency transmission at shorter distances.

THE EFFECT OF POWER

The effect of increasing power is shown in Figures 5 (a), (b) and (c), which show the distances to which 500 microvolts will be transmitted with 25 KW input in various antennas and frequencies. In these figures there is also clearly illustrated the effect of antenna design, the relative advantages of low frequencies over high frequencies with respect to attenuation, and the effect of fading. It should be noted that even with greater heights of antennas on low frequencies, the value of increasing power, while highly advantageous in the day, may be nullified to a large extent at night by fading, except for the increased signal strength up to the fading wall.

An interesting calculation illustrating the effect of power, antenna design and fading on the probable rural service radius of a broadcasting station under specified conditions and on various frequencies is indicated in Figure 6.

An illustration of the relation of conductivity, frequency, power, and antenna design to secure equal suburban coverage from broadcasting stations is indicated in Figure 7. It will be noted that the carrying capacity of the lower frequencies is of paramount importance in making these lower frequencies of greater value than the higher frequencies. The optimum frequency is about 550 kc.

In Figure 8 is illustrated the effect of antenna efficiency at the shorter distances where relatively high field intensities are encountered. It is here that the higher frequencies, properly used, are of some value as compared to the lower frequencies.

Brief Summary of Trends

Field Intensity	500 microvolts							
Antenna Height	100 ft.		200 ft.		500 ft. #		1000 ft. #	
Antenna Input Power	1 KW	25 KW	1 KW	25 KW	1 KW	25 KW	1 KW	25 KW
	Radii in Miles							
	Day							
Frequency								
150 kc	60	200	75	230	125	325	170	370
550 kc	70	150	85	180	110	210	120	245
1000 kc	46	87	53	103	62	120	65	127
1700 kc	28	55	32	65	36	68	36	68
	Night							
150 kc	Day	140	Day	140	Day	140	140	140
550 kc	Day	85	Day	90	102	102	Day	190
1000 kc	Day	55	Day	55	Day	110	Day	Day
1700 kc	Day	35	Day	40	Day	Day	Day	Day

Field Intensity	2000 microvolts for 1 KW; 2500 microvolts for 25 KW							
Antenna Height	100 ft.		200 ft.		500 ft. #		1000 ft. #	
Antenna Input Power	1 KW	25 KW	1 KW	25 KW	1 KW	25 KW	1 KW	25 KW
	Radii in Miles							
	Day							
Frequency								
150 kc	17.5	60.0	24.0	75	40	125	58	170
550 kc	25.0	70.0	37.0	85	48	110	63	120
1000 kc	22.0	46.0	27.0	53	34	62	37	65
1700 kc	15.0	28.0	18.0	32	20	36	20	36
	Night							
150 kc	Day	Day	Day	Day	Day	Day	Day	140
550 kc	Day	Day	Day	Day	Day	102	Day	Day
1000 kc	Day	Day	Day	Day	Day	Day	Day	Day
1700 kc	Day	Day	Day	Day	Day	Day	Day	Day

Optimum height less than 500 and 1000 ft. respectively—
150 kc. 1000 ft.; 550 kc. 1000 ft.; 1000 kc. 500 to 600 ft.; 1700 kc. 300 to 350 ft.

(a) At 150 kc., increasing the power from 1 KW to 25 KW with a 100-foot antenna is equivalent to an increase of 3.3 times in radius for the 500-microvolt signal. Increasing the height 10 times increases the radius of a 500-microvolt signal approximately 2.85 times.

(b) At 1700 kc., with 100-foot height, increasing the power from 1 KW to 25 KW increases the radius of the 500-microvolt signal 1.96 times. Increasing the height 3.5 times is equivalent to increasing this radius 1.28 times.

(c) At 150 kc., with 100-foot height, increasing power from 1 KW to 25 KW will increase the 2-millivolt radius by approximately 3.5 times, while multiplying the height by 10 will increase the radius of the 2-millivolt line approximately 3 times.

(d) At 1700 kc., with 100-foot height, increasing power from 1 KW to 25 KW, with a 100-foot antenna, is equivalent to increasing the 2-millivolt radius by approximately 1.85 times. Increasing the height 3.3 times is equivalent to increasing the radius of the 2-millivolt line approximately 1.35 times.

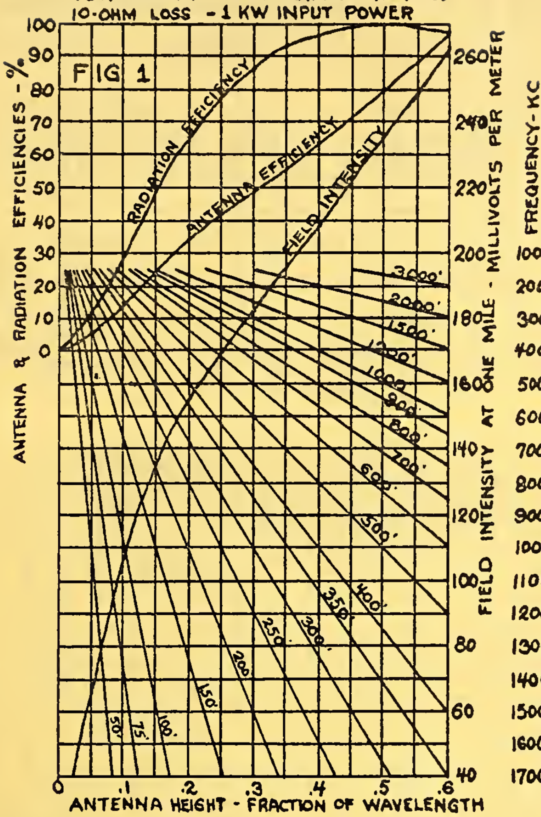
(e) From the foregoing it can be seen that input power is slightly more important than antenna beight in so far as day radius is concerned. However, it can be seen that the antenna factor is of primary importance. At night the antenna factor, because of its control of fading, is of greater importance than power.

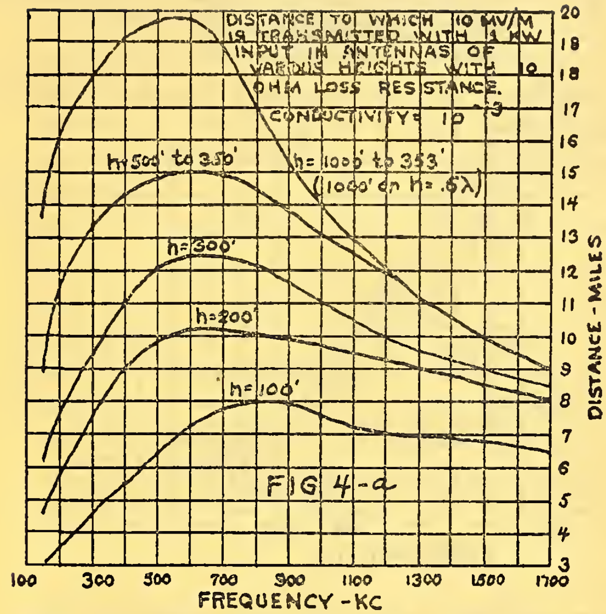
(f) It is only at the relatively shorter distances with the higher field intensities where the difference in the effect of conductivity is not so apparent that high frequencies with proper antennas are of relatively greater value as compared to the lower frequencies on small antennas.

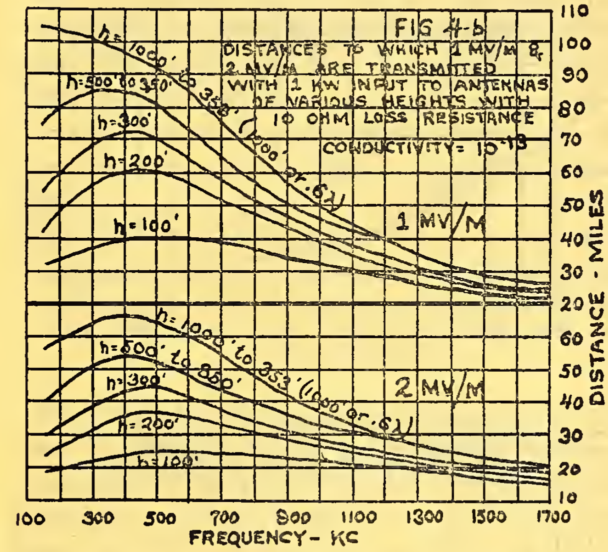
(g) Noise level should be an important influence in the choice of frequencies for specific services. A reference to Figure 7 of the report of the Committee on Radio Propagation Data, submitted March 28, 1933, illustrates the noise intensity to be expected on various frequencies. Applying this data to tbe foregoing table, we find that on 1700 kc., 25 KW will transmit a signal intensity of 500 microvolts to a distance of approximately 68 miles. At this distance the signal to noise ratio will be 50 in the daytime and 12.5 at night. 1 KW input on an antenna 100 feet high at 150 kc. will deliver 500 microvolts at 60 miles, at which distance there will be a signal to noise ratio of 16.5 in the day and 1.22 in the night. However, increasing this power from 1 KW to 25 KW, the signal to noise ratio will be increased to over 50 in the day and to 6.1 at night. Thus it is seen that for daytime the relatively greater value of low frequencies is not seriously impaired in the northern climates.

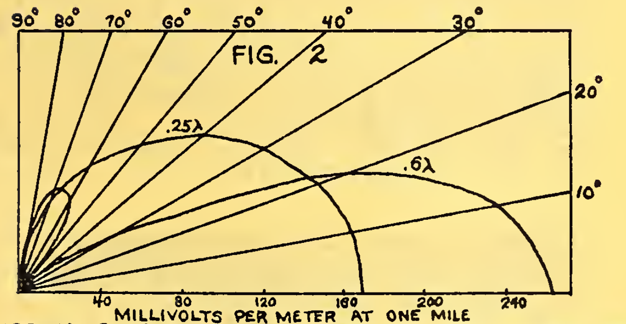
(h) However, at night 25 KW input on a 300-foot antenna at 1700 kc. will transmit a signal intensity of 500 microvolts, without fading, to a distance of approximately 68 miles, where there will be a signal to noise ratio of approximately 12.5. To approximately equal this signal to noise ratio on 150 kc. at this distance, it will be necessary to transmit with 25 KW input power on a 1,000-foot antenna. Thus the greater value of low frequencies is impaired by the noise level factor at night, particularly in tropical regions, and as a corollary the higher frequencies assume greater relative value.

VERTICAL ANTENNA CHARACTERISTICS.
10-OHM LOSS - 1 KW INPUT POWER

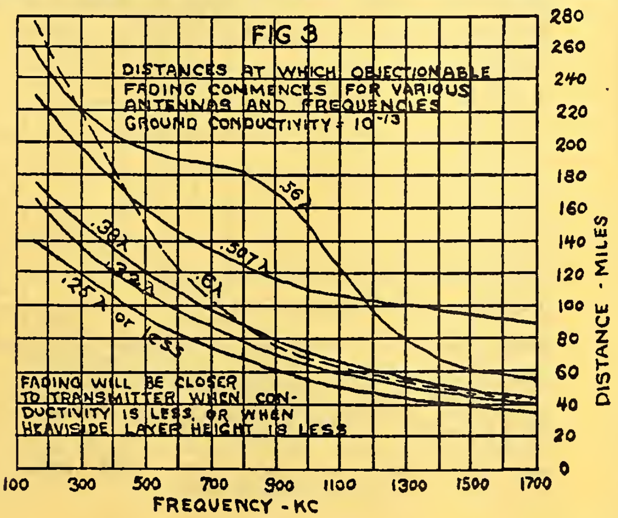


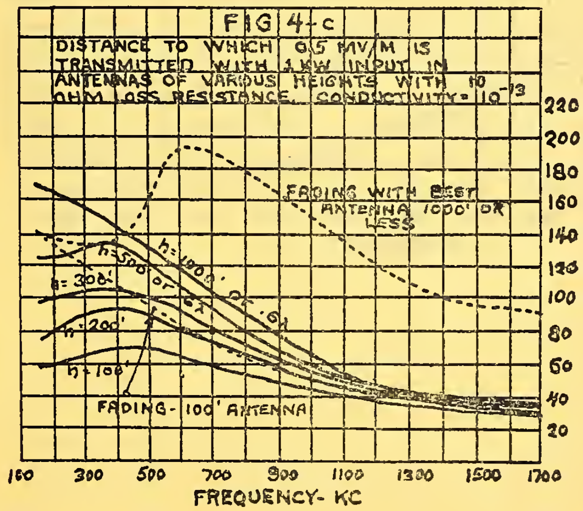


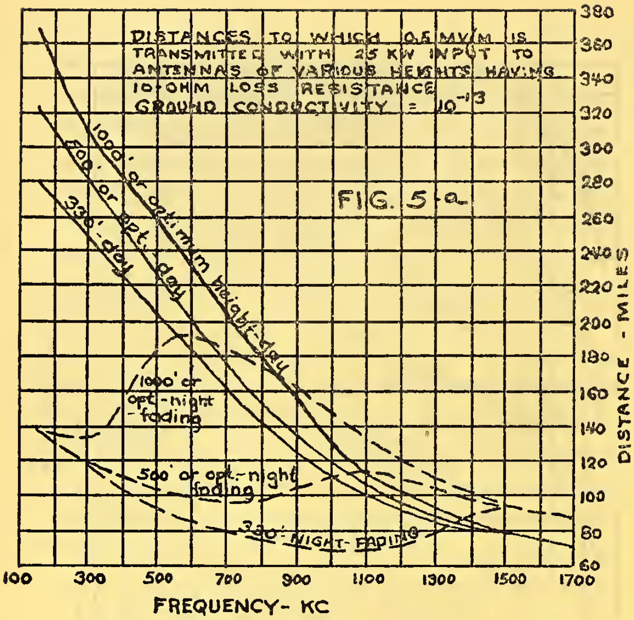


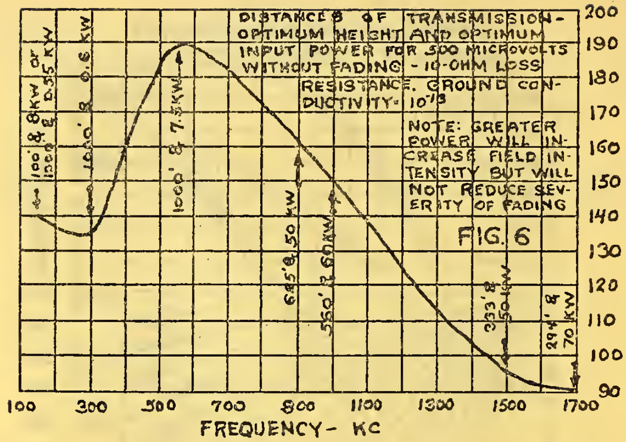


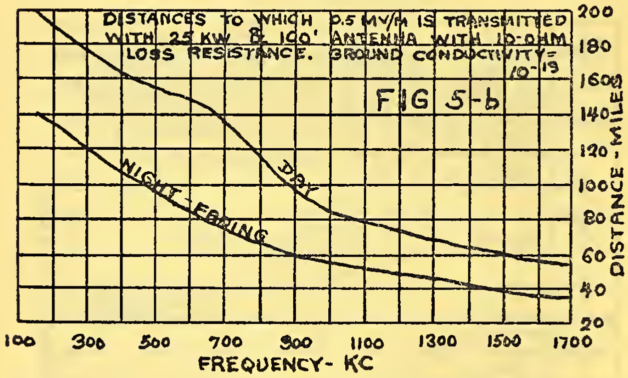
VERTICAL-PLANE RADIATION PATTERNS - 1 KW INPUT 10-OHM LOSS

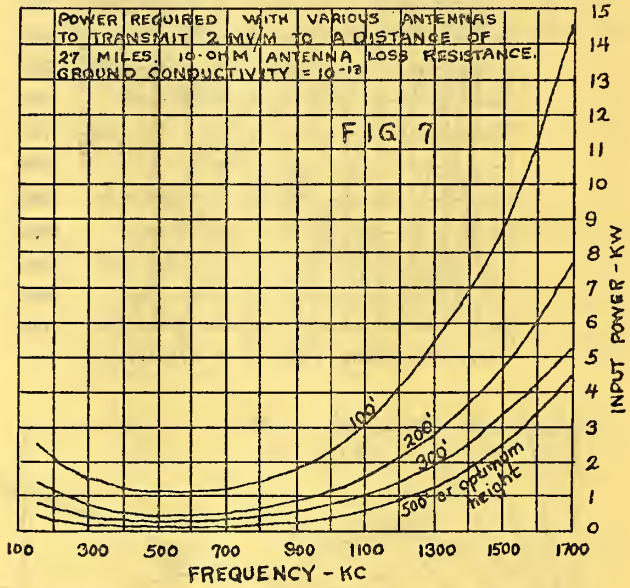


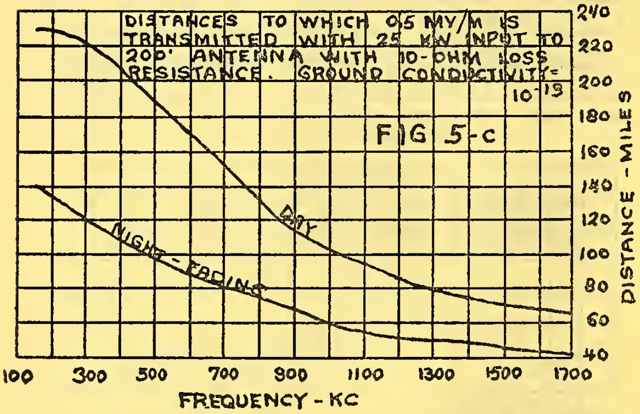


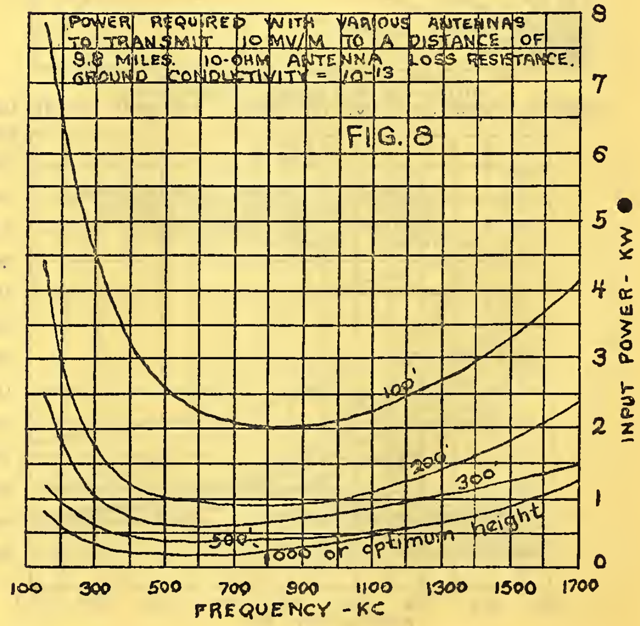

DISTANCES TO WHICH 0.5 MV/M IS TRANSMITTED WITH 25 KW INPUT TO ANTENNAS OF VARIOUS HEIGHTS HAVING 10-OHM LOSS RESISTANCE GROUND CONDUCTIVITY = 10^{-13}
FIG. 5-a
1000' or optimum height-day
500' or opt.-day
330'-day
1000' or opt-night fading
500' or opt.-night fading
330'-NIGHT-FADING
DISTANCE - MILES
FREQUENCY- KC


DISTANCES OF TRANSMISSION-OPTIMUM HEIGHT AND OPTIMUM INPUT POWER FOR 500 MICROVOLTS WITHOUT FADING - 10-OHM LOSS RESISTANCE. GROUND CONDUCTIVITY 10^{-13}
NOTE: GREATER POWER WILL INCREASE FIELD INTENSITY BUT WILL NOT REDUCE SEVERITY OF FADING
FIG. 6
1000' & 7.5KW
1000' & 0.6 KW
685' & 50 KW
550' & 60 KW
333' & 50 KW
294' & 70 KW
FREQUENCY- KC


DISTANCES TO WHICH 0.5 MV/M IS TRANSMITTED WITH 25 KW & 100' ANTENNA WITH 10-OHM LOSS RESISTANCE. GROUND CONDUCTIVITY= 10^{-13}
FIG 5-b
DAY
NIGHT-FADING
DISTANCE - MILES
FREQUENCY- KC


POWER REQUIRED WITH VARIOUS ANTENNAS TO TRANSMIT 2 MV/M TO A DISTANCE OF 27 MILES. 10-OHM ANTENNA LOSS RESISTANCE. GROUND CONDUCTIVITY = 10^{-13}
FIG 7
100'
200'
300'
500' or optimum height
INPUT POWER - KW
FREQUENCY - KC


DISTANCES TO WHICH 0.5 MV/M IS TRANSMITTED WITH 25 KW INPUT TO 200' ANTENNA WITH 10-OHM LOSS RESISTANCE. GROUND CONDUCTIVITY= 10^{-13}
FIG 5-c
DAY
NIGHT-FADING
DISTANCE - MILES
FREQUENCY - KC


POWER REQUIRED WITH VARIOUS ANTENNAS TO TRANSMIT 10 MV/M TO A DISTANCE OF 9.8 MILES. 10-OHM ANTENNA LOSS RESISTANCE. GROUND CONDUCTIVITY = 10^{-13}
FIG. 8
100'
200'
300'
500'
1000 or optimum height
INPUT POWER - KW
FREQUENCY - KC