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GEOGRAPHICAL SEPARATION OF RADIO RANGE STATIONS OPERATING ON THE SAME OR ADJACENT FREQUENCIES IN THE 200-400 KC BAND

by

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Radio Development Section

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SUMMARY

This report describes an investigation made to determine the minimum geographical separation which could be tolerated between radio range stations operating on the same frequency or on frequencies spaced 3 and 6 kc. An analysis is made of the relative signal strengths emitted by a conventional double sideband range of the type originally installed on the Federal airways system, and the single sideband type of simultaneous range now being adopted. It is shown that the strength of the signal emanating from either type of range is dependent upon the operating frequency, the type of ground over which transmission occurs, and, at great distances, reflection from the upper atmosphere.

Radio transmission characteristics for the ground wave under the widely varying conditions encountered in the United States are referred to high and low conductivity earth High conductivity ground, characteristic of plains regions, is the most favorable to radio transmission, while low conductivity ground, typical of mountainous country, represents the least favorable condition. Radio waves are propagated roughly twice as far over high conductivity earth as they are over low conductivity earth. A radio range signal having a strength of not less than 50 microvolts per meter is

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proposed for dependable operation under all but severe static conditions. It is shown that the strongest interfering range signal that can be tolerated is 12.5 microvolts per meter while using the minimum service signal of 50 microvolts per meter. In order to investigate the effect of operating ranges on adjacent frequencies separated by 3 and 6 kc, a representative radio range receiver selectivity characteristic is shown. Conventional 500 watt double sideband ranges transmitting on the same frequency over high conductivity terrain must be separated 460 miles at 200 kc which increases to 800 miles at 400 kc, while 400 watt simultaneous ranges operating under similar conditions on the same frequency must be placed 575 miles apart at 200 kc which increases to 700 miles at 400 kc.

INTRODUCTION

The number of radio range stations is increasing constantly due principally to two factors. First, on all major airways, the necessity for augmenting present facilities has become apparent. This is concurrent with the trend toward increased use of the airways under conditions requiring instrument flying. Second, new airways requiring additional facilities are still being laid out or are projected. All radio ranges must operate between 200 and 400 kc and many frequencies in this band are allocated to other services which have priority. After considering these restrictions, it is apparent that each available frequency must be shared by several radio ranges.

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Therefore, it is important that information be available on the minimum separation that can be tolerated. The subject of broadcast operation is not treated in this report. It is assumed that the service area for voice transmission will be somewhat less than that of a range signal and also influenced to a greater extent by interference at the receiver, varying modulation percentage, and the widely varying characteristics of the human ear.

DISCUSSION

Assuming that power is applied to a single vertical radiator similar to one of those used at a radio range, the field strength developed in the vicinity of the antenna where attenuation is not a factor may be obtained from the following equation:[1]

$$E = \frac{.781\ hIf}{D} \quad (\mu v/\text{meter}) \qquad (1)$$

where h = effective height of radiator in meters

(taken as 16.1 from measurements and calculations)

I = current at current loop

f = frequency in kc

D = distance in miles

In order to obtain values of signal strength at greater distances, the Sommerfeld theory[2] was applied. Fundamentally, this law is expressed by the following equation.

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$$E_R = \frac{E\,f(p)}{R} \qquad (2)$$

E_R = field strength at distance R from antenna.

E = field strength given by equation (1) above.

R = distance from antenna in miles.

f(p) is the numerical distance given by the Sommerfeld integral in which there is included the value of ground conductivity in e.m.u. symbolized by σ.

Values of ground conductivity representing every section of the United States were obtained from the Federal Communications Commission and they checked with values calculated from field strength measurements made by the Radio Development Section where the topography of the ground was similar.

In a range radiating system, the power is divided between two towers, in which the currents have a time phase relation of 180 degrees provided that the courses have not been bent. The field produced by such a combination may be obtained from equation (1) by applying the following correction factor, assuming that the transmitter power remains the same in both cases.

The correction factor:

$$1.414 \sin \left(\frac{\pi d}{e}\right) \qquad (3)$$

where e = wavelength

d = tower separation (assumed = 600' = 183 meters)

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The field strength given by this relation is the maximum existing at any given distance from the range station and it exists along a radial which is 45 degrees "off-course".

With the aid of the above equations, the signal strength existing at various distances from the antenna at 200, 266, and 371 kc was calculated, assuming a maximum ground conductivity of 10^{-13} e.m.u. and a minimum of 2×10^{-14}. The results of these calculations are shown graphically by figures 1, 2, and 3. A transmitter carrier power output of 500 watts and an efficiency of 50 per cent for the coupling equipment are assumed. These curves may be applied to transmitters having different power outputs, in order to do so, it will be necessary to multiply a value selected from the curve by the factor, $\sqrt{\frac{P}{500}}$, where P is the value of the new power being considered. Also on these curve sheets, there is plotted the average strength of the signal propagated through the ionosphere. This is based on the results of an investigation of such propagation published in the Wireless Engineer of June, 1937.

In order to apply the attenuation curves to range stations of the simultaneous type,[3] it will be necessary to introduce another conversion factor. The power supplied to the corner towers in a simultaneous range is adjusted to produce a resultant signal which is 30 per cent of that radiated by the center tower. In evaluating the signal produced by this type of range in terms of that radiated by the conventional double sideband range, field strength values from

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the aforementioned curves must be multiplied by the factor:

$$\frac{.212\ K_1}{K_2\ \sin\left(\frac{\pi d}{e}\cos\theta\right)} \qquad (4)$$

where K_1 = square root of the ratio of unmodulated to modulated transmitter power capacity

K_2 = ratio of sideband to carrier amplitude resulting from attenuation in high "Q" coupling and antenna tuning circuits.

For 100 per cent modulation, the sideband power is 50 per cent of that of the carrier in the conventional double sideband range. Therefore, $K_1 = 1.22$; K_2 was calculated to be .6 based on values of "Q" existing in present range equipment.

Before the minimum tolerable geographical separation between stations can be determined, it is necessary that standards of service signal strength and ratio of interfering to desired signal be set up. Practice indicates that a signal strength of 50 uv/m should be available for satisfactory range reception through average static conditions prevailing at these frequencies. In the matter of interference, tests were made by connecting two standard signal generators, each modulated at 1000 c.p.s. to the input terminals of a radio receiver. The carriers of both generators were adjusted to zero beat and were keyed to simulate range operation. It was found that upon reducing the amplitude of one carrier to a point 12 db below that of the other, the weaker signal did not interfere appreciably with the stronger one. This value was agreed upon by different observers, and was accepted as standard in arriving at a figure for the radius of the interference area as mentioned later.

In order to determine the amplitude of the signal which would be received from an unwanted station operating three or six kc from the desired station, reference was made to the selectivity characteristic of a representative aircraft radio range receiver. The characteristic is shown graphically in figure six. This receiver attenuated a signal three kc removed from the desired signal by 12 db while one separated six kc from the desired signal was attenuated 50 db. Thus, satisfactory range reception with this receiver could be obtained on the basis of the above standards when the level of an unwanted station three kc removed from the desired signal was no higher than that of the desired signal. The amplitude of a signal six kc removed from the desired range signal could be 38 db above that of the desired signal before reception of the desired signal would become unsatisfactory.

The ratios of desired to undesired signal established above were applied to the simultaneous type ranges by recognizing certain factors. By applying equation (4), the strength of the audible signal received from a simultaneous range in terms of that of a double sideband range is obtained. Because of the fact that a stronger signal is produced by supplying a given amount of power to a single antenna instead of a pair of similar antennas which are out of phase, the carrier radiated by the center tower is responsible for any interference which this type of range might produce. Therefore, in applying the ratios of desired to undesired signal evolved herein, the interfering

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signal is considered to be that radiated by the center tower, while the desired signal is assumed to have a strength of 50 microvolts per meter.

From the propagation data mentioned previously, it is possible to obtain the radius of the service area over which a signal of not less than 50 uv/m would be received. Also from this data there was obtained the distance at which a signal 12 db below 50 uv/m would be received for the case of stations on the same frequency and likewise the distance at which a signal 38 db above a 50 uv/m signal would be received in the case of stations whose frequencies are separated 6 kc. Corresponding data for the example of stations with three kc carrier frequency separation would be evident since it has been shown that the level of the unwanted signal may be equal to that of the wanted signal before reception would become unsatisfactory.

RESULTS

Values of radio range service and interference area radii based on the material presented above have been selected for three representative frequencies and are tabulated below. They are divided into two groups, one corresponding to propagation over ground having high conductivity and the other over terrain of low conductivity. In general, it may be said that high ground conductivity conditions will obtain in the middle west and southern plains regions while low ground conductivity will exist in the mountainous country along the Atlantic Coast and in the west. The geographical separation between stations of like power is the sum of the distances in the first two columns.

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Regions of High Ground Conductivity:

Stations operating on the same frequency

Type of Range	Service Area Radius	Interference Area Radius	Geographical Separation
	200 kc		
1/2 kw range	130 miles	335 miles	465 miles
.15 kw range	75	235	310
.4 kw simul.	155	425	580
	266 kc		
1/2 kw range	175 miles	360 miles	535 miles
.15 kw range	110	275	385
.4 kw simul.	165	425	590
	371 kc		
1/2 kw range	190 miles	575 miles	765 miles
.15 kw range	135	400	535
.4 kw simul.	160	575	735

Stations with carriers separated 3 kc

Transmitter Power	Service Area Radius	Interference Area Radius	Geographical Separation
	200 kc		
1/2 kw range	130 miles	130 miles	260 miles
.15 kw range	75	75	150
.4 kw simul.	155	195	350
	266 kc		
1/2 kw range	175 miles	175 miles	350 miles
.15 kw range	110	110	220
.4 kw simul.	165	200	365
	371 kc		
1/2 kw range	190 miles	190 miles	380 miles
.15 kw range	135	135	270
.4 kw simul.	160	195	355

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Stations with carriers separated 6 kc

Transmitter Power	Service Area Radius	Interference Area Radius	Geographical Separation
		200 kc	
1/2 kw range	130 miles	2 miles	132 miles
.15 kw range	75	1	76
.4 kw simul.	155	3	158
		266 kc	
1/2 kw range	175 miles	4 miles	179 miles
.15 kw range	110	2	112
.4 kw simul.	165	4	169
		371 kc	
1/2 kw range	190 miles	7 miles	197 miles
.15 kw range	135	3	138
.4 kw simul.	160	6	166

Regions of Low Ground Conductivity:

Stations operating on the same frequency

Type of Range	Service Area Radius	Interference Area Radius	Geographical Separation
		200 kc	
1/2 kw range	85 miles	225 miles	310 miles
.15 kw range	65	150	215
.4 kw simul.	95	350	445
		266 kc	
1/2 kw range	90 miles	360 miles	450 miles
.15 kw range	70	160	230
.4 kw simul.	85	410	495
		371 kc	
1/2 kw range	85 miles	575 miles	660 miles
.15 kw range	70	375	445
.4 kw simul.	70	575	645

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Stations with carriers separated 3 kc

Transmitter Power	Service Area Radius	Interference Area Radius	Geographical Separation
		200 kc	
1/2 kw range	85 miles	95 miles	180 miles
.15 kw range	65	65	130
.4 kw simul.	95	130	225
		266 kc	
1/2 kw range	90 miles	100 miles	190 miles
.15 kw range	70	70	140
.4 kw simul.	85	115	200
		371 kc	
1/2 kw range	85 miles	95 miles	180 miles
.15 kw range	70	70	140
.4 kw simul.	70	95	165

Stations with carriers separated 6 kc

Transmitter Power	Service Area Radius	Interference Area Radius	Geographical Separation
		200 kc	
1/2 kw range	85 miles	2 miles	87 miles
.15 kw range	65	1	66
.4 kw simul.	95	2	97
		266 kc	
1/2 kw range	90 miles	4 miles	94 miles
.15 kw range	70	2	72
.4 kw simul.	85	4	89
		371 kc	
1/2 kw range	85 miles	7 miles	92 miles
.15 kw range	70	3	73
.4 kw simul.	70	6	76

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The signal strength used in arriving at the values of distance appearing in the tabulation is that which would obtain 45 degrees "off-course". The variation in geographical separation between 200 and 400 kc is shown graphically on the accompanying curve sheets, Nos. 4 and 5, representing high and low ground conductivity respectively.

CONCLUSIONS

In arriving at the conclusions pertaining to the spacing of radio ranges operating on the same or adjacent frequencies, no consideration was given to the possibility of using aircraft direction finders of the "null bearing" type. When taking a bearing with this type of direction finder, the response is maximum to stations 90 degrees removed from that upon which a bearing is being taken. Because of this fact, the ratio of desired to undesired signal must be much greater than that advocated in this report when direction finder operation is contemplated.

Where it is desired to place the maximum number of ranges within a given area and frequency band, it is recommended that the standards of minimum geographical spacing evolved in this study be followed in designating the stations which must share common or adjacent frequencies.

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REFERENCES

1. Electrical Engineers' Handbook, McIllwain and Pender, pp. 8-10.

2. Electrical Engineers' Handbook, McIllwain and Pender, pp. 8-11.

3. Simultaneous Radio Range and Telephone Transmission, by W. E. Jackson and D. M. Stuart, Proc. I.R.E., March 1937, p. 314

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FIGURE INDEX

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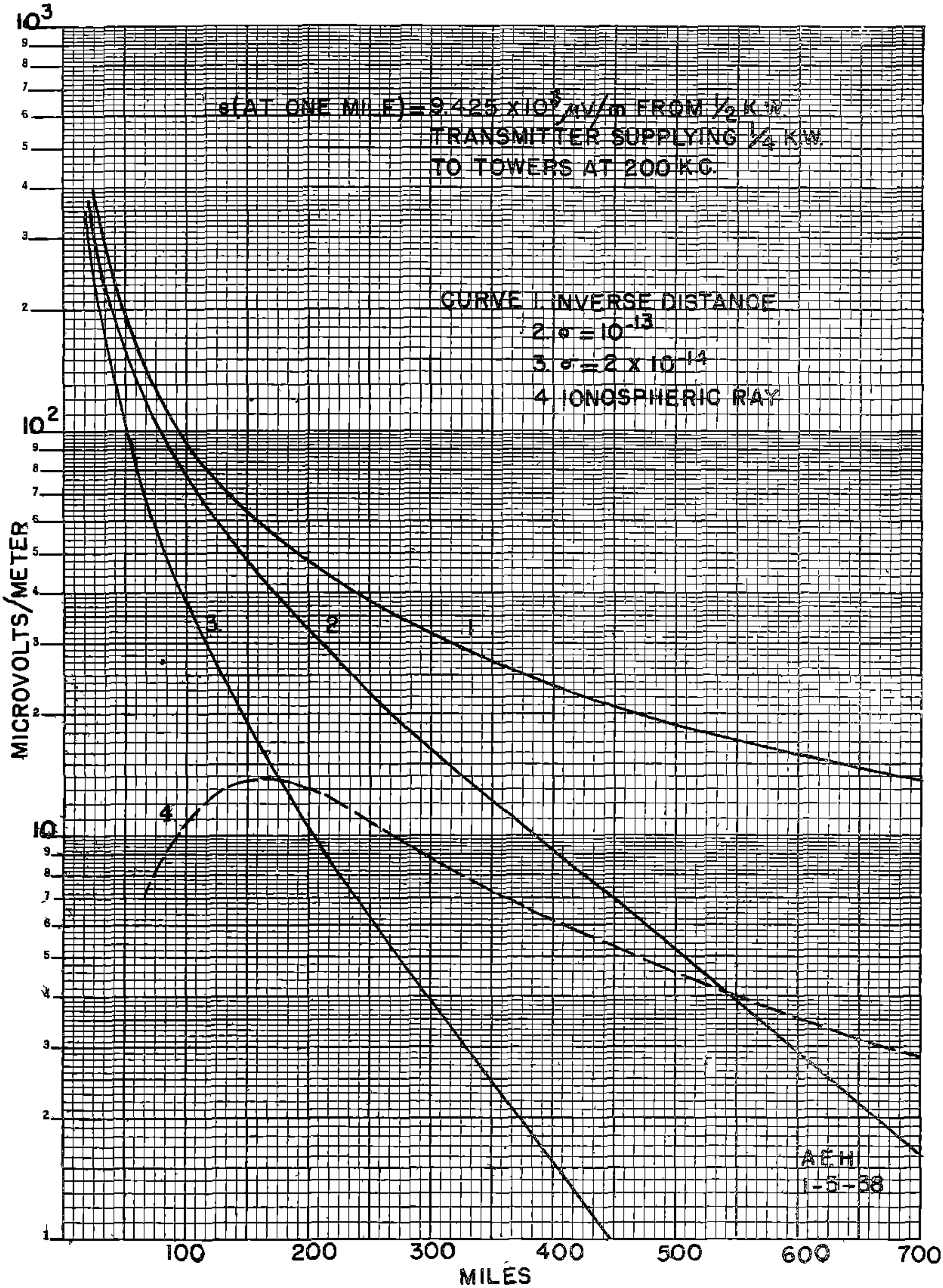

FIG I FIELD STRENGTH ATTENUATION

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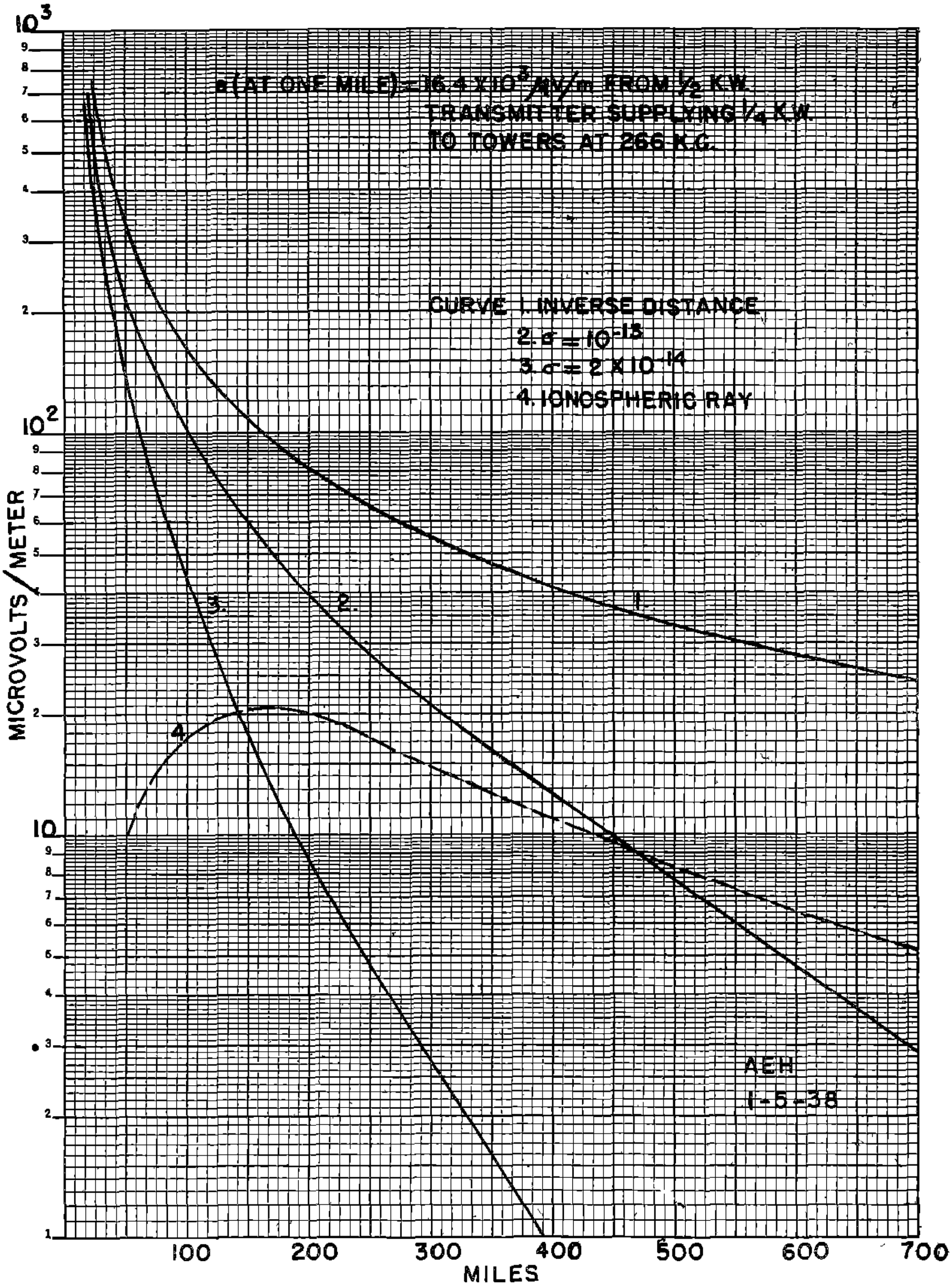

FIG 2 FIELD STRENGTH ATTENUATION

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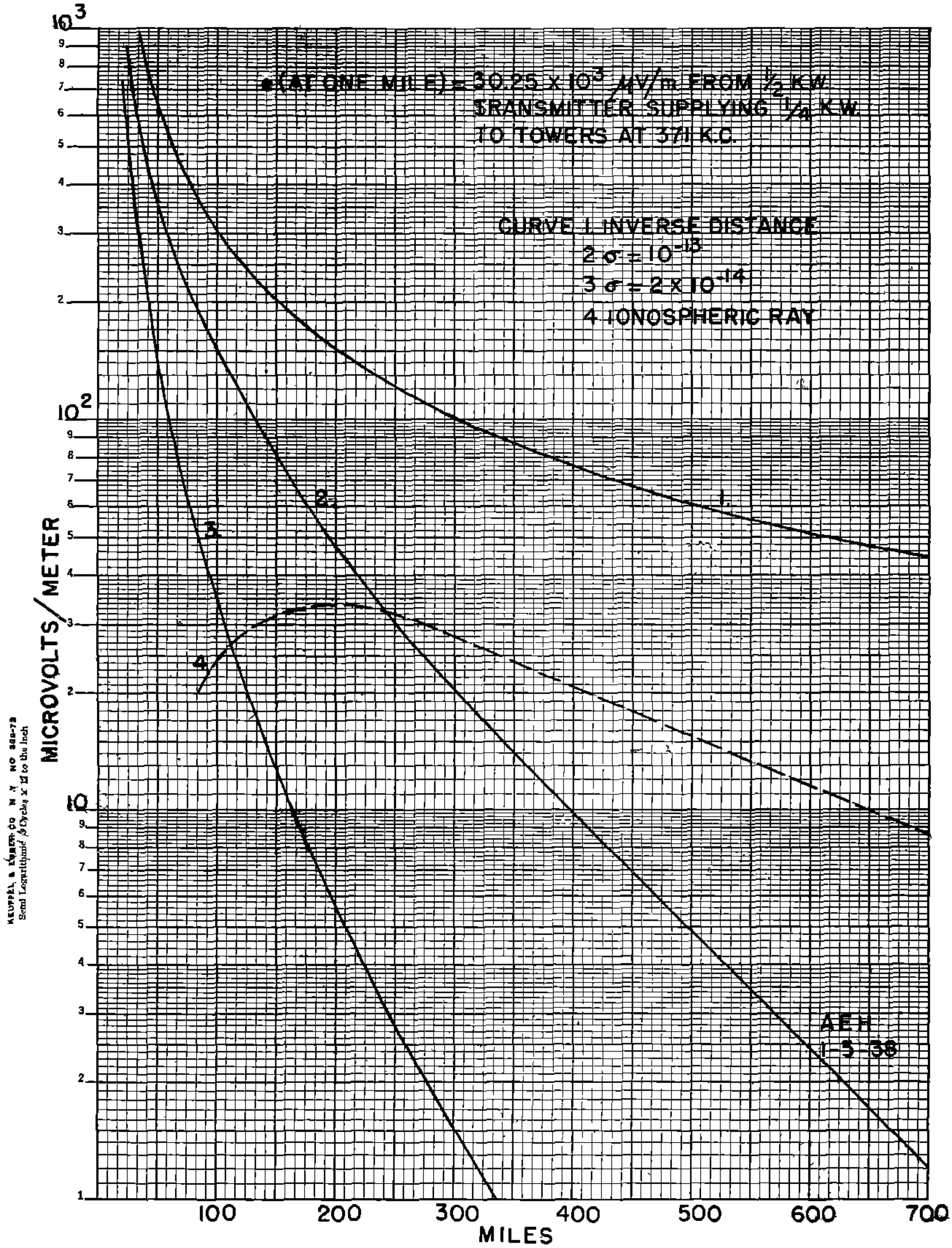

FIG 3 FIELD STRENGTH ATTENUATION

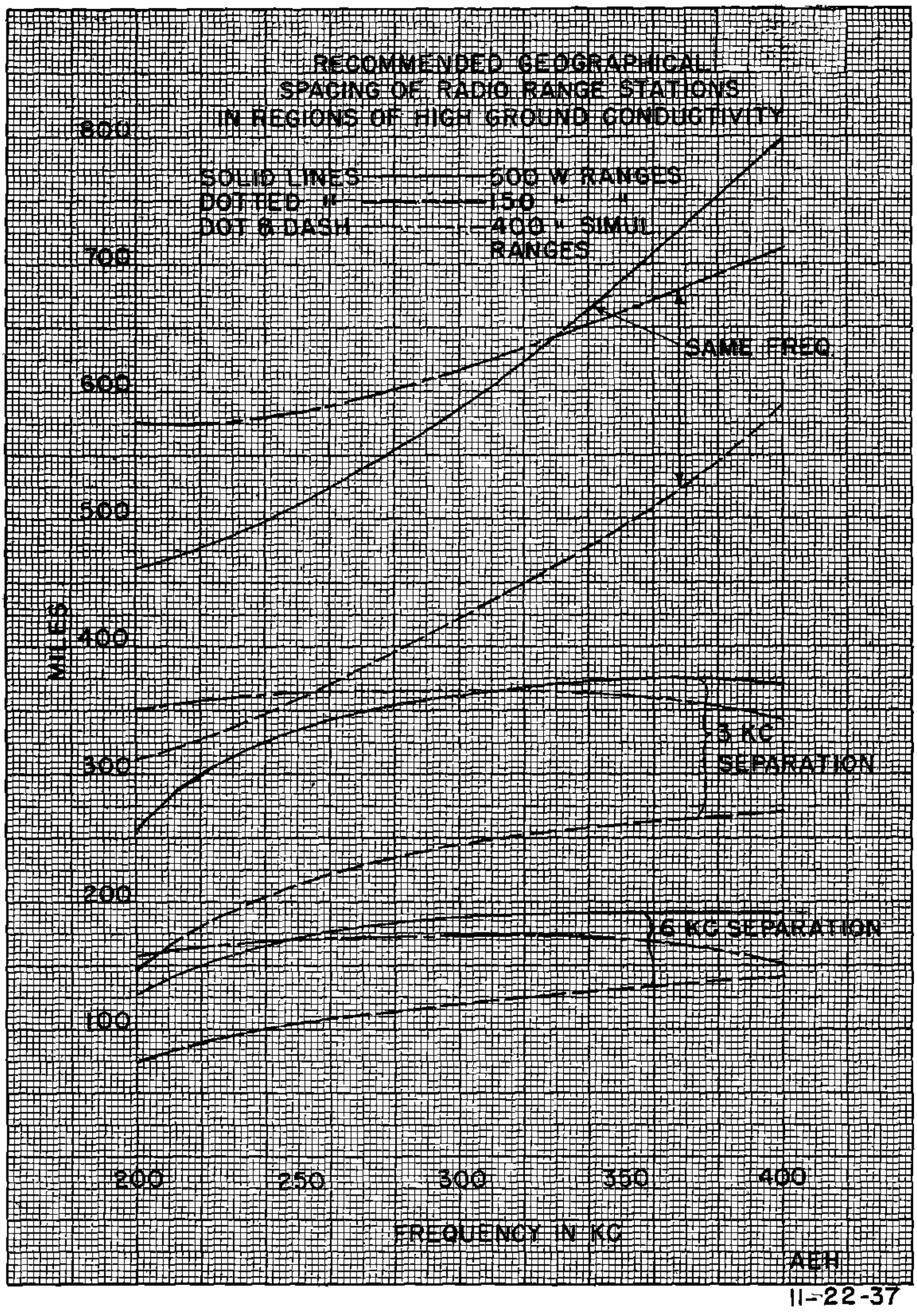

FIG 4 GEOGRAPHICAL SPACING OF RADIO RANGE STATIONS IN REGIONS OF HIGH GROUND CONDUCTIVITY

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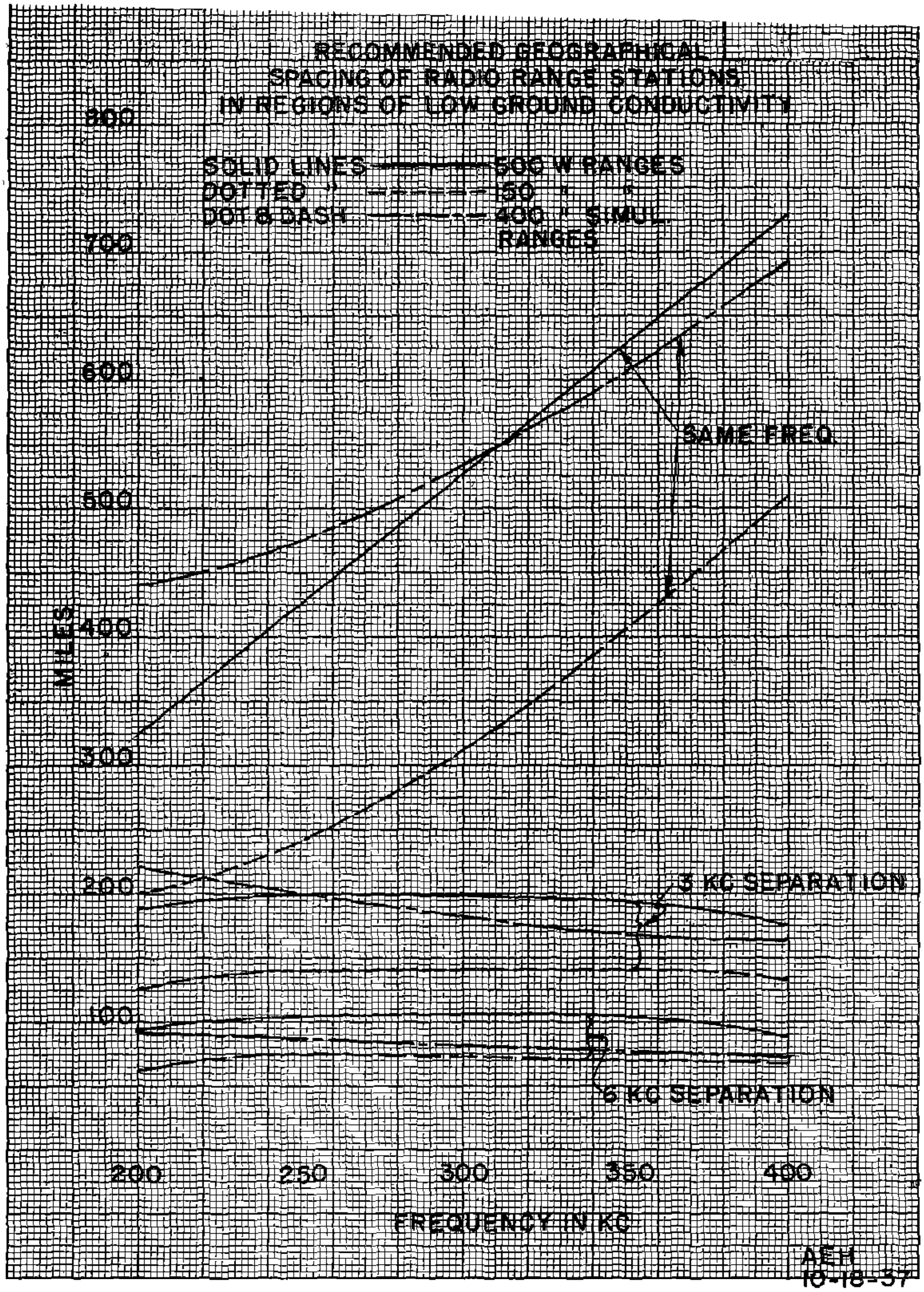

FIG 5 GEOGRAPHICAL SPACING OF RADIO RANGE STATIONS IN REGIONS OF LOW GROUND CONDUCTIVITY

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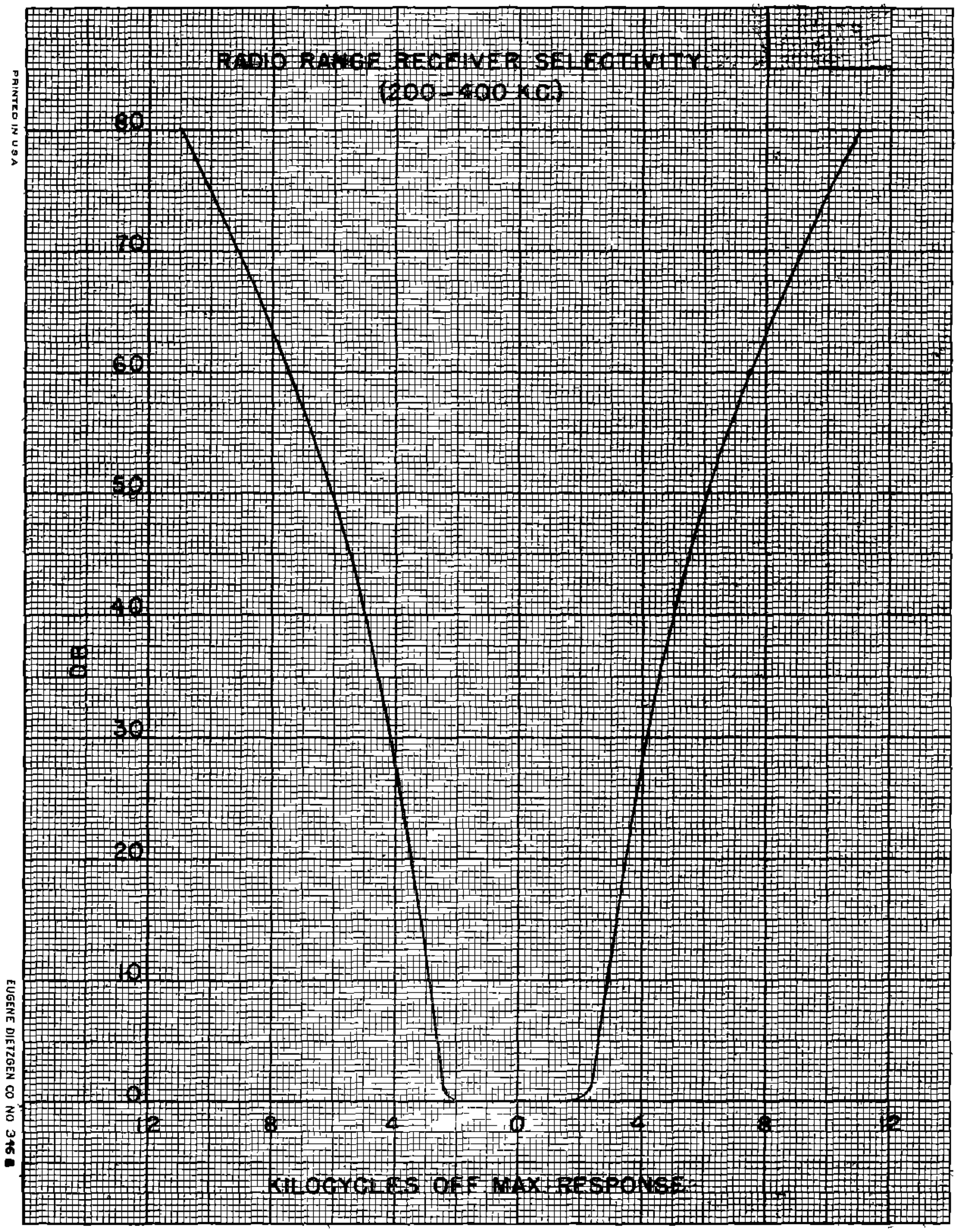

FIG 6 RADIO RANGE RECEIVER SELECTIVITY

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