FCWG

DOCUMENT 106-64

RADIO FREQUENCY SOURCES at the NATIONAL AND SERVICE TEST RANGES

FREQUENCY COORDINATION WORKING GROUP
INTER-RANGE INSTRUMENTATION GROUP
RANGE COMMANDERS COUNCIL

NATIONAL RANGES

WHITE SANDS MISSILE RANGE
PACIFIC MISSILE RANGE
ATLANTIC MISSILE RANGE

SERVICE RANGES

NAVAL ORDNANCE TEST STATION
AIR PROVING GROUND CENTER
AIR FORCE FLIGHT TEST CENTER

IRIG DOCUMENT 106-64

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at the
NATIONAL AND SERVICE TEST RANGES

Prepared by

Frequency Coordination Working Group

Inter-Range Instrumentation Group

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ABSTRACT

Suggested calculations for determining power density from radio frequency sources are discussed. The calculations are specially adapted for use with RF sources at the National and Service Test Ranges. Tabulations of RF sources for each Range are listed in separate appendices. Since each appendix is classified, limited distribution of the appendices will be on a strict need-to-know basis.

If theoretical studies indicate measured data is required, the names and addresses of support organizations are included through which RF measurements may be obtained at the applicable range.

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RADIO FREQUENCY SOURCES
at the
NATIONAL AND SERVICE TEST RANGES

1.0 INTRODUCTION

1.1 Test range radio frequency management personnel receive numerous requests for information about radiation sources which comprise their respective RF environments. The task of amassing on each occasion the necessary data from other records has always been a time consuming and burdensome job. Now with the world-wide scope of many test operations influenced by increased powers of transmitters, the interest in RF environments has grown more acute.

1.2 To fulfill this requirement for information from those with an established need-to-know, the Frequency Coordination Working Group (FCWG) of the Inter-Range Instrumentation Group (IRIG) has published this document. It describes the sources of RF energy at the National and Service Test Ranges.

1.3 It must be emphasized that the RF environments are not fixed and are subject to continuous change. The RF levels in any specific area may increase to an upper limit established by the radiation siting criteria in use at the respective range. Provisions have been made, therefore, to periodically review and update the data contained.

1.4 It is suggested that the data be used to make theoretical calculations. Where the results indicate a problem may exist, the procedure for obtaining measurements in a specific area of interest is indicated.

2.0 SUGGESTED DATA USE

2.1 Ideally, the ranges would provide measured signal levels in all areas of interest. There are two reasons this is not practical. Firstly, the workload would be prohibitive, and secondly, it is not necessary that measured values be known from every source and at every location of interest. Therefore, this document should be used to make theoretical calculations of signal levels. If a potential problem is indicated, measurements may be requested for specific RF sources at specific locations. RF measurements can be obtained by contacting the appropriate office shown in Section 7.0.

2.2 A knowledge of RF propagation on the part of the document user is assumed; however, certain formulas and comments of general interest are included in the following paragraphs.

3.0 POWER DENSITY CALCULATIONS ABOVE 50 MC

3.1 In free space, the power density in watts per square meter can be calculated from

$$P_d = \frac{W_T \; G_T}{4\pi \; R^2} \qquad (1)$$

Where

P_d = Power density in watts/meter^2, peak or average, depending on W_T

W_T = Power input to the antenna in watts, peak or average

G_T = Transmitting antenna power gain factor

R = Distance from the RF source in meters.

3.2 Eq. (1) is valid for far-field radiation conditions. Far-field conditions may be assumed to exist at distances equal to or greater than that given by the following

$$R \geqq \frac{(D + d)^2}{\lambda} \qquad (2)$$

Where

D = Largest linear dimension of the larger antenna in meters

d = Largest linear dimension of the smaller antenna in meters

λ = Wavelength in meters
= 300 divided by frequency in megacycles

R = Separation distance in meters.

3.3 Experience has shown that some of the radars are capable of an RF (radio frequency) power output greater than their rated output. Variation in output may be as great as +2 db above those tabulated which are rated power outputs.

3.4 To convert from radar peak power to average power, multiply peak power by the radar duty cycle.

$$W_{AVG} = (W_{peak})\,(d.c.) \qquad (3)$$

3.5 Unless otherwise indicated in the signal characteristic listing, multiple sources of the same type on the same frequency are non-synchronous at radio frequencies.

3.6 In general, missile gantries or other large nearby structures will effect measured values. Furthermore, ground reflections will modify calculated free space values. In most cases, measured values will equal or be less than the free space calculated value. For the worst case condition, however, assume a complete and in-phase reflection. In calculations this will give a power density four times the value calculated in eq. (1).

$$P_{D_{Total}} = 4\ P_d \tag{4}$$

3.7 A nomogram is useful for performing calculations, such as eq. (1). A nomogram has been included for this purpose. The nomogram included can also be used to solve the following equation

$$W_R = \frac{W_T\ G_T\ G_R\ \lambda^2\ \alpha_R}{(4\pi\ \ R)^2} \tag{5}$$

Where

α_R = Ratio of the RF power flowing to the load including RF losses and mismatch to RF power delivered without loss or mismatch

G_R = Receiving device antenna gain

W_R = RF power absorbed in the load

The remaining factors are defined under eq. (1).

3.8 Any parameter may be determined if the others are known. For example, if the load RF power threshold sensitivity is known, then the required system antenna gain may be determined. The magnitude of the antenna gain required may sometimes be used to estimate whether a problem situation could exist or not. Several examples of the use of the nomogram are given under Para. 6.0.

4.0 FIELD STRENGTH CALCULATIONS BELOW 50 MC

The references below are recommended for information about calculations below 50 megacycles.

Norton, K. A. - Proceedings of IRE
Vol. 24 No. 10 Oct. 1936 page 1367

Kraus, J. D. - Antennas
McGraw-Hill Book Co., Inc.

Jasik - Antenna Engineering Handbook
McGraw-Hill Book Co., Inc.

FCC - Standards of Good Engineering
Practice Concerning Standard
Broadcast Stations
U.S. Government Printing Office

IT and T - Reference Data for Radio Engineers,
International Telephone and Telegraph Corp.

Terman, F. E. - Electronic and Radio Engineering
McGraw-Hill Book Co., Inc.

Henney, Keith - Radio Engineering Handbook
McGraw-Hill Book Co., Inc.

Terman, F. E. - Radio Engineers Handbook
McGraw-Hill Book Co., Inc.

Smith, Langford - Radiotron Designers Handbook
Chapter 22 beginning at Section 3,
Page 892. Radio Corporation of America.

5.0 SEPARATION DISTANCE CALCULATIONS

5.1 The latitude and longitude or X and Y coordinates should be used to determine separation distances between RF source and the area of interest. Where coordinates other than latitude and longitude are specified, such as X and Y coordinates, the reference coordinate system is explained in the individual section for each range. For separations of 20 nautical miles or less, approximate distance from source can be calculated by determining the latitude and longitude differences and converting these to meters, as follows

(1) Multiply each minute of latitude difference by 1852 meters per minute of arc to obtain meters

(2) Multiply each second of latitude difference by 30.86 meters per second to obtain meters

(3) Add (1) and (2) for total latitude difference in meters

(4) Do the same for the longitude difference

(5) Multiply the total longitude difference in meters by the cosine of the latitude

(6) Obtain the separation distance from source in meters as follows

$$R_{Meters} = \sqrt{(Lat.\ Diff._{Meters})^2 + (Long.Diff._{Meters} \times \cos Lat.)^2} \quad (6)$$

For an (X,Y) system of coordinates given in feet -

(1) Subtract X coordinates of source and load

(2) Subtract Y coordinates

(3) Obtain distance in feet as follows

$$R_{Feet} = \sqrt{(X\ Diff._{Feet})^2 + (Y\ Diff._{Feet})^2} \quad (7)$$

(4) Divide by 3.28 to obtain meters

$$R_{Meters} = \frac{R_{Feet}}{3.28} \quad (8)$$

5.2 Where separation is greater than 20 nautical miles, a terrestrial triangle may be used to calculate the distance from the source. The terrestrial triangle contains the north pole (NP) as one vertex and the radiation source (S) and load (O) as the other two. (See Figure 1)

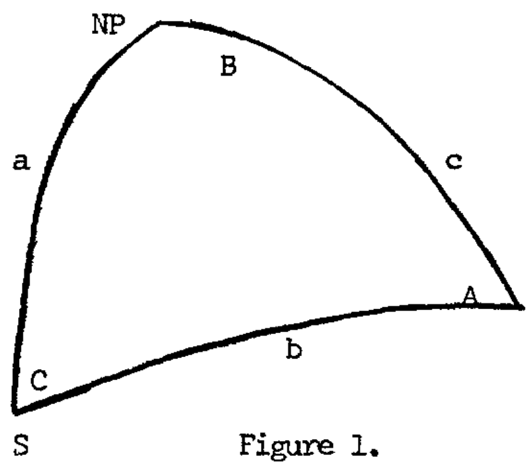


Figure 1.

Separation angle "b" is obtained by using the cosine law to determine its cosine and hence its degrees. The degrees are then converted to distance.

$$\cos b = (\cos a)(\cos c) + (\sin a)(\sin c)(\cos B) \qquad (9)$$

Where

angle a = 90 degrees minus Lat. of source

angle c = 90 degrees minus Lat. of load

angle B = Long. of S minus Long. of O

angle b = Separation distance in degrees

Obtain angle "b" from a table of cosines.

Separation distance in nautical miles is obtained by multiplying the angle "b" by 60. For distance in meters, multiply by 111, 120 meters per degree.

5.3 If the bearing to the load item is of interest, it may be calculated by the law of sines

$$\frac{\sin b}{\sin B} = \frac{(\sin c)}{\sin C}$$

or

$$\sin C = \left(\frac{\sin c}{\sin b} \quad \sin B\right)$$

and

$$C = \arcsin\left(\frac{\sin c}{\sin b} \quad \sin B\right) \qquad (10)$$

angles are the same as defined for eq. (9).

From Figure 1 this is seen to be the bearing angle to O. If angle A had been calculated, it should be subtracted from 360 degrees to obtain the bearing to S.

6.0 EXAMPLES OF CALCULATIONS

Example 1:

A receiver and its antenna are installed at

Latitude 28 degs. 28 min. 49.1256 sec.

Longitude	90 degs.	32 min.	31.9514 sec.

A radar with peak output power of 2.8 megawatts, antenna gain of 51 db, and maximum duty cycle of 0.00154 is located at

Latitude	28 degs.	13 min.	35.2893 sec.
Longitude	90 degs.	35 min.	58.0530 sec.

Determine peak and average power densities and estimate worst case conditions.

Solution:

1. Determine separation distance (by approximate method)

Rec. Latitude	28 degs.	28 min.	49.1256 sec.
	28 degs.	13 min.	35.2893 sec.
		15 min.	13.8363 sec.

15 min. = 15 x 1852 meters
= 27,780 meters

13.8363 sec. = 13.8 x 30.9 meters
= 426.4 meters

Latitude Difference in Meters = 27,780 + 426.4
= 28,206.4 meters

In a similar manner

Longitude Difference = 6362.5 meters

Long. Diff. Corrected = 6362.5 x cos 28.5 degs.
= 5600 meters

Distance Meters = $\sqrt{(28{,}206.4^2 + (5600)^2}$

= 28,212 meters

Surveyed Distance	=	31,371.00 yards
28,212 meters	=	30,751.08 yards
Difference	=	619.9 yards

2. Convert eq. (1) parameters to DB

Peak power in Watts	=	2.8×10^6	=	64.5 DBW
Antenna Gain			=	51.0 DB
$10 \log 4\pi$			=	-11 DB
20 log 28,212			=	-89.0 DB
10 log 0.00154			=	-28.1 DB
10 log 4			=	6 DB

3. Calculate Peak Power Density

Radar Peak Power	=	64.5 DBW
Antenna Gain	=	51.0 DB
10 log W G_T	=	115.5 DBW
10 log 4π	=	-11.0 DB
10 log $\frac{W G_T}{4\pi}$	=	104.5 DBW
20 log R	=	-89.0 DB
10 log $\frac{W G_T}{4\pi R^2}$	=	15.5 DBW Peak/Meter^2
15.5 DBW	=	35.5 Watts/Meter^2 Peak

For this radar this is a pulse 2.4 microseconds in duration occurring 640 times per second.

4. Calculate Average Power Density

Peak Power Density	=	15.3 DBW/Meter^2
Duty Cycle	=	-28.1 DB
Avg. Power Density	=	-12.8 DBW/Meter^2
-12.8 DBW per meter^2	=	0.0525 Watts/Meter^2 Average

5. Calculate Worst Case Conditions

Peak Power Density	=	15.3 DBW/Meter^2
Correction for Reflection	=	6.0 DB
	=	21.3 DBW/M^2
Added for Exceeded Power Rating		2.0 DB
Worst Case Peak		23.3 DBW/M^2 Peak
23.3 DBW/M^2 Peak	=	214 Watts/Meters^2
Average Power Density	=	-12.8 DBW/M^2
Correction for Reflection	=	+6.0 DB
	=	-6.8 DBW/M^2
Added for Exceeded Power Rating		2.0 DB
Worst Case Average	=	-4.8 DBW/M^2
-4.8 DBW/M^2	=	0.33 Watts/Meter^2 Average

Example 2:

Determine the surface separation distance and the source look angle (relative to true north) which produces maximum radiation at the receiving antenna for the following

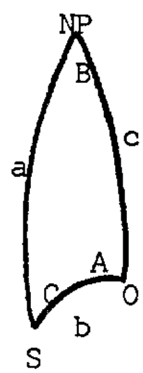
Source Location Shipboard:

Latitude	0.9	degs. South
Longitude	28.4	degs. West

Receiving Antenna Location Shipboard:

Latitude	0.2	degs. North
Longitude	27.0	degs. West

1. Calculate Separation Distance (Exact Method)



angle c = 90 degrees minus 0.2 = 89.8 degrees

angle a = 90 degrees minus (-0.9) = 90.9 degrees

angle B = 28.4 degrees minus 27 degrees = 1.4 degrees

$$\cos b = (\cos 89.8 \text{ deg.})(\cos 90.9 \text{ deg.}) + (\sin 89.8 \text{ deg.})(\sin 90.9 \text{ deg.}) \cos (1.4 \text{ deg.}) \quad (11)$$

Using logarithms -

log cos 89.8 degrees	=	7.5429-10
log cos 90.9 degrees	=(-)	8.1961-10
	=(-)	15.7390-20 or
	(-)	5.7390-10

log sin 89.8 degrees	=	0.0000
log sin 90.9 degrees	=(+)	9.9999-10
log cos 1.4 degrees	=(+)	9.9999-10
	(+)	19.9998-20 or
		9.9998-10

(+) Antilog 9.9998-10	=	+ 0.9995
(-) Antilog 5.7390-10	=	- 0.00005483
		+ 0.99945

cos b = +0.99945

b = 1 degree 54 min.

Separation Distance $= 1 \text{ deg.} \times 60 + \frac{(54)}{60} \text{ deg.} \times 60$

= 60 + 54

= 114 nautical miles

2. Calculate bearing from S to O

$C = \arcsin \frac{\sin c}{\sin b} \quad \sin B$

Using logarithms -

log sin 89.8 degrees	=	10.0000-10
log sin 1.4 degrees	=	8.3880-10
adding		18.3880-20
log sin 1.9 degrees	=	8.5206-10
subtracting		9.8674-10
Antilog 9.8674-10	=	0.7369
sin C	=	0.7369
C	=	47 degrees 28 min.

Bearing from source to receiving antenna is 47 degrees 28 min., and the source is 114 nautical miles.

It should be noted, south latitudes and east longitudes are given negative signs.

Example 3:

Sensitive transistorized equipment is to be installed 4850 meters from an "S" band radar.

The radar characteristics are:

1. Antenna Power Gain: 37 db
2. Frequency: 2900 Mc
3. Power Output Avg.: 670 W
4. Pulse Width: 0.8 microsec.
5. Pulse Repetition Freq.: 1700 PPS

Determine the radar average power density at the site of the sensitive equipment.

Solution:

Refer to nomogram, Example 3.

1. Draw line between radar average power, column (13), and radar antenna gain, column (12). Intersection with column (11) is the effective radiated power.

2. Continue line column (11) through separation distance on column (10). Intersection with column (9) is the average radar power density at the site.

Example 4:

A receiving system has the following characteristics:

Receiving Spurious Response:	-14 DBW at 5480 Mc
Estimated Antenna Gain:	+1.0 db
Estimated System Losses:	Will not exceed 20 db

How close can this system be operated to a radar with characteristics:

Average Power Output:	2 kw or 33 dbw
Antenna Power Gain:	50 db
Frequency:	5480 Mc

Solution:

Refer to nomogram, Example 4.

1. Along the horizontal graph at the bottom of the nomogram find (-25.6 db) opposite 5480 Mc.

2. On columns (3) and (4) draw a line joining the spurious response (-14 dbw) and the wavelength squared (-25.6db). Extend column (5) downward to obtain its intersection.

3. Continue the line through column (6) at the 1 db antenna gain point.

4. Extend column (7) upward to obtain an intersection point.

5. Draw two lines from column (7) through column (8) at the 0 db and -20 db points for the range of system losses.

6. Draw a line between transmitter power +33 dbw and antenna gain +50 db on columns (13) and (12), respectively. Intersection with column (11) is the radar effective radiated power.

7. Find solution to the problem on column (10) by joining the ERP on column (11) with each power density point determined previously on column (9).

8. When there are no system losses (0 db) a spurious response is unlikely at distances over 500 meters or about 1900 feet from the radar. There is an uncertain area between 50 meters and 500 meters where system losses are not specifically defined and the equipment may or may not respond.

   From the nomogram, the system should be considered definitely responsive at distances less than 50 meters which corresponds to a system loss of 20 db.

7.0 REQUESTS FOR MEASUREMENTS

7.1 Field intensity measurements should be requested through the following offices:

1. Eastern Test Range:

   Commander
   Air Force Eastern Test Range
   Attention: ETORC
   Patrick Air Force Base, Florida

2. Pacific Missile Range:

   Commander
   Pacific Missile Range
   Attention: Code 3241
   Point Mugu, California

3. White Sands Missile Range:

   Commanding General
   White Sands Missile Range
   Attention: STEWS-WSC-COM-F
   White Sands Missile Range, New Mexico

4. Naval Ordnance Test Station:

   Commander
   Naval Ordnance Test Station
   Attention: Code 8598
   China Lake, California

5. Air Force Flight Test Center:

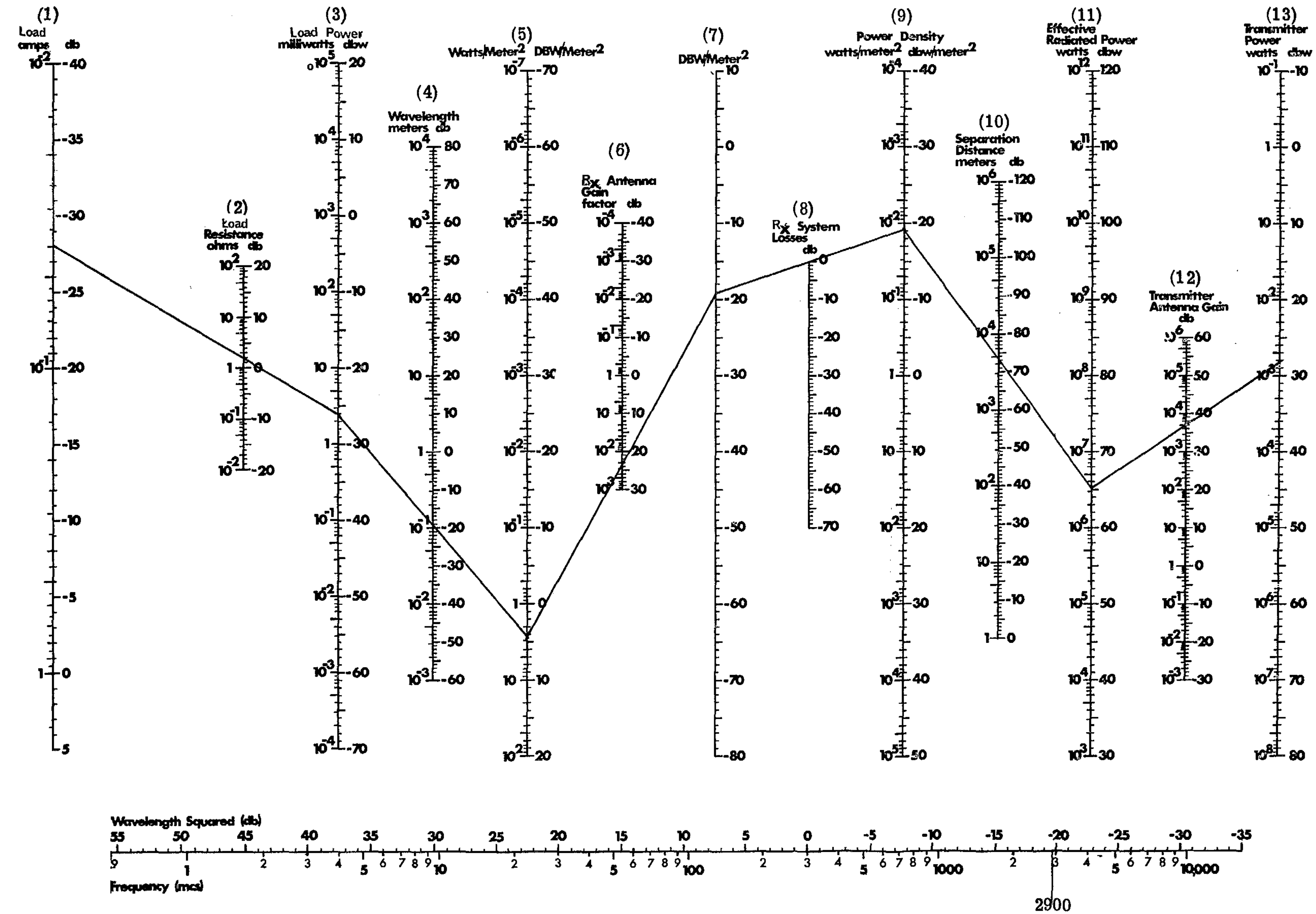
Commander
Air Force Flight Test Center
Attention: FTOOE
Edwards Air Force Base, California

6. Air Proving Ground Center:

Commander
Air Proving Ground Center
Attention: PGLOC-2
Eglin Air Force Base, Florida

EXAMPLE 3

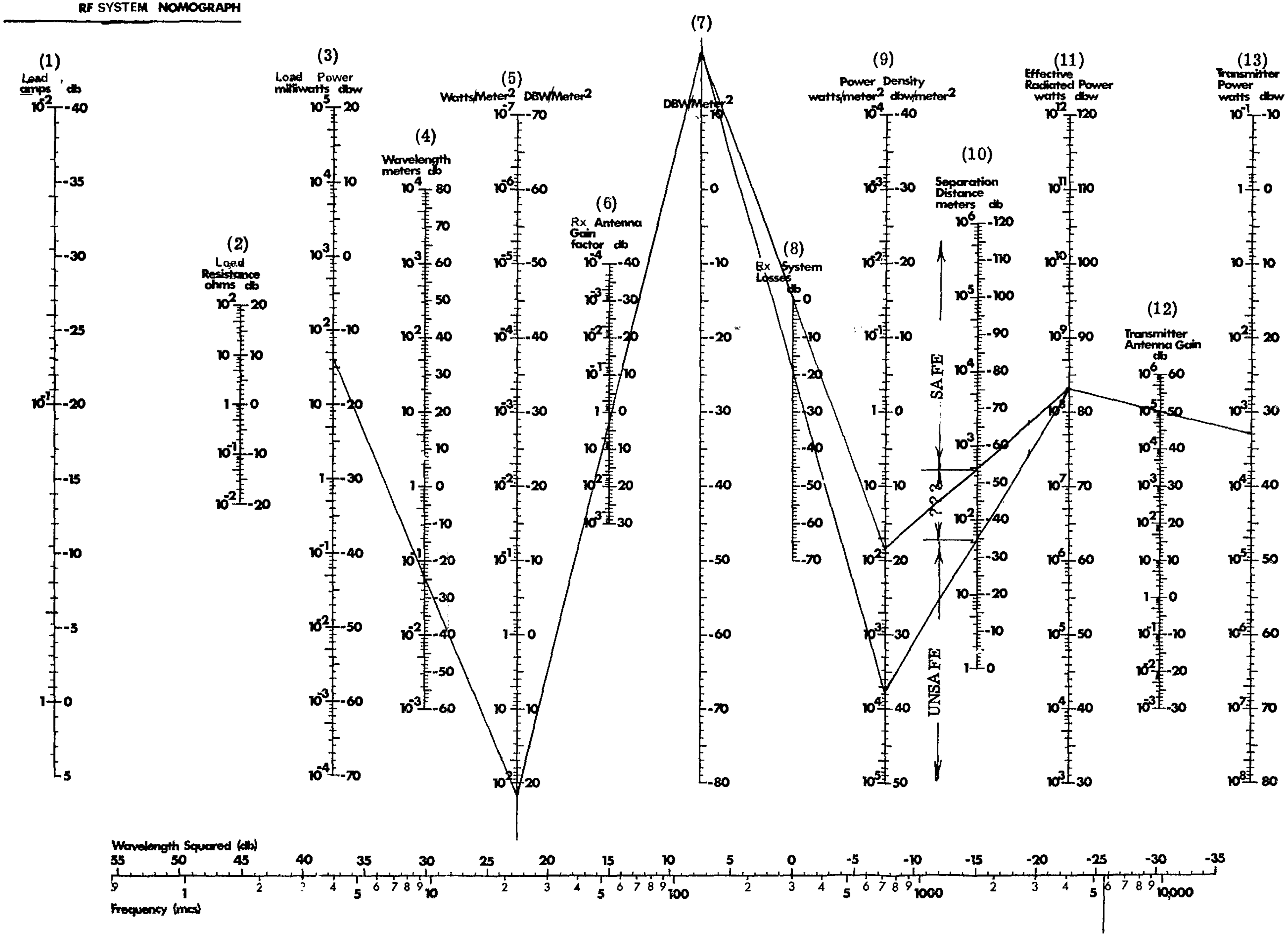
RF SYSTEM NOMOGRAPH



EXAMPLE 3

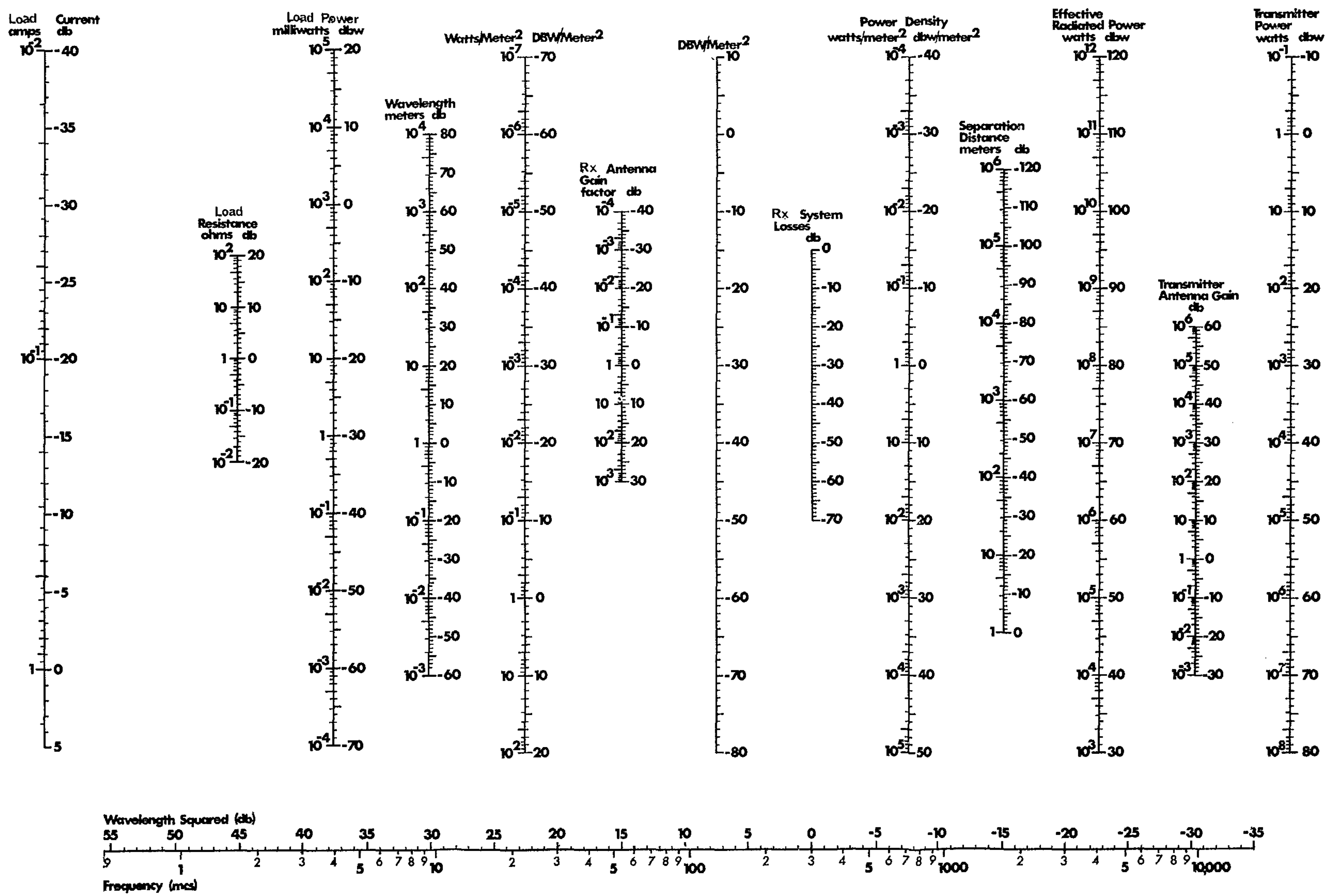
EXAMPLE 4

RF SYSTEM NOMOGRAPH



EXAMPLE 4

RF SYSTEM NOMOGRAPH



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