

20 to 1000 MHz ANTENNAS DEVELOPED BY ROBERTS

In 1957, W. K. Roberts, who was then a member of the staff of the FCC Laboratory, measured the voltage standing-wave ratio of the dipole antennas supplied with certain commercial models of field strength meters. He found that the VSWR values were high enough to lead to some uncertainties in the calibrations of these instruments. This was because the measuring sets also had high VSWR's on their most sensitive ranges; the combination of mismatches at both ends of the antenna transmission line would cause the indicated field strength to vary cyclically with varying frequency. The scale factor of the cyclic variation would depend upon the precise length of the cable.

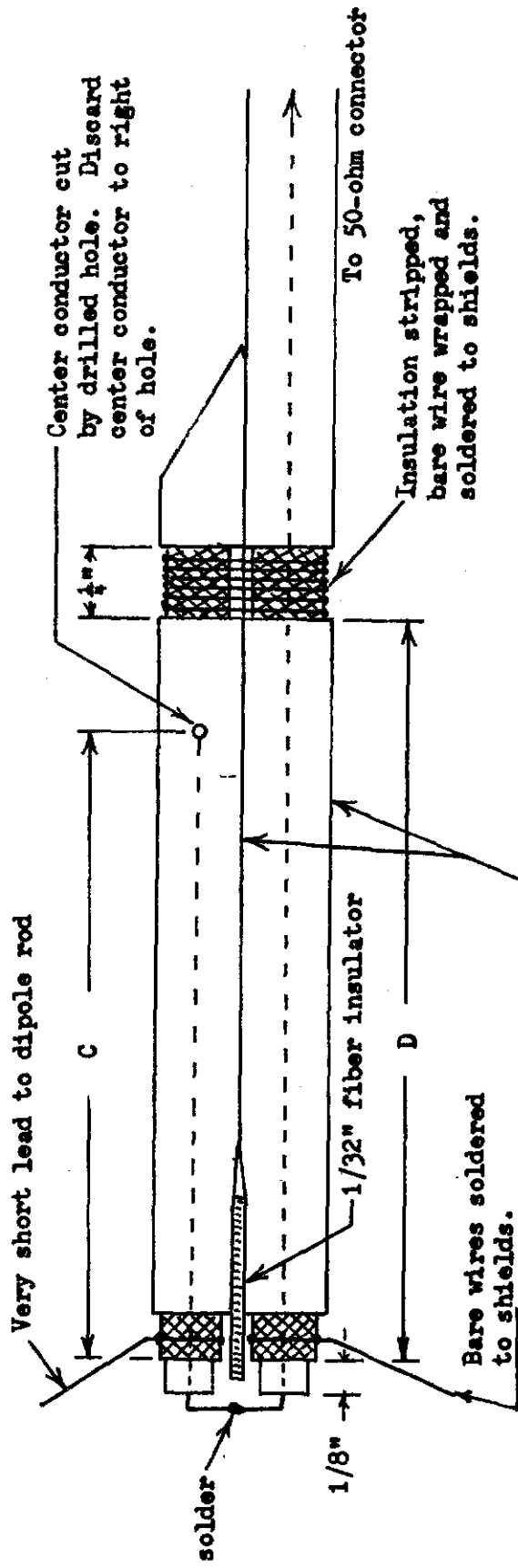
Also in 1957, Roberts developed a wide-band balun suitable for matching the 70-ohm dipole impedance (at resonance) to the 50-ohm line impedance which is common in U. S. field strength meters and spectrum analyzers. The word "balun" also indicates that the device is a transformer between the balanced impedance of the dipole and the unbalanced impedance of the line. A paper describing the operation of the new balun was published: "A New Wide-Band Balun," by Willmar K. Roberts, Proceedings of the IRE, December, 1957, page 1628.

Construction details of the new balun are given in Figures 7 and 8. Figure 8 also shows the equipment setup for measuring the loss of a balun by measurement of the loss of a pair of identical units.

The voltage standing-wave ratio and attenuation of a typical balun of this type are shown in Figure 9. There are small losses in the coaxial cables used in the balun, such that the loss of a typical unit averages about 0.25 dB. This small loss also flattens the curve of VSWR, which should be close to 1.0 near 90 and 180 MHz, but which should theoretically approach 1.4 near 135 MHz.

Because of the good performance and simple construction, this balun design has been widely used by the FCC, and the construction details have been made available to interested persons. The balun can be described as a compensated balun, in which the wide bandwidth is a result of nearly perfect compensation of the impedance of the balun arms at two frequencies by the impedance of the open-ended stub in the upper transmission line of the balun. The design impedance is 50 ohms.

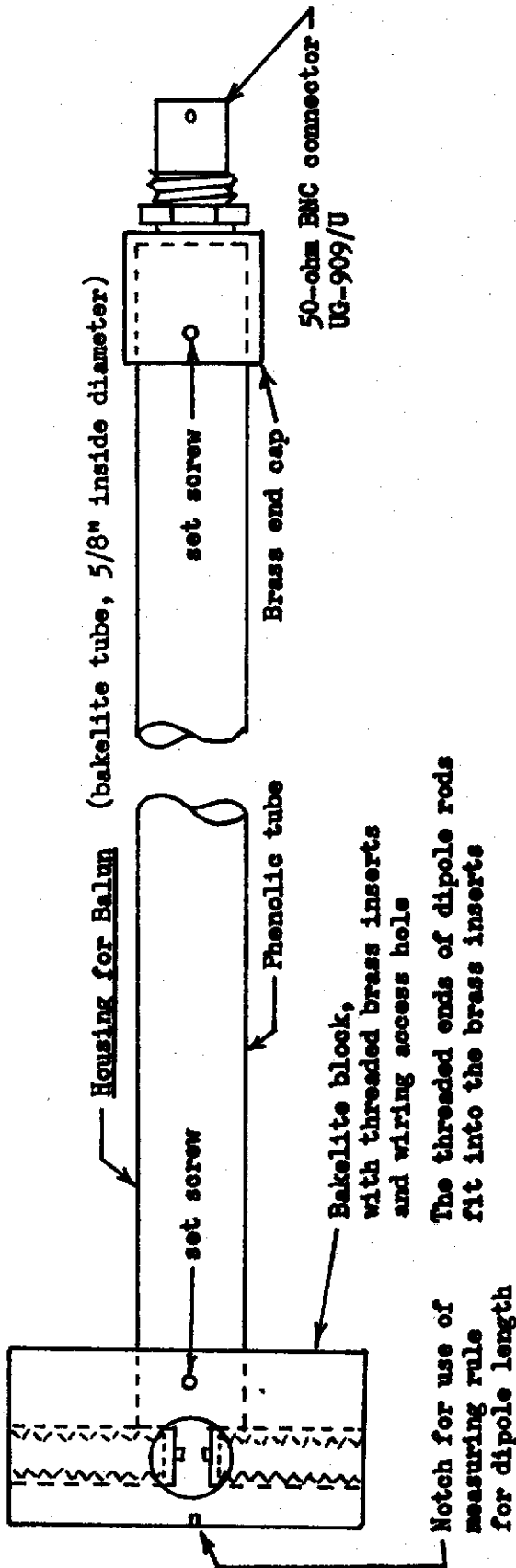
In 1965, Roberts developed an extra-wide-band version of the balun by placing a spacer between the balun arms. Proper compensation would require a non-standard low value of characteristic impedance for the impedance-compensating stub. Instead, compensation was achieved by a series L - C circuit, in which the inductance is that of the leads of the capacitor. Some adjustment of the inductance is necessary to obtain proper operation at the high end of the frequency range. Figure 10 gives the details of this balun, which is also widely used by the Commission. This balun also has a design impedance of 50 ohms.



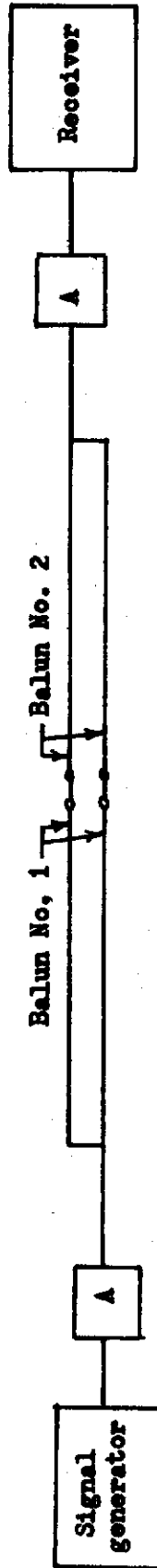
Cable material: RG-58/U — Lace cables together with lacing cord, $\frac{1}{8}$ " between laces.

<u>Frequency range</u> Megahertz	<u>Length C</u> inches	<u>Length D</u> inches
20 - 65	43.3	43.3
65 - 180	14.2	16.25
180 - 400	6.125	7.5
400 - 1000	2.7	3.0
220 - 450	5.5	6.625

Figure 7. CONSTRUCTION OF BALUNS FOR FIELD STRENGTH MEASURING DIPOLE ANTENNAS, AS DEVELOPED BY W. K. ROBERTS



A = 50-ohm attenuators



Measurement of attenuation of balun. Two identical baluns are used. The connections should be reversed, and the attenuation of the average of the two connections is considered to be twice the attenuation of a single balun.

Reference: Willmar K. Roberts, "A New Wide-Band Balun," Proceedings of the IRE, December, 1957, page 1628.

Figure 8. HOUSING FOR BALUN, AND MEASUREMENT OF ATTENUATION OF BALUN, AS DEVELOPED BY W. K. ROBERTS

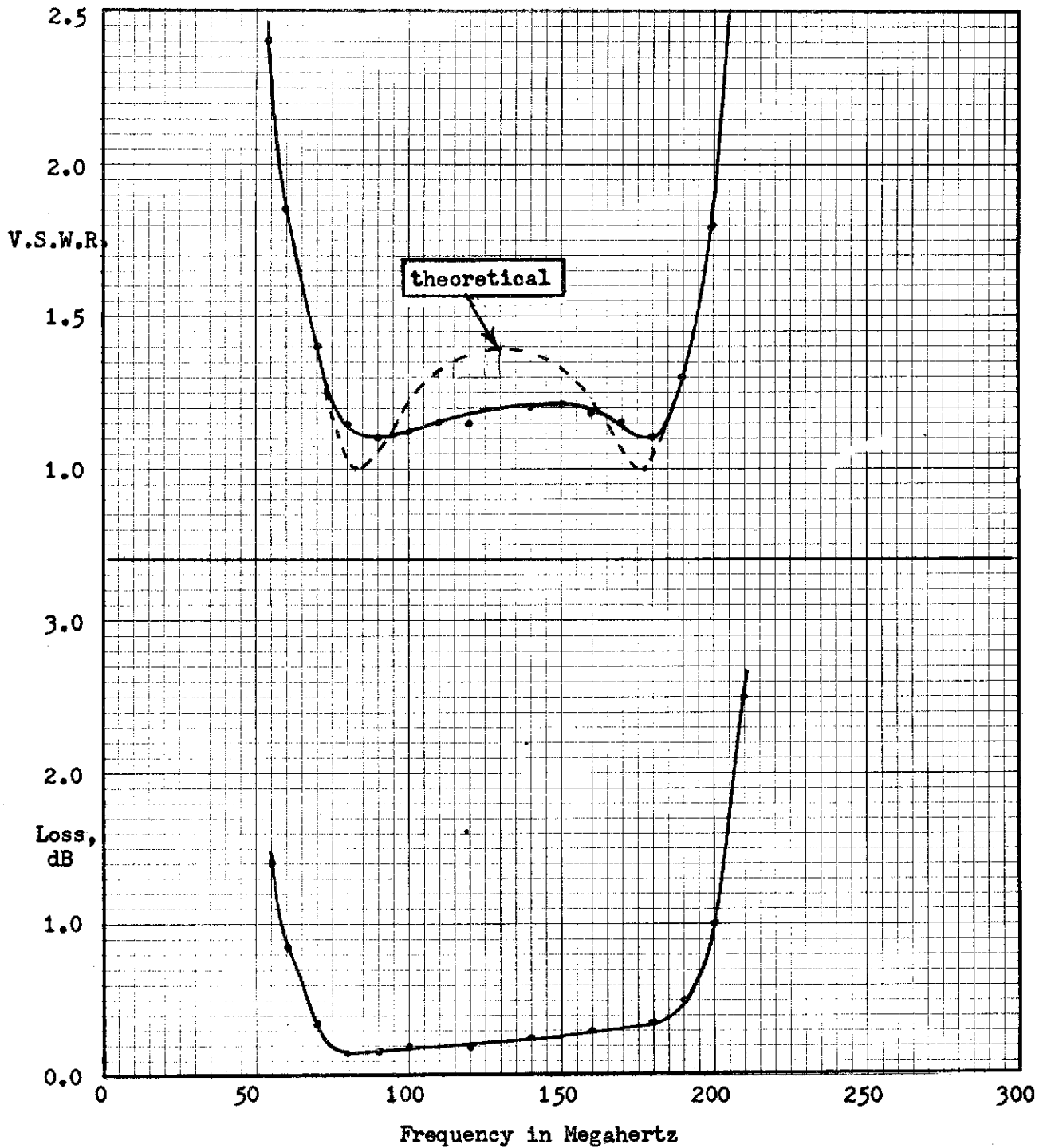


Figure 9. Voltage standing-wave ratio and loss of typical Roberts balun. VSWR relative to 50 ohms was measured with a 70-ohm resistor connected to balanced end. Loss was measured as one-half the loss of identical baluns connected together at their balanced ends.

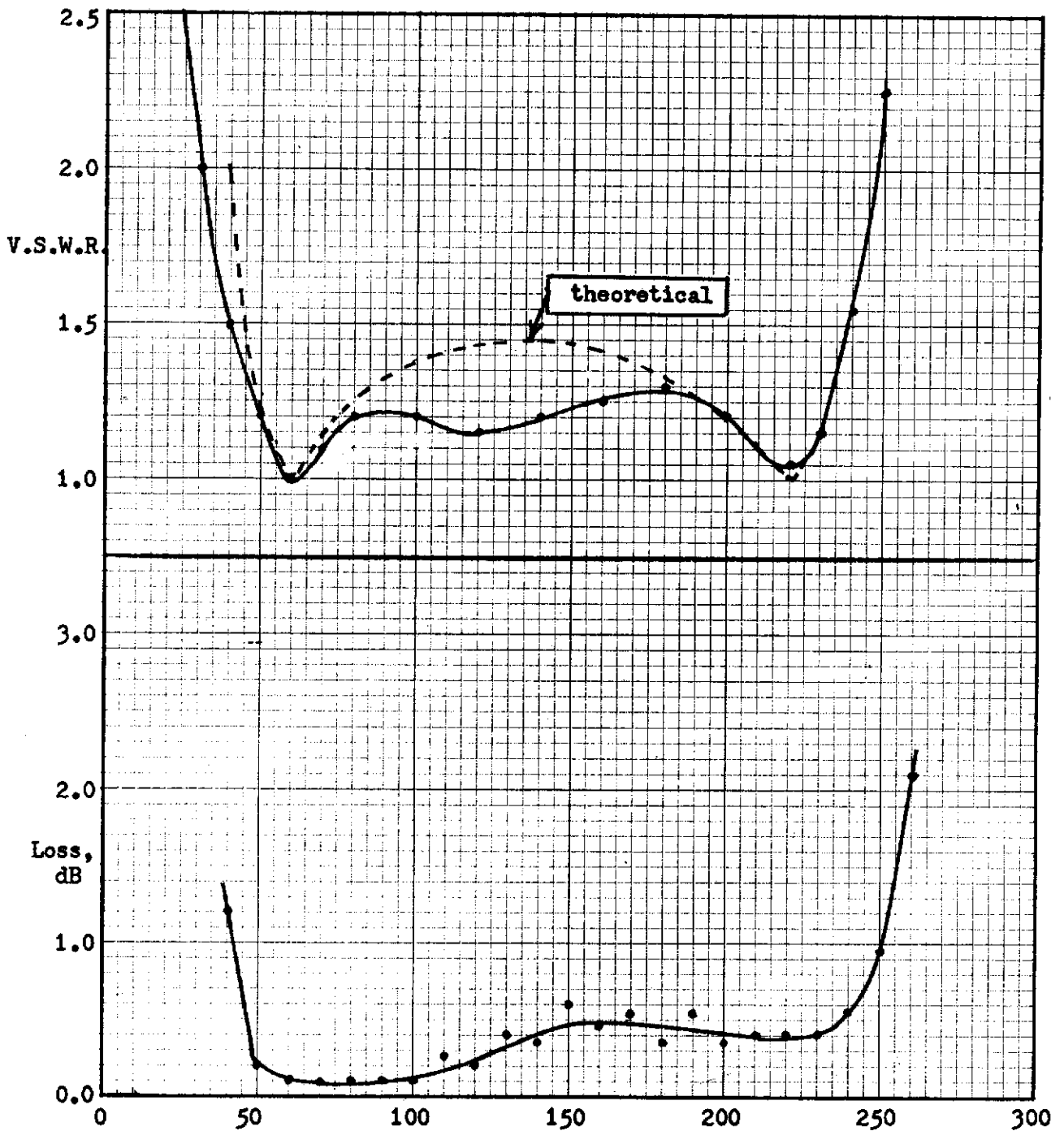


Figure 11. Voltage standing-wave ratio and loss of Roberts extra-wide-band balun. VSWR relative to 50 ohms was measured with a 70-ohm resistor connected to balanced end. Loss was measured as one-half the loss of identical baluns connected together at their balanced ends.

ANTENNA FACTOR CALCULATION

This section deals with the calculation of antenna factor for field strength measurements. In general:

$$\text{Field strength} = \text{Received voltage} + \text{Antenna factor}$$

(dB above 1 uV/meter) (dB above 1 uV) (dB per meter)

The receiving area of an antenna is defined by:

$$A = \frac{G \lambda^2}{4\pi} \quad \text{square meters}$$

The power received by the antenna then:

$$P_r = PA = \frac{PG \lambda^2}{4\pi} \quad \text{watts}$$

where: P = power density in watts per square meter
 G = antenna gain (power gain over isotropic)
 λ = wavelength in meters

But the field strength E is related to the power density by:

$$E = \sqrt{120 \pi P} \quad \text{volts per meter}$$

Combining the previous two equations, we have:

$$P_r = \frac{E^2 G \lambda^2}{480 \pi^2} \quad \text{watts}$$

The received power is given by:

$$P_r = \frac{V^2}{Z_o} \quad \text{watts}$$

where: V = received voltage
 Z_o = receiver input impedance

Then:

$$\frac{V^2}{Z_o} = \frac{E^2 G \lambda^2}{480 \pi^2}$$

But:

$$\lambda = \frac{300 \text{ meters per second}}{f \text{ (MHz)}}$$

Therefore:
$$E = \frac{V f \pi}{75} \sqrt{\frac{30}{Z_o G}} \quad (f = \text{frequency, MHz})$$

But the antenna factor $K = \frac{E}{V}$, then:
$$K = \frac{f \pi}{75} \sqrt{\frac{30}{Z_o G}}$$

Or, in logarithmic form: $K = 20 \log f \text{ (MHz)} - G \text{ (dB)} - 29.78 \text{ (dB)}$
 (for Z_o = 50 ohms)

ANTENNA FACTOR CALCULATION, cont'd.

Example of antenna factor calculation for a 50-ohm measuring system:

Let $V = 96$ microvolts = +39.6 dBuV (the received voltage)

$f = 102.5$ MHz

$G = +1.5$ dB (the antenna gain over isotropic)

Then:

$K = 20 \log f \text{ (MHz)} - G \text{ (dB)} - 29.78 \text{ (dB)}$

$K = 40.214 - 1.5 - 29.78$

$K = 8.934$ dB

But: $E \text{ (dBuV/meter)} = V \text{ (dBuV)} + K \text{ (dB)}$

$E = +39.6 + 8.934 = 48.534$ dB above 1 uV/meter

$E = 267$ microvolts per meter

This logarithmic calculation is usually most convenient, because many modern field strength meters have indications calibrated in dB above one microvolt, and their furnished antenna factors are in dB.

CALCULATION OF FIELD STRENGTH WHEN THE MEASURING SET IS CALIBRATED IN DBM RATHER THAN IN DB ABOVE 1 MICROVOLT

At microwave frequencies, and sometimes at lower frequencies, the signal levels are often calibrated in dBm (decibels relative to 1 milliwatt.) Following a similar derivation, the preceding formulas lead to:

$$E = \frac{\pi f}{75} \sqrt{\frac{30 P_r}{G}} \quad (\text{volts per meter}), \text{ (MHz)}, \text{ (Watts)}$$

$$\text{and } E = 20 \log f + 77.213 - G + P_r$$

(dBuV/m) (MHz) (dB) (dB) (dBm)

Example: $f = 10,525$ MHz, $G = 15.2$ dB, $P_r = -30.5$ dBm:

$E = 80.444 + 77.213 - 15.2 - 30.5$

$E = 111.95$ dB above 1 uV/meter = 0.396 volts/meter

ANTENNA FACTOR OF A HALF-WAVE RESONANT DIPOLE ANTENNA

A half-wave resonant dipole antenna has a directional pattern shaped like a figure 8. Its impedance at resonance is of the order of 70 ohms, resistive. (The theoretical thin dipole's resistance is slightly over 73 ohms.) The theoretical power gain of the thin resonant dipole is 1.64, which corresponds to 2.15 dB over a theoretical isotropic antenna. The power gain of an actual dipole is very close to the same value, because gain is related to pattern shape, and the pattern of the real antenna is practically the same as the pattern of the theoretical dipole.

Losses in the antenna itself are practically negligible. Mismatch loss is also negligible if a balun having excellent impedance-matching characteristics is used. However, allowances should be made for balun loss and for loss in the transmission line leading from the balun to the field strength meter (or spectrum analyzer). (It is assumed here that the measuring set's input impedance is designed for the impedance of the transmission line.)

Referring to the formula for antenna factor for any antenna, derived in the preceding section entitled "Antenna Factor Calculation," we have:

$$\begin{array}{l} \text{Antenna Factor} = 20 \log_{10} f_{(\text{MHz})} - G_{(\text{dB})} - 29.78_{(\text{dB})} \\ \text{(any antenna)} \\ \text{(50-ohm system)} \end{array}$$

This formula may now be adjusted for the gain of a dipole, and for balun loss and cable loss as follows:

$$\begin{array}{l} \text{Antenna Factor} = 20 \log_{10} f_{\text{MHz}} - 2.15 + B + C - 29.78 \text{ (dB)} \\ \text{(half-wave dipole)} \\ \text{(50-ohm system)} \end{array}$$

or:

$$\begin{array}{l} \text{Antenna Factor} = 20 \log_{10} f_{(\text{MHz})} + B + C - 31.93 \text{ (dB)} \\ \text{(half-wave dipole)} \\ \text{(50-ohm system)} \end{array}$$

where B = balun loss, dB at frequency f

C = cable loss, dB at frequency f