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Effective radiated power

by

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Abstract

Effective Radiated Power (ERP) is the amount of power that must be delivered to an ideal half-wavelength dipole to produce a given signal level. This note presents the basic relationships among power, gain, and field strength. It then provides methods for calculating effective radiated power from total radiated power, effective isotropic radiated power (EIRP), and field strength.

Indexing Terms

Radio, amateur
Communication, MF

1. INTRODUCTION

This note presents the basic relationships among power, gain, and field strength. It also provides methods for calculating effective radiated power (ERP) from total radiated power, effective isotropic radiated power (EIRP), and field strength.

The FCC defines [1] "Effective Radiated Power" in terms of an ideal half-wavelength dipole. ERP is in effect the power that must be delivered to the dipole in order to produce the field strength in question.

2. BASIC RELATIONSHIPS

The basic relationship among power, gain, and field strength is (from (1) of [RN93-6])

$$W = \frac{G\,P_t}{4\pi d^2} = \frac{e_z^2}{2\eta_0} \tag{1}$$

where

W = power density in W/m^2,
G = gain relative to an isotropic radiator (dBi),
P = power delivered to the antenna (W),
d = distance (m),
e_z = electric-field strength (V/m, peak), and
η_0 = free-space impedance (377 Ω).

The first quantity in (1) represents the radiated power spread over the surface area of a sphere of radius *d*. The second quantity is the power density associated with a given electric field.

3. GAINS

Gain *G* accounts for variation in the antenna pattern as well as losses in the ground and antenna itself. In general, gain varies with direction. As used in (1), the gain is defined with respect to power that spreads uniformly over the surface of a sphere; i.e., an ideal *isotropic* radiator.

The radiation patterns of an isotropic radiator, short monopole, and half-wave dipole are shown in Figure 1 as functions of elevation angle β. For an isotropic radiator with no loss,

$$G_I = 1 = 0 \text{ dBi} \quad . \tag{2}$$

Based upon the radiation patterns given by Krauss (Section 5-5 of [2]), the gain of a short, lossless monopole over an ideal ground at zero elevation is

$$G_M = 3 = 4.77 \text{ dBi} \quad . \tag{3}$$

The gain of a half-wave dipole in free space is similarly derived from Section 5-7 of [2] as

$$G_D = 1.644 = 2.16 \text{ dBi} \quad . \tag{4}$$

Most of the difference in the gains of the monopole and half-wavelength dipole is due to compression of the radiation from the monopole into the hemisphere above the ground. For example, the gain of a quarter-wave monopole is 3 dB higher than that of a half-wave dipole. The rest of the difference is due to changes in the shape of the pattern.

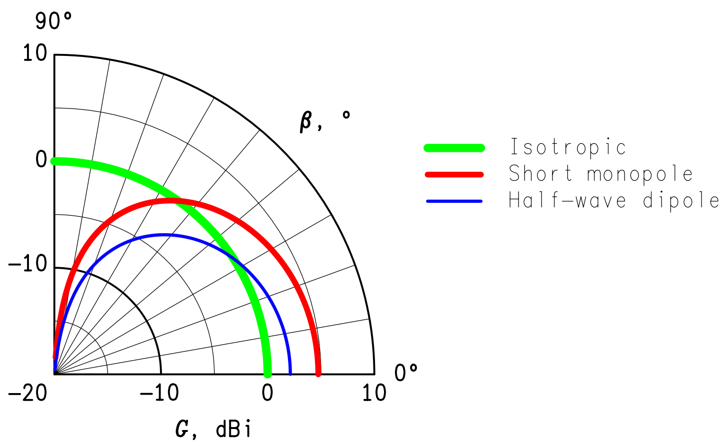

Figure 1. Antenna patterns.

4. ERP FROM RADIATION RESISTANCE OR POWER TO ANTENNA

The radiation resistance R_r can often be calculated from standard equations for a given antenna. Given R_r and the peak current I delivered to the antenna, the *Total Radiated Power* is

$$P_t = I^2 R_r / 2 \quad . \tag{5}$$

The *Effective Isotropic Radiated Power* is then given by

$$P_{\text{EIRP}} = G P_t \quad . \tag{6}$$

For example, the EIRP of a short monopole in the horizontal plane (zero elevation) is 4.77 dB larger than the total radiated power.

Since ERP is defined with respect to a half-wave dipole, it is given by

$$P_{\text{ERP}} = P_{\text{EIRP}} / G_D = G P_t / G_D \quad . \tag{7}$$

Thus for a short monopole, the ERP is 4.77 - 3.0 = 1.77 dB (factor of 1.82) larger than the total radiated power.

5. ERP FROM FIELD STRENGTH

If field strength e_z is measured, the power density at the measurement distance can be calculated from the right side of (1). Given the power P_t delivered to the antenna, the gain can then be calculated from the left side of (1). Once gain is known, ERP can be calculated from (7).

Equation (1) and hence this method of calculating gain and ERP are based upon a free-space variation of field strength with the inverse of distance. The distance at which the measurements are made must therefore be chosen to avoid both the near-field and surface-wave regions.

Four criteria must be considered in selecting the distance at which the field strength is measured:

- Good signal strength,
- Far enough to be out of near field,
- Near enough to be in inverse-distance (free-space) region, and
- Away from conductors and other objects that might alter the amplitude of the field.

Near a monopole antenna, the electric field varies with the inverse-cube of distance. The near field and radiated field are equal at a distance of λ/π, which is 95 meters for 500 kHz. The measurement distance should be well beyond this transition distance to avoid corruption by the near field.

As distance increases further, the variation of field strength with distance transitions from $1/d$ for free space to $1/d^2$ for a flat-earth surface wave. The surface-wave attenuation factor (Figure 2) for ground of conductivity σ and permittivity ε_r is given approximately (208a) of [3] as

$$A = \frac{2 + 0.3p}{2 + p + 0.6p^2} - (p/2)^{1/2} \exp(-5p/8) \sin b \, , \tag{8}$$

where

$$x = 60\,\sigma\,\lambda \quad , \tag{9}$$

$$b = \arctan[(\varepsilon_r + 1)/x] \, , \tag{10}$$

and

$$p = (\pi d/\lambda x)\cos b \tag{11}$$

is the numerical distance. Basically, $p \ll 1$ for free-space $1/d$ attenuation and $p \gg 1$ for for surface-wave $1/d^2$ attenuation. For typical ground conductivities of 0.01 to 0.001 S/m, the transition from $1/d$ to $1/d^2$ attenuation occurs at 3 to 30 km.

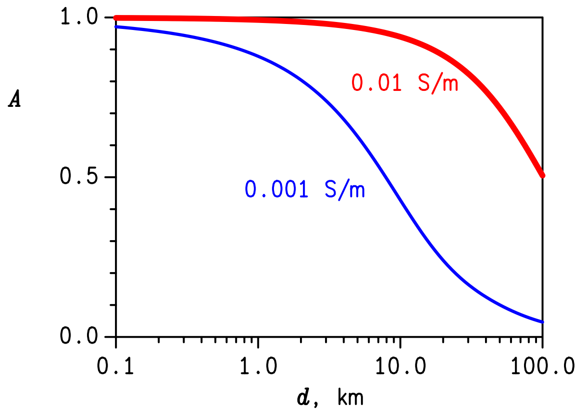

Figure 2. Surface-wave attenuation factor.

Overall, a distance of about 0.5 to 1 km is best for field-strength measurement. The near field causes no more than a 4-percent error, and the effects of surface-wave propagation cause no more than a 12-percent error.

6. REFERENCES

[1] FCC rules, 47 CFR, Subpart A, Section 2.1., Oct. 1, 2005.

[2] J. D. Krauss, *Radio Astronomy*. New York: McGraw-Hill, 1966. [BOK26]

[3] F. E. Terman, *Radio Engineering*, Second Edition. New York: McGraw-Hill, 1937. [BOK87]