Federal Communications Commission
Office of Engineering and Technology
Laboratory Division

August 7, 2015

GUIDELINES FOR DETERMINING THE EFFECTIVE RADIATED POWER (ERP) AND EQUIVALENT ISOTROPICALLY RADIATED POWER (EIRP) OF AN RF TRANSMITTING SYSTEM

1. Introduction

Many FCC rule parts specify power and/or emission limits in terms of the transmitter system (transmitter, radiating antenna, and cable connector) effective radiated power (ERP) or equivalent (or effective) isotropically radiated power (EIRP).

These guidelines are intended to demonstrate how to determine the EIRP or ERP from the results of a power measurement performed under far-field conditions with respect to all transmit and receive (measurement) antennas.

EIRP and ERP are similarly defined as the product of the power supplied to the antenna and the antenna gain (when the power and gain are represented in linear terms). The primary difference is that for ERP the antenna gain is expressed relative to an ideal half-wave dipole antenna, whereas with EIRP the antenna gain is expressed relative to an ideal (theoretical) isotropic antenna. EIRP and ERP can be expressed mathematically as described in the following sections.[1]

1.1. Field Strength Approach (linear terms):

$$\mathbf{eirp = p_t \times g_t = (E \times d)^2/30} \qquad (1)$$

where:

- $\mathbf{p_t}$ = transmitter output power in watts,
- $\mathbf{g_t}$ = numeric gain of the transmitting antenna (unitless),
- **E** = electric field strength in V/m,
- **d** = measurement distance in meters (m).

$$\mathbf{erp = eirp/1.64 = (E \times d)^2/(30 \times 1.64)} \qquad (2)$$

where all terms are as previously defined.

[1] Derivations of the equations presented herein are not provided in this document. Readers interested in how these equations are derived are referred to NTIA Technical Memorandum TM-10-469, *Derivations of Relationships among Field Strength, Power in Transmitter-Receiver Circuits and Radiation Hazard Limits,* F. H. Sanders, U.S. Department of Commerce, National Telecommunications and Information Administration, June, 2010.

1.2. Power Approach (logarithmic terms):

$$\textbf{ERP or EIRP} = P_T + G_T - L_C \quad (3)$$

where;

- **ERP or EIRP** = effective radiated power or equivalent isotropically radiated power (expressed in the same units as P_T, typically dBW, dBm, or power spectral density (PSD)[2]), relative to either a dipole antenna (ERP) or an isotropic antenna (EIRP);
- $\mathbf{P_T}$ = transmitter output power, expressed in dBW, dBm, or PSD;
- $\mathbf{G_T}$ = gain of the transmitting antenna, in dBd (ERP) or dBi (EIRP);
- $\mathbf{L_C}$ = signal attenuation in the connecting cable between the transmitter and antenna, in dB.[3]

1.3. Relationship Between ERP and EIRP:

The numeric gain of an ideal half-wave dipole antenna is 1.64 and the numeric gain of an ideal isotropic antenna is 1.0.

The gain of an ideal half-wave dipole antenna relative to an ideal isotropic antenna is 10log1.64 or 2.15 dBi.

Therefore, if the antenna gain in dBd is unknown, it can be determined from the gain in dBi via the following relationship:

$$G_T(\text{dBd}) = G_T(\text{dBi}) - 2.15 \text{ dB}. \quad (4)$$

Alternatively, the EIRP can be determined from Equation (3) and then converted to ERP based on the maximum antenna gain relationship by applying the following equation:

$$\text{ERP} = \text{EIRP} - 2.15 \text{ dB}. \quad (5)$$

Similarly, the EIRP can be determined from the ERP as follows:

$$\text{EIRP} = \text{ERP} + 2.15 \text{ dB}. \quad (6)$$

2. Applications

The following paragraphs discuss the appropriate methods for applying the equations presented above depending on the power measurement configuration used.

2.1. DUT power measured in a conducted test configuration

[2] Power spectral density (PSD) is often used to characterize the power in a noise-like (*e.g.*, digitally modulated) signal by expressing the output power over a specified reference bandwidth.

[3] NOTE: In personal/portable radios utilizing an integral antenna, this factor is typically negligible. However, in a fixed station transmit system that utilizes a long cable run between the transmitter and the transmitting antenna, this factor can be significant.

When the DUT power is measured using a direct connection between the transmitter antenna port and the measurement instrumentation via a coaxial cable (conducted test), and the transmit antenna gain is a known quantity, then the ERP and/or EIRP can be calculated by direct application of Equation (3) and using the relationships defined in Equations (4), (5), or (6), as appropriate.

The value to be used for $\mathbf{P_T}$ in these equations is the measured power level (in dBm, dBW or PSD), adjusted to account for external test peripherals (cable loss, external attenuation, and/or external amplification).

The value to be used for $\mathbf{G_T}$ is the gain associated with the DUT transmit antenna, expressed in either dBd (ERP) or dBi (EIRP). Typically, the maximum rated antenna gain is used in determining the maximum ERP or EIRP levels at or near the fundamental frequency; however, this practice can lead to conservative (*i.e.*, overestimated) values when applied to spurious emissions on frequencies that are well removed from the frequency range over which the transmit antenna is presumed to have been optimized.

The value used for $\mathbf{G}_\mathrm{T}$ may require some adjustment for devices that utilize multiple transmit antennas (*e.g.*, MIMO) and/or beam forming or beam steering (*e.g.*, Smart Antenna) technologies. In such configurations, an adjustment to the transmit antenna gain used in calculating the ERP or EIRP may be required. For additional guidance on determining and applying this adjustment factor, refer to clauses 13 and 14 in ANSI C63.10-2013 and FCC guidance provided in KDB Publication 662911.

2.2. Direct calculation from the DUT power measured in a radiated test configuration (*i.e.*, signal/antenna substitution techniques not used).

When the DUT power is measured using a radiated test configuration, the EIRP can be mathematically approximated using the power (logarithmic) approach as follows:

$$\mathbf{EIRP = P_R + L_P} \tag{7}$$

where;

- **EIRP** = equivalent (or effective) isotropically radiated power (in same units as P_R);
- $\mathbf{P_R}$ = adjusted received power level, in dBW, dBm, or PSD;
- $\mathbf{L_P}$ = basic free space propagation path loss, in dB.

The received power level $\mathbf{P_R}$ is the measured power adjusted for measurement antenna gain, connecting cable loss, and any external signal amplification or attenuation used in the test configuration. Mathematically:

$$\mathbf{P_R = P_{Meas} - G_R + L_C + L_{Atten} - G_{Amp}} \tag{8}$$

where;

- $\mathbf{P_{Measured}}$ = measured power level, in dBW, dBm or psd;
- $\mathbf{G_R}$ = gain of the receive (measurement) antenna, in dBi;
- $\mathbf{L_C}$ = signal loss in the measurement cable, in dB;
- $\mathbf{L_{Atten}}$ = value of external attenuation (if used), in dB;

- $\mathbf{G_{Amp}}$ = value of external amplification (if used), in dB.

The free space propagation path loss $\mathbf{L_P}$ is determined from the following equation:

$$\mathbf{L_P = 20 \, Log \, F + 20 \, Log \, D - 27.5} \quad (9)$$

where:

- $\mathbf{L_P}$ = basic free space propagation path loss, in dB;
- **F** = center frequency of radiated DUT signal, in MHz;
- **D** = measurement distance, in meters.

The ERP can then be determined from the EIRP by applying Equation (5).

When the DUT power is measured using a radiated test configuration, the eirp can be directly determined using the field strength (linear) approach by applying Equation (1).

The erp can then be determined from the eirp by applying Equation (2).

2.3. DUT power measured in a radiated test configuration using signal/antenna substitution techniques.

The ERP/EIRP can be determined from the power setting of a signal generator used in the signal/antenna substitution test configuration as follows:

$$\mathbf{ERP \text{ or } EIRP = P_{SigGen} + G_T - L_C} \quad (10)$$

where:

- $\mathbf{P_{SigGen}}$ = power setting of the signal generator that produces the same received power reading as the DUT, in dBm, dBW or psd;
- $\mathbf{G_T}$ = gain of the substitute antenna, in dBd (ERP) or dBi (EIRP);
- $\mathbf{L_C}$ = signal loss in the cable connecting the signal generator to the substitute antenna, in dB.

Change Notice

08/07/2015: 412172 D01 Determining ERP and EIRP v01r01 replaces 412172 D01 Determining ERP and EIRP v01. Changes made to discuss far field measurements, spurious emissions, reference to ANSI C63.10-2013 and editorial edits.