THE EFFECT OF RANGE LENGTH ON THE MEASUREMENT OF TRP

James D. Huff
Carl W. Sirles

The Howland Company, Inc.
4540 Atwater Court, Suite 107
Buford, Georgia 30518

Abstract

Total Radiated Power (TRP) and Total Isotropic Sensitivity (TIS) are the two metrics most commonly used to characterize the over the air (OTA) performance of a handheld wireless device. The minimum range length for these measurements has usually been determined using the far-field criteria of $R>2D^2/\lambda$. Since the devices are relatively small (<30cm) and the frequencies relatively low (<2GHz), the range length required to meet the far-field criteria is less than 120 cm. However, wireless devices are being designed that operate at the higher frequencies of the IEEE 802.11 standards, and many of these devices are no longer small handheld devices but rather notebook computers, appliances or even vehicles. Applying the far-field criteria to testing such devices can generate requirements for large and expensive chambers. This paper demonstrates through both numerical simulations and actual measurements that accurate TRP and TIS measurements can be made at range lengths significantly shorter than those indicated by $R>2D^2/\lambda$.

Keywords: **far-field, OTA, TIS, TRP, wireless**

1. Introduction

The generally accepted criteria for the separation of the source antenna and the antenna under test (AUT) is that the separation R should be greater than or equal to $2D^2/\lambda$, where D is the diameter of the AUT and λ is the wavelength at the test frequency. This has come to be known as the far-field criteria and is the main driver in determining the chamber size required for a measurement. In most cases a test separation of greater than $2D^2/\lambda$ is appropriate. However, in the wireless industry we have cases where testing at a distance of $2D^2/\lambda$ does little to improve the accuracy of the measurements.

2. The TRP Measurement

One of the most common parameters measured on a wireless device is the total radiated power (TRP). The measurement is made by placing the device under test (DUT) in an anechoic chamber on a two axis positioning system and the DUT positioned to different coordinates in a spherical coordinate system. The transmitted power is then sampled at equally spaced increments in phi and theta over the entire sphere surrounding the DUT. These relative power measurements are then converted to Effective Isotropic Radiated Power (EiRP) using a range reference measurement. The EiRP values are then weighted by the sine of theta and summed to calculate the total radiated power.

3. The Basic Concept

TRP is measured by sampling the radiated power over a spherical surface surrounding the DUT. In Figure 1 we have two spheres surrounding a device transmitting power P_0. It is obvious that the same total power that radiates outward from the DUT passes through both the large sphere and the small sphere on its way to infinity. Therefore in concept it should be possible to make accurate TRP measurements at distances much shorter than those indicated by the far-field criteria of $R>2D^2/\lambda$.

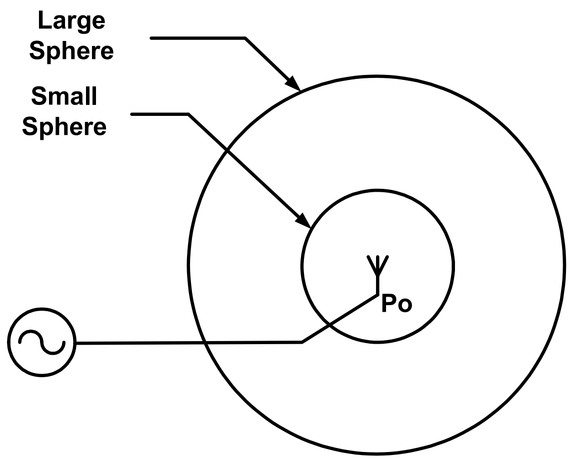

Figure 1
The Basic Concept

4. The Mathematics of TRP

TRP is defined as

$$TRP = \oint U(\theta,\phi) d\Omega$$

Where U is the radiation intensity in watts per steradian.

$$d\Omega = \sin(\theta) d\theta d\phi$$

which yields

$$TRP = \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} U(\theta,\phi) \sin(\theta) d\theta d\phi$$

By definition

$$EiRP(\theta,\phi) = P_T G_T(\theta,\phi) = 4\pi U(\theta,\phi)$$

and

$$U(\theta,\phi) = \frac{EiRP(\theta,\phi)}{4\pi}$$

and finally we get

$$TRP = \frac{1}{4\pi} \int_{\theta=0}^{\pi} \int_{\phi=0}^{2\pi} EiRP(\theta,\phi) \sin(\theta) d\theta d\phi$$

What is actually measured is a relative power that must be corrected to get EiRP. The received power P_r in our measurement can be expressed as

$$P_r = P_o G_t(\theta,\phi) G_r(\theta,\phi) \left(\frac{\lambda}{4\pi R} \right)^2$$

Where

- P_0 is the transmitted power of the DUT
- G_t is the gain of the DUT
- G_r is the gain of the measurement antenna
- λ is the wavelength at the measurement frequency
- R is the separation of the DUT and the measurement antenna

EiRP can be expressed as

$$EiRP = P_o G_t(\theta,\phi)$$

And we will define path loss PL as

$$PL = G_r(\theta,\phi) \left(\frac{\lambda}{4\pi R} \right)^2$$

Therefore

$$EiRP = \frac{P_r}{PL}$$

This shows us that if we measure the received power in dBm and we measure the range loss in dB, we can subtract the range loss from the received power to convert our relative measurements into absolute measurements of EiRP.

5. The Implications of the Mathematics

There are four implications that that can be found in the mathematics of TRP.

1. The effect of R is taken out by the range reference measurement
2. The frequency dependence is also taken out by the range reference measurement
3. If a dipole is used to make the range reference measurement, then the range reference measurement can be made at very short range lengths.
4. An accurate power measurement is required. This implies that the measurement antenna must be outside of the reactive near-field of the DUT.

6. Measurement Simulations

In order to investigate the effects of range length and DUT size, a simulation program was written that calculates TRP for different values of R and D. The input parameters are

- Transmit power
- Range length
- Frequency
- DUT gain
- Measurement antenna gain
- DUT diameter/Minimum measurement sphere

The simulation program assumes the worst case scenario where the phase center of the DUT is at the edge of the DUT. The simulation program also allows one to vary the orientation of the DUT relative to the measurement sphere. The following simulations were done with the phase center on the z axis. This appears to be the worst case position.

It is possible to draw several conclusions from the results of the simulation. The first row of Table 1 and Table 2 show the effect of the coarse sampling interval of 10 and 20 degrees respectively.

The measurement error increases with the increasing DUT diameter. However, this is primarily due to the fact that the simulation program assumes that the phase center of the DUT is on the z axis of the measurement system and that it is located at the edge of the DUT. If the approximate location of the phase center of the DUT is known, these errors can be reduced.

The most important conclusion that can be drawn from the simulation results is that it should be possible to test devices that are relatively large at relatively short range lengths. These errors are frequency independent so that a handset operating in the frequency band of 802.11a (3.95 to 5.85GHz) would have the same errors as a handset operating at the cellular band (824 to 894 MHz).

DUT Diameter (cm)	Range Length (cm)						
	120	150	200	250	300	350	400
0	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01	-0.01
30	0.01	0.00	0.00	-0.01	-0.01	-0.01	-0.01
60	0.08	0.05	0.02	0.01	0.00	0.00	0.00
90	0.20	0.12	0.06	0.04	0.02	0.01	0.01
120	0.39	0.23	0.12	0.07	0.05	0.03	0.02
150	0.66	0.39	0.20	0.12	0.08	0.06	0.04
180	1.06	0.59	0.30	0.18	0.12	0.09	0.06
210	1.62	0.88	0.43	0.26	0.17	0.12	0.09

Table 1
TRP errors with 10 degree measurement interval

DUT Diameter (cm)	Range Length (cm)						
	120	150	200	250	300	350	400
0	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04	-0.04
30	-0.02	-0.03	-0.04	-0.04	-0.04	-0.04	-0.04
60	0.04	0.01	-0.01	-0.03	-0.03	-0.03	-0.04
90	0.15	0.08	0.02	0.00	-0.01	-0.02	-0.03
120	0.32	0.18	0.08	0.03	0.01	-0.01	-0.01
150	0.54	0.32	0.15	0.08	0.04	0.02	0.00
180	0.79	0.49	0.24	0.14	0.08	0.05	0.02
210	0.93	0.69	0.36	0.20	0.12	0.08	0.05

Table 2
TRP Errors with 20 degree measurement interval

7. Experimental Verification

In order to validate this concept of measuring TRP at short range lengths, TRP measurements were made at two different range lengths in the same chamber. One set of measurements was taken at a 60 inch range length while a second set of measurements was made at a 24 inch range length. Both free space (the phone by itself) and simulated use (the phone with a SAM head phantom) were made in both the cellular band and the PCS band.

The experimental setup is shown in Figure 3. The normal range length was 60 inches in the chamber. In order to shorten the range length, a 36 inch spacer was made that moved the measurement antenna to within 24 inches of the DUT. The results of these measurements are shown in Tables 3 and 4.

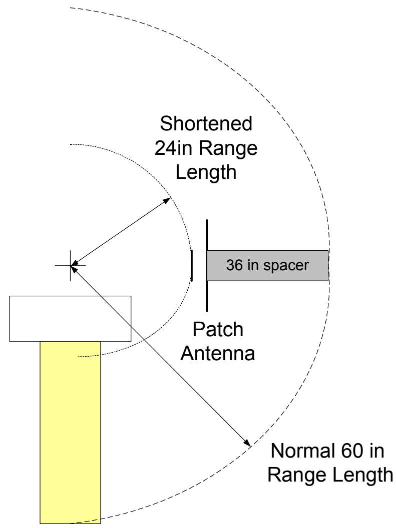

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Figure 3
Experimental Setup

The experimental results typically compare to within a few tenths of a dB. The biggest delta between the measurements was 0.48dB. These differences can be attributed to

- Two different range reference measurements
- Different phasing of extraneous signals
- Changes in the standing waves between the two measurements

Band	Frequency (MHz)	TRP @ 24in (dBm)	TRP @ 60in (dBm)	Delta (dB)
Cellular	824	26.70	26.48	-0.22
Cellular	837	26.59	26.31	-0.28
Cellular	849	26.84	26.56	-0.28
PCS	1850	27.13	26.92	-0.21
PCS	1880	27.61	27.25	-0.36
PCS	1910	27.49	27.26	-0.23

Table 3
Free Space Measurements

Band	Frequency (MHz)	TRP @ 24in (dBm)	TRP @ 60in (dBm)	Delta (dB)
Cellular	824	15.67	15.60	-0.07
Cellular	837	16.57	16.23	-0.34
Cellular	849	16.41	15.93	-0.48
PCS	1850	20.68	20.97	+0.29
PCS	1880	20.79	21.08	+0.29
PCS	1910	20.79	20.69	-0.10

Table 4
Simulated Use Measurements

8. Minimum Measurement Distance

Given that we can make reasonably accurate TRP measurements at relatively short range lengths, what should be the criteria for the minimum range length? It is certainly desirable to keep the measurement antenna outside of the reactive near-field of the DUT. The reactive near-field is usually assumed to extend out to 2 to 3 wavelengths from the DUT. If we assume the worst case scenario where the antenna is on the outer edge of the DUT, and DUT is physically centered on the spherical coordinate system, then the minimum measurement distance is as shown in Figure 4. Mathematically this relationship can be expressed as

$$R > 3\lambda + D/2$$

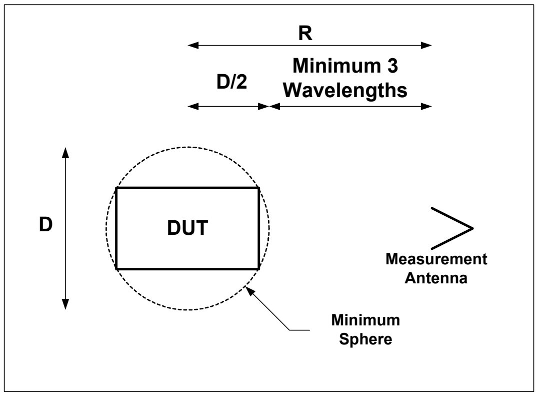

Figure 4
Minimum Measurement Distance

Table 5 compares the proposed minimum measurement distance to that required by the far-field criteria of $R>2D^2/\lambda$.

DUT	Size (cm)	Freq (MHz)	$2D^2/\lambda$ (m)	$3\lambda+D/2$ (m)
Cellular Phone	15	836	0.13	1.15
Cellular Phone w/ SAM phantom	30	1880	1.13	0.63
Laptop	46	2400	3.39	0.60
Laptop	60	6000	14.41	0.45
Automobile	366	2000	178.73	2.28

Table 5
Comparison of Measurement Distance Criteria

9. Summary

It has been demonstrated through both calculations and experimental results that accurate TRP measurements can be made at range lengths significantly shorter than those indicated by the far-field criteria. The principal of reciprocity allows us to apply the same criteria to the measurement of Total Isotropic Sensitivity (TIS). Thus the two most important over-the-air parameters of a wireless device can be measured in much smaller chambers than indicated by the classical far-field criteria. As wireless devices move to higher frequencies such as those of 802.11a and increase in size from handheld cellular phones to notebook computers, the ability to make accurate TRP and TIS measurements in existing chambers will become more and more important.

10. References

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