USING SPHERICAL NEAR-FIELD TRANSFORMS TO DETERMINE THE EFFECTS OF RANGE LENGTH ON THE MEASUREMENT OF TOTAL RADIATED POWER

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ABSTRACT

Total radiated power (TRP) and total isotropic sensitivity (TIS) are two metrics most commonly used to characterize the performance of a wireless device. These integrated measurement parameters are not as sensitive to the measurement distance as a single point measurement such as an antenna gain measurement, but it is difficult to accurately quantify the effects of measurement distance on these two parameters. This paper presents a simple approach to quantifying the effects of measurement distance using spherical near-field transforms. Data is taken on a typical wireless device at different range lengths and transformed to the far-field using a spherical near-field transform. The total radiated power is then calculated for both the measured data and the transformed data. The difference in the two calculations shows the effect of a finite range length on the measurement. Measured results are presented for three different range lengths. For each of these range lengths the data is transformed to the far-field and the TRP is calculated.

Keywords:

Cellular, CTIA, wireless, TRP, Uncertainty, EIRP, Errors, Far-Field, Near-field, OTA

1.0 Introduction

Until recently a wireless device was typically a small, hand-held device such as a mobile phone operating at frequencies of between 800MHz and 2000MHZ. Satisfying the far-field criteria when measuring such a device required a range length only slightly in excess of 1 meter. There is currently a trend to add wireless communication technology to both fixed devices such as a teller machine and large mobile devices such as an automobile. Satisfying the far-field criteria for these large devices becomes a much more difficult and expensive proposition.

The metrics most commonly used to characterize the performance of a wireless device are total radiated power (TRP) and total isotropic sensitivity (TIS). The metrics are calculated from samples of radiated power or receiver sensitivity taken typically at 15 degree spacing in phi and theta. It has long been known that these parameters derived from an integration of numerous samples are not as sensitive to the measurement distance as a single point measurement, but it has been difficult to quantify the sensitivity. In this paper we describe a series of measurements that were designed to accurately determine this effect.

2. Background

In the US the most commonly accepted standard for wireless measurements is the Test Plan for Mobile Station Over-the-Air Performance published by CTIA Certification, a division of CTIA-The Wireless Association. The current revision of the test plan is version 3.1. The metrics that are defined by this test plan to quantify the performance of a wireless device are its total radiated power (TRP) and its total isotropic sensitivity (TIS). We will focus on TRP measurements and rely on the principal of reciprocity to apply our results to TIS measurements.

The total power radiated by a device can be expressed as

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

where U is the radiation intensity in watts per steradian. With a little mathematical manipulation

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

For a series of discrete measurements TRP is calculated as follows:

$$TRP \cong \frac{\pi}{2NM}\sum_{i=1}^{N-1}\sum_{j=0}^{M-1}\left[EiRP_{\theta}(\theta_i,\phi_j) + EiRP_{\phi}(\theta_i,\phi_j)\right]\sin(\theta_i)$$

where N is the number of angular intervals in the theta range of 0-180 degrees and M is the number of angular intervals in the phi range of 0-360 degrees. The CTIA requirement is a minimum data spacing of 15 degrees in phi and theta.

The minimum measurement distance is defined by the CTIA to be the largest of $2D^2/\lambda$ (the phase uncertainty limit), 3D (the amplitude uncertainty limit), and 3λ (the reactive Near-Field limit), where D is defined as 30cm and lambda is the wavelength at the measurement frequency. Minimum measurement distances (R) for different wireless frequency bands are shown in Table 2-1 below.

Table 2-1

Minimum Measurement Distance R

Band	Lower Freq	Upper Freq	R Min
	(MHz)	(MHz)	(m)
GPS	1574.4	1576.44	0.95
3GPP Band 24	1525	1660.5	1.00
3GPP Band 8	880	960	1.02
AWS-1 TX (3GPP Band 4 TX)	1710	1755	1.05
Cellular(3GPP Band 5)	824	894	1.09
3GPP Band 3	1710	1880	1.13
3GPP Band 14	758	798	1.19
3GPP Band 1 TX	1920	1980	1.19
PCS(3GPP Band 2)	1850	1990	1.19
3GPP Band 25	1850	1995	1.20
3GPP Band 13	746	787	1.21
3GPP Band 17	704	746	1.28
3GPP Band 12	698	746	1.29
AWS-1 RX (3GPP Band 4 RX)	2110	2155	1.29
3GPP Band 1 RX	2110	2170	1.30
WLAN 2.4 GHz	2400	2483	1.49
3GPP Band 7	2500	2690	1.61
WLAN 5 GHz	4910	5835	3.50

The measurement distances shown in Table 2-1may seem modest, and in one sense they are. However, if one has an existing chamber with a 1.2m range length, a requirement to test at 1.29m is a problem. Also, remember that these range lengths are based on a 30cm test zone. If the test zone size has to be increased to accommodate a wireless electric meter, appliance or vehicle, the measurement distance requirement becomes much more critical. So given that using classical far-field criteria will require the use of large chambers with long range lengths for some devices, it seems prudent to ask if these range lengths are really necessary to make accurate TRP measurements.

3. Methodology

Previous attempts to quantify the effect of measurement distance on the measurement of TRP have used both simulations and actual measurements. The simulations were too simplistic to be convincing, and measurements at different range lengths were subject to too many measurement uncertainties that were unrelated to measurement distance. What is needed is an approach that can keep all the measurement parameters and measurement uncertainties constant with the exception of measurement distance. This would allow us to separate the effects of measurement distance from all other effects.

The concept presented in this paper is to collect the data for a TRP calculation at a fixed (and finite) measurement distance. We will use this data to calculate a value for TRP. Then we will take the same data set and transform it to the far-field using a spherical near-field transform. This will give us a new data set which represents the gain pattern of the DUT measured at an infinite measurement distance. If we also calculate a value for TRP using this new data set, we will have the value of TRP that would have been measured at an infinite range length. The difference between these two values will be the effect due to measurement distance since they have both been derived from the same original data set.

In order to calculate TRP, we need to convert the raw measurements into values of EiRP. To do this we use a calibrated dipole as a gain transfer standard and convert the relative radiation pattern measurements into units of absolute gain. It is not necessary to actually measure the input power since it will be the same for both data sets and hence cancel out.

$$EiRP(\varphi,\theta)=G(\varphi,\theta)*P_o$$

The far-field transform also requires a gain standard, and we use the same data set for the gain standard that we used in the finite range length calculation. Again since we are interested in the delta TRP the gain of the dipole is in both measurements and cancels out.

4. Measurement Configuration

The measurement setup is shown in Figure 4-1 below. A Howland distributed axis wireless test lab was used with a Howland Model QR-4 dual polarized quad-ridged horn mounted as the probe antenna. The theta travel was 0-165 degrees. The equipment under test was mounted on the phi axis with a full 360 degrees of travel.

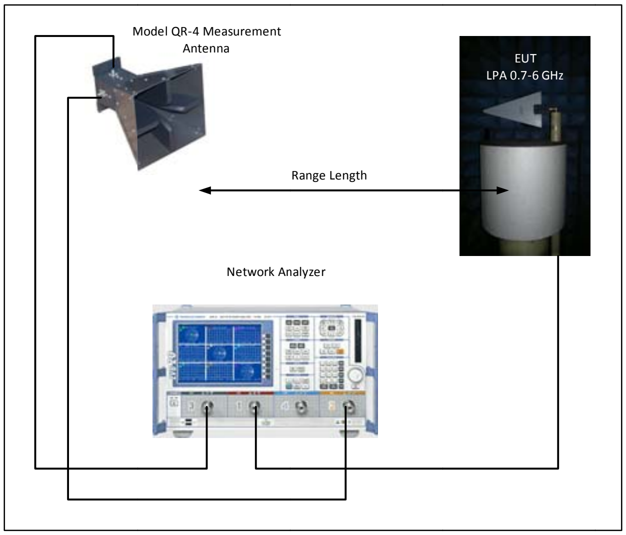


Figure 4-1 Measurement Setup

A four channel Rohde & Schwarz Model ZVB20 was used as the measurement receiver. A Sunol Sciences Log Periodic Antenna (LPA) was chosen as the EUT. The LPA had several advantages as the EUT. Its broadband frequency response allowed fast, multi-frequency measurements. Because it was moderately directive and relatively large compared to most mobile antennas, we felt that it offered a worst case scenario.

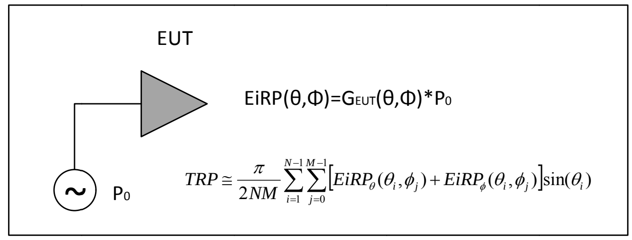
Measurements were made at the eight frequencies in Table 2-1that resulted in a range length of greater than 120cm.

For gain standards Howland VA100 precision coaxial dipoles were used. These dipoles were calibrated using the three antenna method.

Data was taken in 5 degree increments in phi and theta resulting in 2,664 individual data points per frequency. A similar data set was taken on the calibration dipoles and used in the spherical near-field transform.

The maximum range length of the test system was 143cm measured from the center of the test zone to the aperture of the QR-4 probe antenna. Spacers were used to shorten the range length so that measurements could be made at 120cm and 129cm.

TRP values were calculated from the measured data using the formula shown in Figure 4-2 below.



$$TRP \cong \frac{\pi}{2NM}\sum_{i=1}^{N-1}\sum_{j=0}^{M-1}\left[EiRP_{\theta}(\theta_i,\phi_j)+EiRP_{\phi}(\theta_i,\phi_j)\right]\sin(\theta_i)$$

Figure 4-2 TRP Calculation

Next the measured data was transformed to the far-field using the Howland N2F Spherical Near-field Transform Software and the TRP re-calculated using the transformed, or far-field, antenna pattern. The difference between the two TRP values is the effect on TRP due to range length. Figure 4-3 shows principal H-plane patterns of both the data taken at 120cm and the same data transformed using spherical near-field transforms.

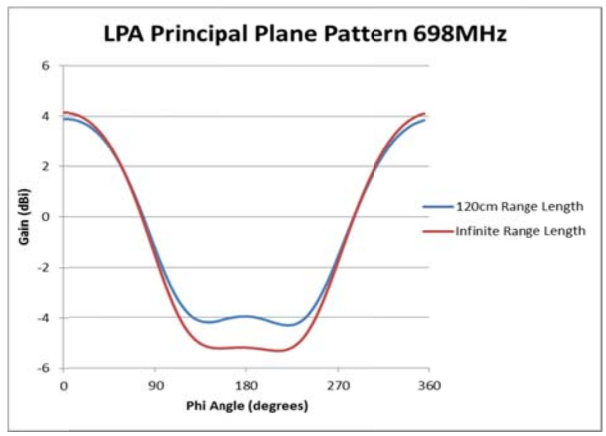


Figure 4-3 Near-field and Far-field patterns

5. Results

The results of the measurement program are shown in Table 5-1 below.

Table 5-1 TRP Delta Near-field to Far-field

Frequency (MHz)	R=120cm (dB)	R=129cm (dB)	R=143cm (dB)
698	-0.14	-0.11	-0.08
704	-0.13	-0.07	-0.08
748	0.01	0.12	-0.04
2155	-0.03	-0.08	0.05
2170	-0.01	-0.10	0.00
2483	-0.11	-0.19	-0.04
2690	-0.04	-0.10	-0.07
5835	-0.07	-0.04	0.07

6. Conclusions

There is no clear trend in the data that points to decreased measurement uncertainty with increasing range length. Regardless of the measurement distance, the data seems to fall in a range of +/- 0.2dB. If there is a trend, it must be small enough that the residual uncertainties in our measurements are masking it. Perhaps the most convincing example of this is the results for 5835MHz. The far-field criteria would have indicated a measurement distance of 3.5 meters was required. However, we see virtually no change in the TRP at range lengths of 120cm, 129cm, 143cm or even an infinite number of centimeters.

7. Summary

In this paper we have shown that range length has very little effect, if any, on the measurement of total radiated power.

8. References

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