TOTAL RADIATED POWER MEASUREMENT FOR ANTENNA INTEGRATED RADIOS USING A SPHEROIDAL COUPLER

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1. Introduction

Recently we see rapid increases of 'antenna integrated radios' such as RFID and UWB devices in addition to cellular phones and wireless LAN. These devices, having no monitoring terminals of Tx output power, must be tested based on radiation measurement where performances are expressed in terms of total radiated power (TRP). There exist several method for measuring TRP [1] – [3]. These methods, however, need large-scale facility such as radio anechoic chamber and 2-axis scanner. Furthermore they are time consuming and difficult to measure low-level spurious radiation.

In this paper, we propose a novel TRP measurement method with very high sensitivity using a spheroidal coupler[4]. Although the behavior of electromagnetic waves in the coupler is complex due to multiple reflections, we can evaluate the maximum TRP from the equipment under test (EUT) by applying displacement technique to the EUT and the receiving antenna. We developed a spheroidal coupler with diameter of about one meter and verified the feasibility of TRP measurements using EUT at 2.4 GHz.

2. Principle of TRP measurement

2.1 Spheroidal coupler

Fig. 1 shows a basic configuration of TRP measurement system using a spheroidal coupler (SC) which consists of a metallic spheroidal cavity. An EUT or a transmitting (Tx) antenna and receiving (Rx) antenna located around the two foci, F1 and F2. The diameters of the long and short axes are 2a and 2b, respectively. The eccentricity is denoted by “e”, and the focal length by f_L (= ae), and the shape of the spheroid is expressed as

$$\frac{z^2}{a^2}+\frac{x^2+y^2}{b^2}=1 \qquad (1)$$

Since a SC is an over-sized cavity, behaviors of electromagnetic waves may become very complex due to multiple reflections. A typical example of reflection of Tx antenna, S_{11}, and transmission between Tx and Rx antennas S_{21} are shown in Fig.2. The parameters of the simulation model are: 2a = 800 mm and e = 0.5; the Tx and Rx antennas are identical half-wavelength dipoles resonant at 2.4 GHz. Both dipoles are laid along the z-axis in a co-linear arrangement.

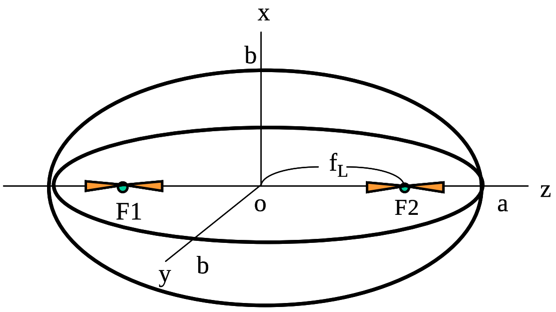


Fig. 1 Geometry of a spheroidal coupler

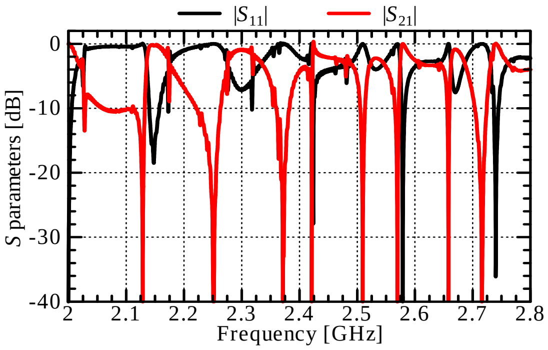


Fig. 2 Frequency characteristics of S-parameters (Δz = 0mm).

2.2 Displacement method

In order to achieve TRP measurements in such multiple-reflection environment, we propose "displacement method" in which Tx and Rx antennas are moved from the focal points along the z-axis as shown in Fig.3. By doing this, we can find the optimal positions where S_{11} becomes sufficiently small, consequently S_{21} becomes almost 0 dB. Usually, the Tx and Rx antennas are displaced symmetrically by Δz from the focal points in the inside or outside directions. At the steady state in a lossless SC, since some part of the input power P_o may be reflected at the input port of the Tx antenna, the received power P_L at the load connected to the Rx antenna is written as

$$P_L = P_o \eta_r \left(1 - |S_{11}|^2\right) \qquad (2)$$

where η_r is the radiation efficiency of the Tx antenna, thus $P_o\eta_r$ denotes the TRP. Therefore if we find the optimal position where S_{11} becomes 0, the receive power P_L coincides with TRP of the EUT. Fig. 4 shows a simulated result of S_{11} and S_{21} at 2.4GHz. The model is same as that described previously. In this figure, Δz expresses the length of symmetrical displacement from the foci, "+" means outward and "-" means inward. We can see periodic variations in S_{11} and S_{21}. At the position "A", Δz = -94 mm, S_{11} reduces less than -30dB, and S_{21} becomes almost 0 dB, that is a perfect matching is achieved. On the other hand at the position "B", Δz = -40 mm, a perfect reflection occurs. By applying this method to the required frequencies, we can obtain frequency characteristics of the maximum S_{21}.

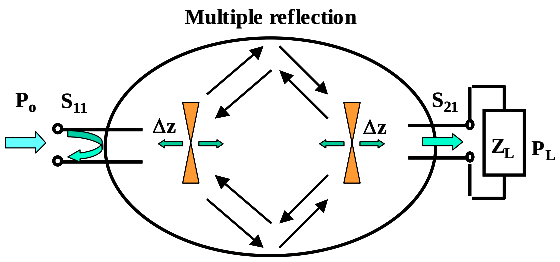


Fig. 3 Principle of displacement method

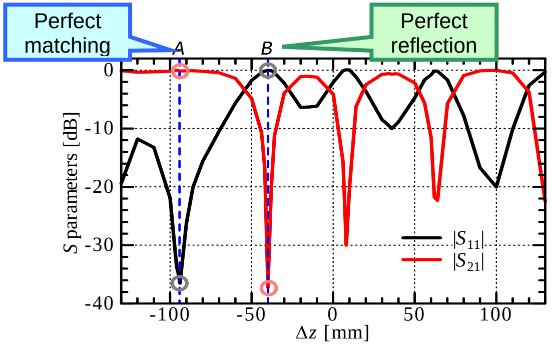


Fig. 4 Reflection and transmission versus symmetrical displacement (2.4GHz)

2.3 Current distributions of the Tx antenna within the SC

A question may be raised. "Are characteristics of Tx antenna in the SC identical with those in free space?" In order to answer this question, we investigated current distribution and input impedance of a dipole antenna within the SC, and compared with those in free space. Fig. 5 shows the current distributions on the Tx dipole. The solid lines show real parts, and the dotted lines show imaginary parts, and the blue curves and red curves express the current distributions at the perfectly matched and perfectly reflected positions in Fig.4, respectively. The black line indicates the current distribution in free space. We can see at the matched position the current distribution, thus also input impedance, agree very well with those in free space. On the other hand, at the perfect reflection, the real part current becomes zero, meaning input resistance to be zero Ω, and a large imaginary current flows along the dipole. It is interpreted that radiation does not occur and large reactive power is stored around the dipole.

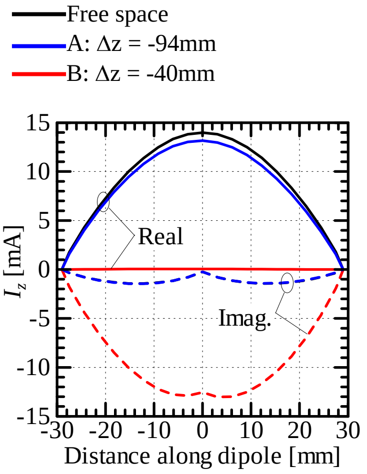


Fig. 5 Current distributions on Tx dipole

2.3 Measurement of antenna radiation efficiency

The above discussions suggest us a possibility to measure antenna radiation efficiency similarly as Wheeler cap method. An actual antenna has loss expressed by inner resistance R_i. If we measure an input resistance at the maximum reflected position B, we obtain R_i, while at the position A, we get a matched resistance $R_m = R_i + R_r$ (R_r : radiation resistance) that is approximately same as the input resistance in free space. From these resistances measured in the SC, we can obtain the radiation efficiency η_r of Tx antenna as

$$\eta_r = \frac{R_r}{R_i + R_r} = 1 - \frac{R_i}{R_m} \qquad (3)$$

3. Development of a spheroidal coupler and measured results

3.1 Developed SC and its coupling characteristics

We developed a prototype of the SC for measuring TRP of wireless LAN terminals in GHz band. Taking account of frequencies, the size of EUT, and the range of displacement, we decided the diameter of the long axis to be about one meter, and the eccentricity 0.5. The overall structure including the base when the upper half of the SC is removed is shown in Fig. 6. The spheroidal reflector is made of FRP and its inner wall is painted with conductive paint. As Tx and Rx antennas, we used commercial antennas, i.e. sleeve antennas for z-polarization and standard dipole antennas with bulun for transverse polarization. Fig. 7 shows the picture of the set-up for coupling measurement between sleeve antennas. Fig. 8 (a) and (b) show measured maximum S_{21}at 2.4GHz for the sleeve-antenna pair and dipole-antenna pair, respectively. They are the results after displacement technique was used. The unit steps of displacement were 10 mm.

In Fig. 8 (a), S_{21} between –0.3 dB and –1.0 dB are observed within the bandwidth of the sleeve antennas, while in Fig.8 (b), S_{21} between –0.5 dB and –1.0 dB are observed. Sharp drops seen in these figures are considered due to resonances occurred in an over-sized cavity. In TRP measurement, however, since the resonant modes and the frequencies are different for the different polarizations, we can avoid the difficulty of resonances by dual-polarization measurement. The above coupling values include losses of both Tx and Rx antennas, so we can say a very highly sensitive coupler was achieved.

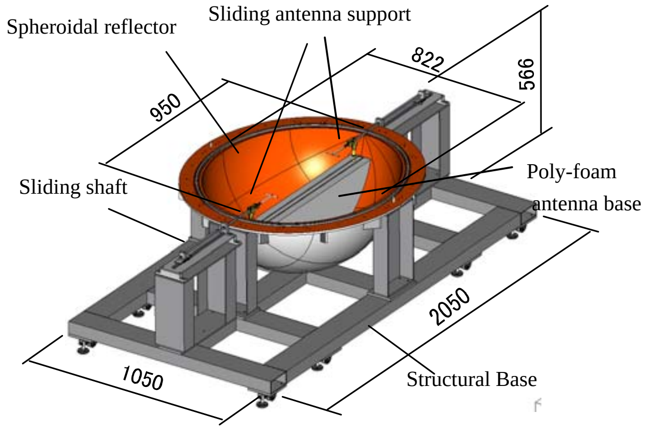
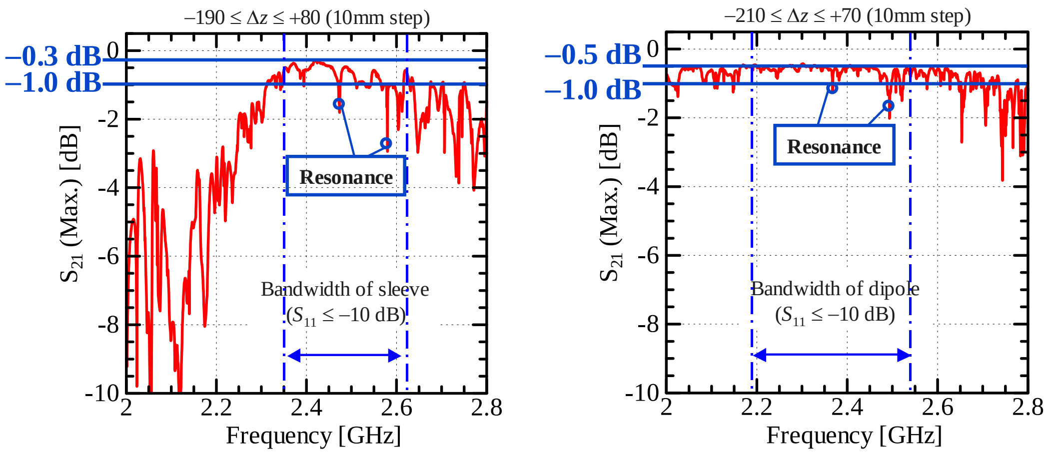


Fig. 6 Overall structure of the spheroidal coupler

Fig. 7 Coupling measurement between the sleeve antennas



(a) Sleeve antenna

(b) Dipole antenna

Fig. 8 Coupling between identical antenna pairs

3.2 TRP measurements of an EUT

We also developed an EUT for TRP measurement, which radiates a CW signal of 2.412 GHz. The EUT consists of a metallic cubic body with side length of 65 mm, and a monopole antenna. The nominal output power of each EUT is 10 mW. Fig. 9 shows the set-up of TRP measurements for the case of z-polarization, namely the EUT vs. the sleeve antenna. The proposed method needs calibration of the measurement system where Tx reference antenna with known radiation efficiency and a signal generator (SG) are used in addition to the SC and the Rx antenna. On the other hand, in order to clarify the accuracy of the proposed method we also measured TRP of the EUT in a far-field range based on the standard method of CTIA [2]. The measured value was 8.86 dBm. In TABLE I, these measured data are listed. It can be seen that the values are very close each other.

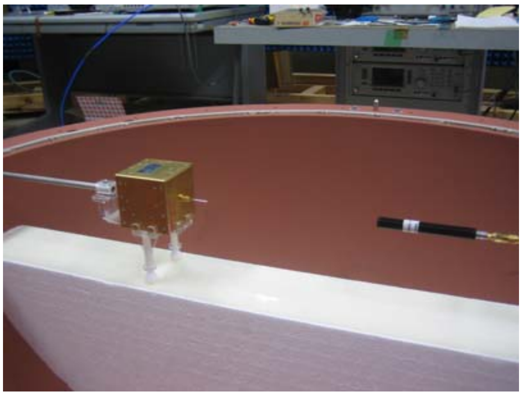


Fig. 9 TRP measurement of EUT
(z-polarization, Rx : sleeve antenna)

TABLE I Comparison of measured TRP

	Measurements in the Spheroidal coupler		Far-field measurement (CTIA Std.)
Reference antenna	Sleeve	Dipole	
Radiation efficiency (far-field meas.)	83.9% (- 0.76 dB)	74.1% (- 1.30 dB)	
TRP (dBm)	9.14	8.82	8.86

4. Conclusions

We proposed and developed a novel TRP measurement system for small radio terminals using displacement method in a spheroidal coupler, and verified that the maximum TRP was evaluated with high accuracy. Elimination of the conventional radio anechoic chamber and spherical positioner cuts system size and cost. Furthermore, thanks to very high sensitivity, it makes possible to measure TRP of not only in-band signals but also low level spurious radiation.

Acknowledgments

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