Estimation Method of EUT Reflection Coefficient in TRP Measurement System 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). Existing methods for measuring TRP, [1] – [3], however, need large-scale facility such as radio anechoic chamber and 2-axis positioner. Furthermore they are time consuming and difficult to measure low-level spurious radiation.

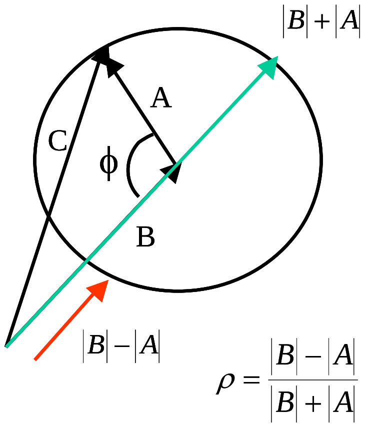
Previously we proposed a novel TRP measurement method using a spheroidal coupler (SC) which achieves high-sensitive and short time measurement with a simple facility [4]. The key technology is "displacement method" that measures the EUT (Equipment Under Test) TRP by changing the positions of the EUT and the receiving antenna. In the system, however, theoretical basis whether the maximum received power might always coincide with TRP is not clear.

This paper describes an estimation method of the reflection coefficient of EUT by "phase rotation technique" that provides a highly accurate and reliable TRP measurement. The developed system and the experimental results will be also shown.

2. Estimation Method of EUT Reflection Coefficient

The method to estimate the input and output reflection coefficients in the SC is based on phase rotation technique. The principle of this technique is depicted in Fig. 1. If we give continuous phase shifts to one of the two input signals by using a variable phase shifter (VPS), one is known and the other is unknown, we have a rippled output signal. From the ratio of the minimum and the maximum output signals, "ρ", we can determine the amplitude of the unknown signal.

Fig. 2 shows a configuration of a TRP measurement system employing phase rotation technique. In the spheroidal coupler, the EUT and the receiving antenna are arranged, and the output signal by the receiving antenna is connected to a receiver, such as a spectrum analyzer, through the connecting cable and the VPS. A fixed reflector providing a fixed reflection is inserted between the VPS and the receiver. As VPS, we used four coaxial cable line stretchers which are serially connected.



$$\rho = \frac{|B|-|A|}{|B|+|A|}$$

Fig.1 Principle of phase rotation technique

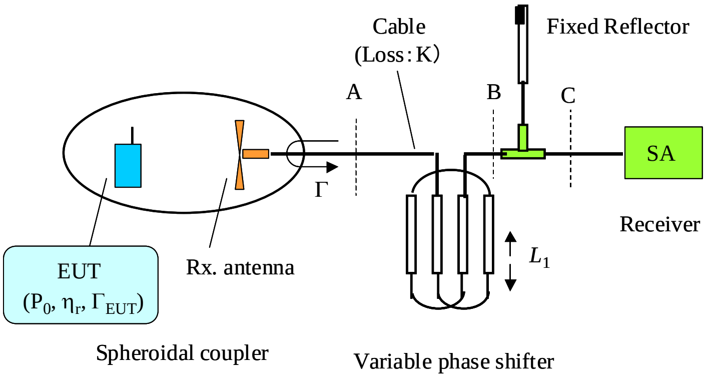


Fig.2 TRP measurement system using phase rotation technique

We denote the transmitted power of EUT by P_0, the antenna radiation efficiency by η_r, the input reflection coefficient of EUT by Γ_{EUT}, the output reflection coefficient of the spheroidal coupler by Γ, the total transmission coefficient of the cable and the VPS by K, phase shit by ϕ , and the reflection coefficient of the fixed reflector seen from port B by Γ_r.

The S-matrix of the spheroidal coupler can be written as

$$[S_C]=\begin{bmatrix} S_{C11} & S_{C12} \\ S_{C21} & S_{C22} \end{bmatrix}=\begin{bmatrix} \Gamma_{EUT} & S_{C12} \\ S_{C21} & \Gamma \end{bmatrix} \tag{1}$$

and the S-matrices of the integrated circuit of the connecting cable and VPS, and the fixed reflector are expressed as

$$[S_P]=\begin{bmatrix} 0 & Ke^{-j\phi} \\ Ke^{-j\phi} & 0 \end{bmatrix} \tag{2}$$

and

$$[S_r]=\begin{bmatrix} S_{r11} & S_{r12} \\ S_{r21} & S_{r22} \end{bmatrix}=\begin{bmatrix} \Gamma_r & S_{r12} \\ S_{r21} & S_{r22} \end{bmatrix} \tag{3}$$

Since the system in Fig.2 consists of cascade-connected three portions, the SC, the connecting cable and the VPS, and the fixed reflector, we can derive a transmission coefficient S_{21} for the overall system. In this case, the port 1and the port 2 are the input port of the EUT and the output port of the fixed reflector. After matrix analysis, S_{21} becomes

$$|S_{21}|^2=\frac{K^2|S_{C21}|^2|S_{r21}|^2}{\left|1-K^2e^{-j2\phi}\Gamma\Gamma_r\right|^2} \tag{4}$$

By varying the phase of the VPS, we obtain a rippled received signal, and then a ratio of the minimum and maximum received signals "ρ".

By using "ρ", and taking account of K depending on the line length, we finally obtain the output reflection coefficient Γ of the SC as

$$|\Gamma|=\frac{(1-\rho)}{|\Gamma_r|\left[K^2(l_{\min})+\rho K^2(l_{\max})\right]} \tag{5}$$

Since the SC is a high Q and low loss system, the following relation holds.

$$|\Gamma_{EUT}|=|\Gamma| \tag{6}$$

Therefore, TRP of the EUT can be obtained by the measured received power $P_R(EUT)$ and Γ as

$$TRP=P_0\eta_r=\frac{P_R(EUT)}{\left(1-|\Gamma_{EUT}|^2\right)}C \tag{7}$$

where C is a proper constant of the SC, expressing common losses such as the spheroidal reflector and others. C can be eliminated by a calibration with a reference system equipped by a reference transmitting antenna and a signal generator.

3. Developed system and experimental results

3.1 Configuration of the system

We developed an automatic TRP measurement system for radio terminals at UHF band. The overall configuration is shown in Fig. 3. The system computer controls the displacement of EUT and the receiving antenna, the length of the VPS, and data acquisition and processing.

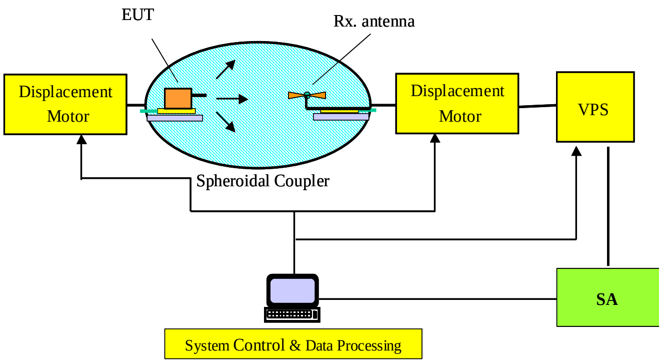


Fig.3 Automatic TRP measurement system

In Table 1, major parameters of the system are shown. The picture in Fig. 4 shows an inner view of the coupler when the top reflector is removed where we can see an EUT and a receiving sleeve antenna arranged co-linearly.

Fig.4 Inner view of the SC

Table 1: Structural parameters of the spheroidal coupler system

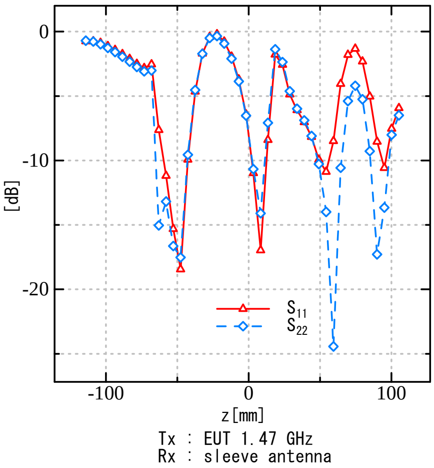
Diameter of major axis (2a)	1200 mm
Diameter of minor axis (2b)	1094 mm
Eccentricity (e)	0.41
Spheroidal reflector	
Material	FRP
Inner wall conductive painting	Resin with 45% Cu
Range of displacement (Tx, Rx, each)	300 mm
Range of variable line length of VPS	300 mm (75 mm × 4)

3.2 Measured results

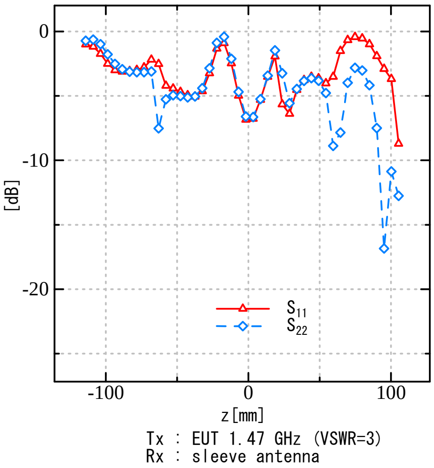
Fig.5 shows a comparison of the measured S_{11} and S_{22} in the SC. The measurements were carried out for two different antenna models. One has a matched and the other has a mismatched (VSWR=3) monopole antennas mounted on a metallic body which has the same size with 1.47GHz EUT as shown in Fig.4. Fig.5 (a) and (b) show reflection coefficients for a matched and a mismatched antennas, respectively. The abscissa "z" expresses the amount of symmetrical displacement of the EUT and the receiving antenna. z=0 means focal positions, "+" and "-" mean outside and inside directions, respectively. From the measurements, we see that S_{11} and S_{22} agree very well for every displacement positions for both cases. The results gives theoretical basis to TRP measurement using a SC as described previously.

Fig. 6 shows a directly measured and estimated "Γ"s, output reflection coefficients in the SC. Tx. and Rx. antennas are sleeve antennas which are co-linearly arranged and displaced to vary Γ. The estimated Γ were obtained from the measurements using phase rotation technique (PRT) for two different fixed reflectors, one is Γ_r=-1.55 dB, and the other is Γ_r=-10.0 dB. From this figure, we can say that the estimated Γs are very close each other in spite of different Γ_r, and they agree with the direct measurement obtained by a VNA.

Finally we describe TRP measurement. The EUT is a test transmitter generating 1.47GHz CW signal with 10.08 dBm output power. The power is delivered to a monopole antenna mounted on the metallic body as shown in Fig. 4. Fig. 7 shows a result of displacement. The system configuration is same as Fig.2. In the measurement, the line length of the VPS was set to be the shortest, and the Γ_r to be zero. The maximum received power, 6.79 dBm was obtained at z=-50mm. Fig.8 shows a ripple characteristics by phase rotation. L_1 is the length of the VPS.



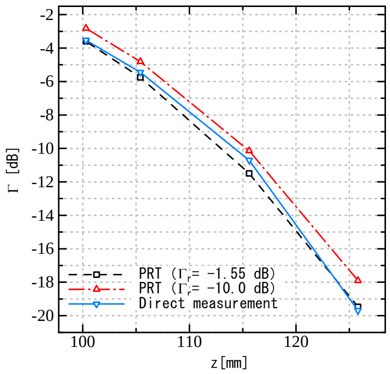
(a) Matched monopole



(b) Mismatched monopole (VSWR=3)

Fig.5 Comparisons of S_{11} and S_{22} in the SC

From the measurements, we obtain Γ =-14.97 dB. The value is very low, and this means at the z=-50mm, almost perfect coupling between the EUT and the Rx. antenna was achieved.
In Table 2, parameters and the measured data are listed.



frequency : 1.47GHz
Tx. and Rx. antennas : sleeve antennas

Fig.6 Output Reflection coefficients of SC

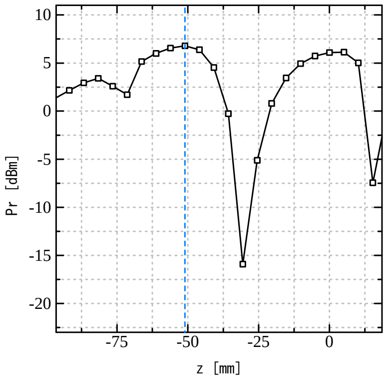


Fig.7 Received power for displacement

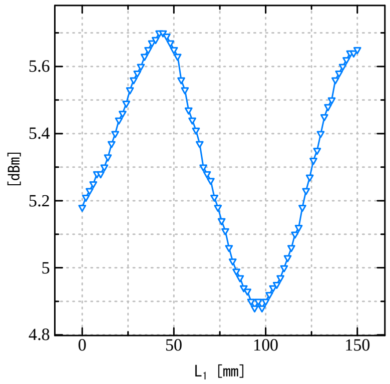


Fig.8 Ripples of receive power

Table 2: System parameters and measured data

Frequency	1.47 GHz
Tx : EUT Rx : Sleeve antenna	P_0 = 10.08 dBm η_r = -0.21 dB
Fixed reflector Overall loss	Γ_r = -1.71 dB 2.97 dB
Max received power	P_r(EUT) = 6.79 dBm
Loss compensated Rx power	9.76 dBm
Estimated Γ	-14.97 dB
TRP	9.90 dBm

4. Conclusions

We proposed an estimation method of reflection coefficients of EUT by phase rotation technique in TRP measurement using a spheroidal coupler, and developed an automatic TRP measurement system. By compensating the received power with reflection loss, the maximum TRP can be exactly obtained. The measured data verified that the system provided highly accurate and reliable TRP measurements.

Acknowledgments

This work has been conducted under the sponsorship of the R&D program for expansion of radio resources promoted by the Ministry of Internal Affairs and Communications, Japan.

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