Estimation of Radiated Power of Radio Transmitters Using a Reverberation Chamber

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Abstract: A procedure for estimating radiated power of radio transmitter is proposed based on a statistical property of field intensity time variation distribution in a reverberation chamber. When random varying multipath waves produced by stirrers in a reverberation chamber are received together with a direct wave, the resulting mixed waves are regarded as a kind of multipath waves. Theoretical and experimental results are reported regarding a procedure for estimating radiated power from the 63.2% value of CDF (Cumulative Distribution Function) of an envelope of multipath waves.

Key words: Reverberation chamber, probability distribution, Rice distribution, normalization

1 Introduction

Wireless equipment continues to shrink and become lighter in weight as electronics has evolved, and many radio transmitters which equipped with built-in antenna are being developed.

Addressing measurement methods for these wireless devices, the Telecommunications Technology Council issued a partial report covering "Technical requirements of measurement procedures for radiated power of wireless equipment with built-in antennas." The measurement procedure was based on substitution method of antenna in a full anechoic chamber. At the same time, other measurement procedures were also reported including the random-field method, the reverberation chamber method and other techniques. A number of methods have been investigated for measuring radiated power of wireless devices with built-in antennas using a reverberation chambers[1].

In our work we have attempted to estimate the radiated power of a radio transmitter based on statistical property of field intensity time variation distribution in a reverberation chamber, and here we report theoretical considerations and experimental findings associated with this work.

2 Theoretical Considerations

When a sensor is placed in a reverberation chamber to detect electromagnetic fields produced by a wave source, many reflected waves reach the sensor in addition to the direct wave from the wave source to the sensor. The sensor picks up the mixed waves combining direct waves and multipath waves. If the wave source, the sensor, and the medium (the propagation path) are immobile, then the envelope level of the mixed wave detected by the sensor is constant, but the value changes considerably depending on the position of the wave source and the sensor. If on the other hand the wave source or the sensor or the medium is moved, then the envelop level changes, and the reception level is regarded as a kind of random variable. Use of a reverberation chamber involves a method in which stirrers inside the chamber rotate, thus causing the medium (the propagation path) to vary over time.

When the receiver output voltage for a mixed wave is $v(t)$ and the probability density function (PDF) of the envelope is $r(t)$, and multiple reflected waves are regarded as multipath waves, the probability that envelope r will enter interval $[r, r + dr]$ is given by

$$p(r)dr = dr\,\frac{r}{\sigma^2}\,\exp\{-\frac{r^2 + A^2}{2\sigma^2}\}\,I_0[A\frac{r}{\sigma^2}] \qquad (1)$$

when $r \geq 0$.

Here σ^2 is the power corresponding to the multipath waves, $A^2/2$ is the power corresponding to the direct wave, and I_0 is a 0th-order modified Bessel function[2]. Equation (1) contains two parameters, A and σ. Here we define a new parameter ρ, the ratio of direct wave power to multipath wave power:

$$\rho = \frac{A^2/2}{\sigma^2} \qquad (2)$$

Normalizing the envelop r using the square root of the sum of direct wave and multipath wave power, we obtain

$$p(R) = 2\,(1+\rho)\,R\,\exp\{-(\rho + [\,1+\rho\,]\,R^2\,)\} \cdot I_0[\,2R\,\sqrt{\rho\,(1+\rho)}\,], \qquad (3)$$

Note that

$$R = \frac{r\,/\,\sqrt{2}}{\sqrt{A^2/2 + \sigma^2}} \qquad (4)$$

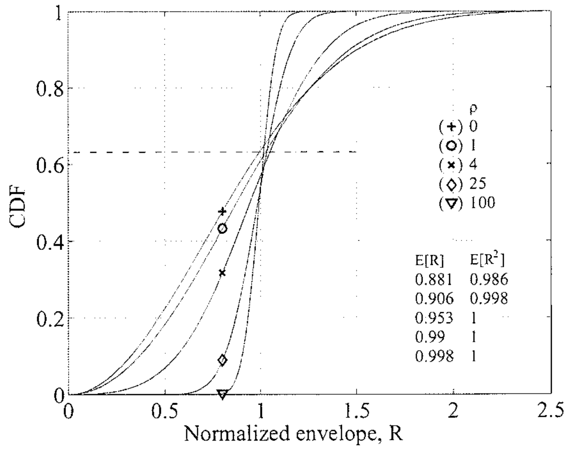

Fig.1: CDF of Rice distribution

Here the numerator coefficient $1/\sqrt{2}$ is added to make the mean square root of the envelope equal 1.

The squared mean of the envelop is given by

$$E[r^2(t)] = A^2 + 2\sigma^2 \tag{5}$$

This means that

$$E[R^2(t)] = \frac{E[r^2(t)]/2}{A^2/2 + \sigma^2} = 1 \tag{6}$$

Figure1 shows the cumulative distribution function $F(R)$ (CDF) derived by integrating R in Eq. (3). One can see that the squared mean on the normalized envelope equals 1 and is not dependent on ρ.

When the step function is U, $F(R) = U(R-1)$ when $\rho \to \infty$ and becomes a Rayleigh distribution when $\rho = 0$, so $F(R) = 1 - \exp(-R^2)$. In other words, the two intersect at a CDF of $1 - e^{-1} = 0.632$. The intersection point shifts somewhat with respect to ρ between the two, but it will be apparent from Fig. 1 that the degree of slippage is never more than 0.5 dB when the CDF is 0.632.

In other words, the CDF of the normalized envelope is practically constant at 63.2% regardless of ρ.

3 Reverberation Chamber and APD Measurement Equipment

Table 1 shows the specifications of the reverberation chamber. The APD measurement equipment developed by EMCLAB[3] was used to ascertain statistics of changed signals.

The equipment converts the video output signal from a spectrum analyzer from analog to digital, then measures various statistical characteristics in real time for the specified time interval.

Table 2 shows the specifications of the APD measuring equipment.

Table.1: Specifications of the reverberation chamber

Chamber	Size	5.5 m $*$ 4.5 m $*$ 3 m
Stirrer	Size	2 m $*$ 0.7 m
	Position	Ceiling, directly opposite, right, left Separated 70 cm from wall
	Rotation rate	Max. 120 rpm 4 stirrers rotate independent of each other
Shield characteristics	150 MHz -10 GHz	> 100 dB
	18 GHz	> 90 dB

Table.2: Specifications of APD measuring equipment

Observation time interval	Approx. 1 sec
Dead time of measurement	Approx. 1 %
Sampling rate	20 M sample / sec (50 n sec)
Amplitude resolution	256 steps
Measured data	PDF, APD (1-CDF), CRD, PDD, PSD

4 Measurement of Direct Wave and Multipath Waves

4.1 Determination of data acquisition time

Since the radio waves emitted from the radio transmitter are reflected off the walls and stirrers in the reverberation chamber, the amplitude of signals reaching the receiver vary randomly. Yet the random signals vary depending on the placement of the stirrers in the chamber, so the signals exhibit periodicity. This means that the signals can be subjected to proper data processing by acquiring the data corresponding to the period.

Period t of the received random signals that are dependent on the placement of stirrers is given by

$$t = \frac{N_A - N_B}{2(f_A - f_B)} \tag{7}$$

where the rotation rates of stirrers A and B are f_A and f_B, respectively, and N_A and N_B are integers.

For example, based on this equation, we find that the random signal period is 10 seconds when the rotation rate of stirrer A is 120 rpm and the rotation rate of stirrer B is 117 rpm.

Figure 2 shows the PDF measured results when stirres are set to the condition mentioned above. Light

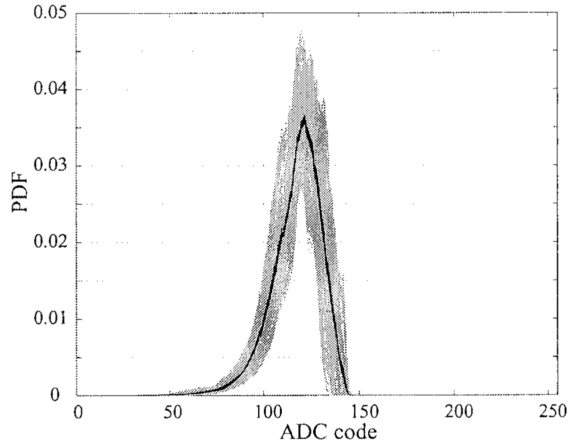

Fig.2: PDF by 1sec and 10sec

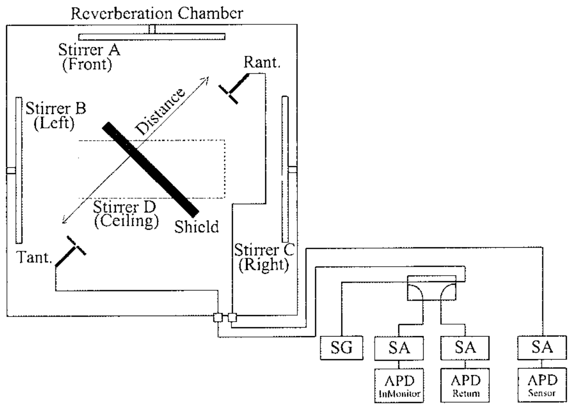

Fig.3: Multipath wave measurement (No shield in case of mixed wave measurement)

lines (300 lines) show plots of the measurement results obtained by 1sec measurement time. Bold lines (30 lines) show the results for the 10sec measurement time. From this figure, appropriate data processing is required for statistical acquisition.

In the following analysis, we assume two stirrers, one rotating at a rate of 120 rpm and the other at a rate of 117 rpm, and data based on a measurement time interval of 10 seconds.

4.2 Experiment to corroborate the theory

We conducted the following measurement experiments to corroborate our theoretical findings.

First, in order to measure just a direct wave included in the mixed waves, we employed the measurement system in a full anechoic chamber. Since multipath waves were excluded and only direct wave was present, ρ approximated ∞ and the envelope level did not change. In order to measure just the multipath waves, we set up a metal shield between the transmitting and the receiving antennas, started up the stirrers, and recorded measurements using the measurement system shown in Fig. 3. For this series of measurements, the direct wave was eliminated, so ρ was approximately 0.

The mixed waves (including both direct and multipath waves) were measured by starting the stirrers in the chamber and taking measurements again with the setup shown in Fig. 3, but this time without the metal shield. Although the ratio of radiated power of the direct wave to multipath waves was not clear, on theoretical ground we expected that the CDF value of 63% would not be dependent on ρ.

Figure 4 shows the CDF measurement results for direct wave, multipath waves, and mixed waves. Note that the horizontal axes have been normalized using the square root of total power. In the figure it is apparent that the direct, multipath, and mixed waves all intersect at a CDF of 63.2%, and as we noted in the earlier theo-

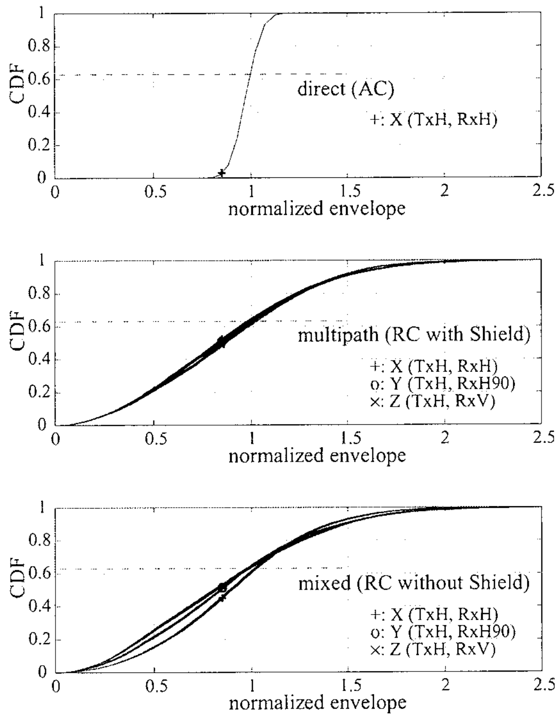

Fig.4: CDF of direct (upper), multipath (middle) and mixed (lower)

retical discussion, the CDF of 63.2% is not depend on the ratio of direct wave and multipath waves power ρ. These results corroborate the validity of the theoretical considerations.

5 Estimation of Radiated Power

In the setup of Fig. 5 we assume receiving antenna R positioned at P_2 yields a CDF of 63.2% in response to radiated power from reference transmitting antenna T positioned at P_1. Moreover, when an equipment under test (EUT) with radiated power of P_x is substituted for reference transmitting antenna T, the point where the

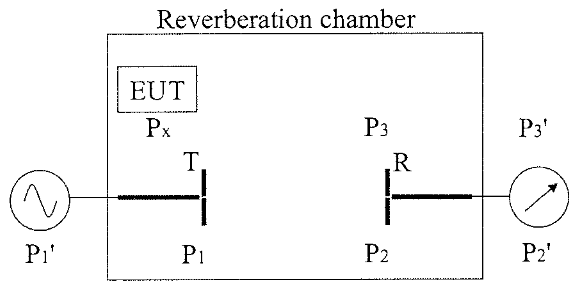

Fig.5: Block diagram of measurement of chamber loss and estimation of radiated power

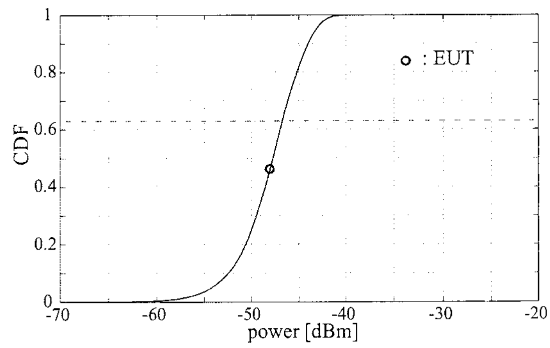

Fig.6: Estimation of radiated power of EUT

receiving antenna has a CDF of 63.2% is P_3. Since theoretically the CDF of 63.2% should remain constant regardless of the ρ, the following equation holds:

$$\frac{P_x}{P_1} = \frac{P_3}{P_2} \tag{8}$$

Hence,

$$P_x = \frac{P_1}{P_2} P_3 \tag{9}$$

And defining P_1/P_2 as chamber loss L_c, we have

$$P_x = P_3 L_c \tag{10}$$

If chamber loss L_c does not depend on the position, directionality, and radiated pattern of the transmitting antenna, then we should be able to estimate the radiated power P_x by measuring the 63.2% CDF value of the EUT.

The chamber loss L_c of -16.3 dB was derived from the experiment. Substituting for the EUT in Fig. 5, we attempted to estimate the radiated power P_x assuming a biconical antenna with signal generator having -20 dBm output. The measurement results are presented in Fig. 6. One can see from the figure that P_3 is -43.7 dBm where the CDF of receiving antenna is 63.2% , so adopting the measured chamber loss L_c of 16.3 dB and using Eq. (10), the radiated power P_x of the EUT is estimated P_x = -43.7 dBm + 16.3 dB = -27.4 dBm.

To derive the radiated power of the actual EUT, the SG output at the input end of the EUT antenna was found using a power meter to be -25.3 dBm, a 2.1 dBm difference from the estimated EUT radiated power of -27.4 dBm derived using the setup described earlier.

6 Conclusion

We demonstrated that the direct, multipath, and mixed waves of a radio transmitter in a reverberation chamber yield a constant CDF value of 63.2 % regardless of the ratio of radiated power ρ between direct waves and multipath waves.

It was shown that radiated power of a radio transmitter can be estimated by measuring the chamber loss and field intensity time variation for the CDF of 63.2%. When this is done, it is necessary to make the unit measurement time the same as the period of the received random signal. Yet we also found that the variation in chamber loss due to the positioning, directionality, and radiation pattern of the transmitting antenna was a major source of error in estimating the radiated power.

While investigating ways to minimize errors in reverberation chamber losses and estimates, we plan to continue to conduct measurement tests using actual equipment. We also plan to evaluate the applicability of this approach to a much wider frequency range up to 6 GHz.

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