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A Study and Investigation of Small Antenna Efficiency Measurement using Reverberation Chamber

A.A.H. AZREMI*, P.J. SOH AND M.S. ANUAR

School of Computer and Communication Engineering
Kolej Universiti Kejuruteraan Utara Malaysia (KUKUM)
Jejawi, 02600 Arau, Perlis.

**Corresponding author. Tel : 604-9798440, Fax : 604-9798141*
E-mail address : azremi@kukum.edu.my (A.A.H. Azremi)

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ABSTRACT

Numbers of small antennas were designed and various kinds of antennas were tested for measurement. Amplitude fluctuations in signals received over mobile radio channels are typically modeled by a Rayleigh distribution. The field statistics in the volume of the enclosure are shown to correspond to the Rayleigh statistics found in properly functioning reverberation chambers when a sufficiently large number of modes are excited. The purpose of this paper is to show that the antenna efficiency can be measured accurately in much faster, easier and cost effectively reverberation chamber using three different antennas (two monopole antennas with attenuator and surface mount resistor, and modified folded monopole patch antenna). It also gives an investigation of the statistical characteristics in Rayleigh communications channels by using reverberation chamber. Scattering parameters taken from the measurement of the antenna radiation efficiency using reverberation chamber is implemented into Rayleigh Probability Density Function (PDF) model and it really shows that they are in good agreement with those of theoretically predicted Rayleigh model.

Keywords : Reverberation Chamber, Small Antenna, Antenna Efficiency Measurement

INTRODUCTION

New concepts of antenna have been developed rapidly by the increasing use of terminal antennas, which is physically and electrically small antennas mounted on devices, such as mobile devices [1]. In [2][3], small antenna is defined as one occupying a small fraction of one radian sphere in space. The use of the reverberation chamber hasbecome one of the popular methods in order to determine small antennas efficiency in multipath environment [4]. The old method of efficiency measurement, which is measuring radiation patterns, is very useful if the environment is well known. But, in case of terminal antenna, such as mobile phone antennas, it works in variable environment depending on its surroundings. The most convenient efficiency parameter in changing environment or multipath surroundings is the radiation efficiency. Thus, the best way to characterize and measure the radiation efficiency is by the use of reverberation chamber. However, one of the best methods and has been classified as traditional method to determine the antenna efficiency is by using the Wheeler Cap method, where it uses the standard of laboratory equipment, speed of measurement, repeatability and accuracy [2] [5]. Wheeler Cap method is another method of antenna efficiency measurement using a radiation shield, as measurement using radiated method is laborious [2] [3]. The measurements make use of a reverberation chamber which in principle is a resonant cavity, and they include measurements of the classical radiation efficiency of small antennas, the gain when using diversity antennas, the maximum available capacity of a MIMO antenna system, radiated power, receiver sensitivity and implemented diversity gain of actual terminals. If a signal is transmitted between a base station and a mobile unit that is moving through a multipath environment, wave interference among the multipath components results in severe fading of the received signal. Amplitude fluctuations in signals received over mobile radio channels are typically modeled by a Rayleigh distribution.

The field statistics in the volume of the enclosure are shown to correspond to the Rayleigh statistics found in properly functioning reverberation chambers when a sufficiently large number of modes are excited [8]. Many work has been done in this area to understand the behaviour of fields in electrically large enclosures [9]. Research had been conducted on the behaviour in reverberation chambers show that under the ideal conditions of large number excited modes the probability density function of the magnitude of individual field components follows a Rayleigh distribution. In [9], the variation of field behaviour near the conducting walls inside the chamber was investigated where it has demonstrated the effects on Q factor and number of modes excited in using reverberation chamber.

REVERBERATION CHAMBER SETUP FOR EFFICIENCY MEASUREMENT

This section introduces the procedure for measuring the efficiency of small antennas in a reverberation chamber. The measurements were done in a reverberation chamber, with dimensions of 0.8m x 0.8m x 1m. Setup for the measurements is shown as in Figure 1 [7] [10]:

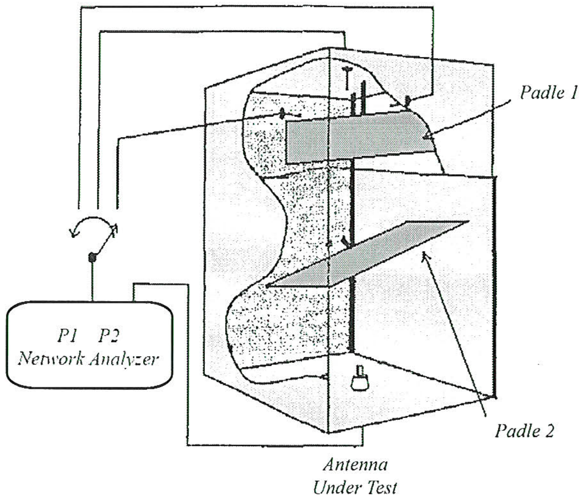

Figure 1. Reverberation Chamber setup for efficiency measurements.

For antenna efficiency measurement setup, it is basically needs the scattering parameters for transmission and reflection coefficient at the excitation antenna with respect to the Antenna Under Test (AUT), whether it is reference antenna or AUT. The scattering parameters are measured at the two antenna ports between one port of the fixed transmitting antenna (Port 1) and the port of AUT (Port 2) from the network analyzer. It is necessary to first measure the reference case and then the AUT case for efficiency measurement. The transfer function for reference case is calculated by using the following formula [7] [10]:

$$P_{ref} = \frac{\left|\overline{S_{21,ref}}\right|}{\left(1-\left|\overline{S_{11}}\right|^2\right)\left(1-\left|\overline{S_{22,ref}}\right|^2\right)} \tag{1}$$

Where, P_{ref} is the power of reference antenna, S_{11} is the reflection coefficient at the excitation antenna, S_{22} is the reflection coefficient at the reference antenna and S_{21} is the transmission coefficient between the excitation and the reference antenna. In [2][6][7][10], the test case can be carried out by interchanging the reference antenna with AUT or device under test and keep the same setup conditions as the reference case. The power transfer function for the test case then will be:

$$P_{aut} = \frac{\left|\overline{S_{21,aut}}\right|}{\left(1-\left|\overline{S_{11}}\right|^2\right)\left(1-\left|\overline{S_{22,aut}}\right|^2\right)} \tag{2}$$

Where, P_{aut} is the power of the AUT, S_{11} is the reflection coefficient at the excitation antenna, S_{22} is the reflection coefficient at the AUT and S_{21} is the transmission coefficient between the excitation antenna and the AUT.

As shown in [2][4][6][7][10], it is very important for efficiency measurement using reverberation chamber where the chamber has to be loaded in exactly in the same way for both cases. In addition, the net transfer power used from both (1) and (2) were calculated by considering three positions of excitation antenna, which are position A, B and C inside the reverberation chamber itself. The transfer function for both cases can generally be described as [4]:

$$P = \frac{1}{3}\sum_{i=A,B,C}\left[\frac{\left|\overline{S_{21,i}}\right|}{\left(1-\left|\overline{S_{11,i}}\right|^2\right)\left(1-\left|\overline{S_{22,i}}\right|^2\right)}\right] \tag{3}$$

Where i is the location of the excitation antennas at position A, B and C as in Figure 1. The transfer function for each position was calculated before averaging the values of transfer function P_{ref} and transfer function P_{aut}. The absorption efficiency e_{abs} then can be calculated as:

$$e_{abs} = \frac{P_{aut}}{P_{ref}} \tag{4}$$

Thus the total radiation efficiency, e_{rad} can be calculated with the following expression [2][6][7]:

$$e_{rad} = \left(1-\left|\overline{S_{22,aut}}\right|^2\right)\frac{P_{aut}}{P_{ref}} \tag{5}$$

RAYLEIGH DISTRIBUTION MODEL

The mobile radio channel is characterized by two types of fading effects; large scale fading and small scale fading. The fading amplitudes can be modelled by a Rician or a Rayleigh distribution (which the case is small scale fading), depending on the presence or absence of specular signal component. Fading is Rayleigh if the multiple reflective paths are large in number and there is no dominant Line of Sight (LOS) propagation path. If there is also a dominant LOS path, then the fading is Rician distributed. The fading amplitude r_i at the ith time instant can be represented as:

$$r_i = \sqrt{\left(x_i + \beta\right)^2 + y_i^2} \tag{6}$$

Where b is the amplitude of the specular component and x_i, y_i are samples of zero mean stationary Gaussian random processes each with variance s_0^2. The Rician fading is given by [12]:

$$f_{rician}(r) = \frac{r}{\sigma_0^2} \exp\left[-\frac{\left(r^2 + \beta^2\right)}{2\sigma_0^2} \right] I_0 \left[\frac{r\beta}{\sigma_0^2} \right] \quad r \geq 0 \tag{7}$$

Where I_0 is the zero order modified Bessel function of the first kind. If there is no dominant path, with zero Rician K-Factor and, $I_0 = 1$ yielding the worst case Rayleigh PDF [12]:

$$f_{rayleigh}(r) = \frac{r}{\sigma_0^2} \exp\left[-\frac{r^2}{2\sigma_0^2} \right] \quad r \geq 0 \tag{8}$$

In reverberation chamber case, the time variable multipath propagation is generated using the stirrer rotation. The statistical property of the received signals amplitude by any arbitrary antenna shows a Rayleigh type of distribution.

RESULTS AND DISCUSSIONS

The efficiency measurements were carried out using HP8720C Network Analyzer, with full two port calibration for specified frequency at 3.26GHz. Measurement results for the three AUTs are presented in order to give an indication of the relative accuracy between two methods; calculated efficiency from simulation; and measured efficiency from reverberation chamber method, which was taken by considering time measurement for 5 minutes, 15 minutes and 30 minutes. Table 1 show the comparisons where the radiation efficiencies were expressed in percentage values.

Table 1 Efficiencies for Various Types of Antennas.

Antennas under Test	$\eta_{simulation}$	$\eta_{Reverberation\ Chamber}$		
		5 Minutes	15 Minutes	30 Minutes
Modified Folded Monopole	75.62 %	85.65 %	87.64 %	87.22 %
Monopole with 20Ω SMT Resistor	69.05 %	62.37 %	67.21 %	66.18 %
Monopole with 3 dB Attenuator	58.53 %	43.95 %	45.51 %	51.55 %

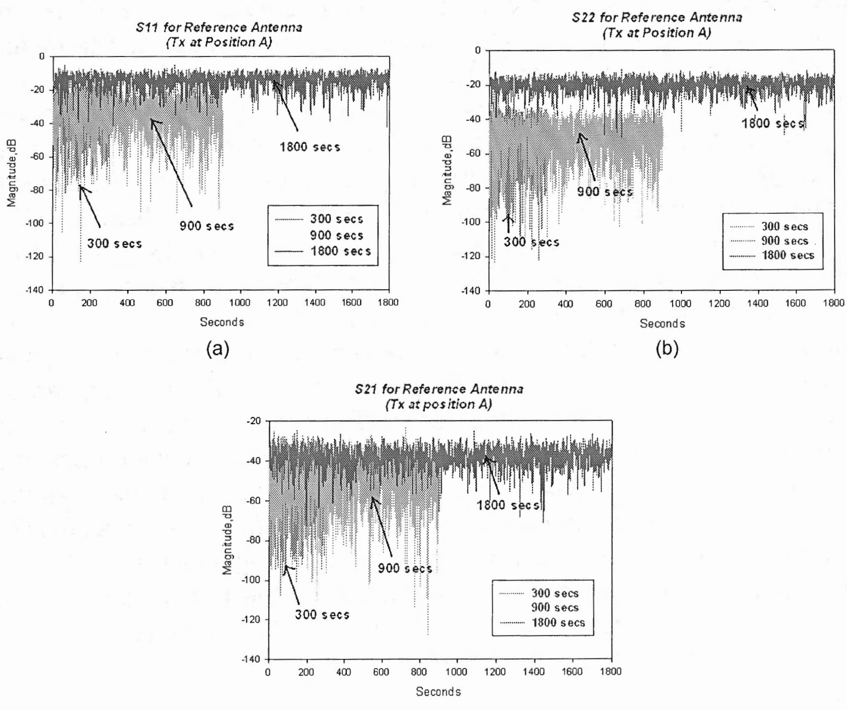

Figure 2. The scattering parameters at different time measurement for reference antenna when the transmitter was measured at the top side inside the reverberation chamber.

The efficiency for reverberation chamber method was calculated using (1) to (5). The scattering parameters were obtained in real values and imaginary values. The absolute total gain for these parameters then was calculated before averaging all the values with respect to number of points from the software interface. This procedure was repeated for every scattering parameter, i.e. S_{11}, S_{22}, S_{21} and also every position of transmitters for reference antenna and AUT, i.e. A, B and C before it can be applied in into (1) and (2). The absorption efficiency then can be calculated using (4) and the total radiation efficiency for the antenna was obtained from (5). However, the total radiation efficiency was expressed in terms of percentage for synchronization with the percentage of efficiency obtained from the simulation results. From Table 1, it can be observed that the modified folded monopole showed a very high efficiency when measuring it using the reverberation chamber method [7].

The simulated result that is showing high efficiency was obtained by considering the free space environment. The simulation usually considers and assumes that the real environment (where in terms of simulation is open free space) is ideal. For monopole antenna with 20Ω surface mount resistor, it clearly can be observed that there was a good agreement between both measured results. This antenna was expected to have lower efficiency than the reference monopole. Therefore, the obtained result where the percentage was around 50% to 70% has really proved that the high efficiency for perfect or ideal monopole can be decreased by introducing any source of loss or resistance. It can be noted that the measurement was accurate with almost equal accuracy among all the measurements. This lossy antenna can be compared with the efficiency of the reference monopole, which was 88.91% efficiency from the simulator. The measured efficiency of the antenna was dropped by almost 20% or by 14dB difference. It is appropriate to conclude that if the antenna was made for lossy condition, the efficiency will be affected and dropped, as expected. For monopole antenna with 3dB attenuator, it can be seen that the measured result shows good agreement between all methods of measurement. The efficiency gave measured values ranging of 50% with ± 8%. This really correlated with theoretical value, where if an ideal antenna (which is zero loss and most of the return loss S_{11} is zero across the band) and a perfect attenuator were used, the measured efficiency supposed to be at 50% [5].

The efficiency measurement from reverberation chamber method also gave well relation with the simulation results. It really shows that the multipath environment inside the chamber does not affect the accuracy of the antenna efficiencies. By cascading with the attenuator, the power reflected from the antenna was reflected back into the attenuator. Therefore, it has increased the overall loss of the reference antenna and thus, decreased the efficiency. Figure 3(a) shows the measured received signal powers at position A (normalized to mean power) versus the recording time (second). The S21 parameters, i.e. transmission between the receiver and the transmitting antenna at position A above is approximated by the useful function of hist (the histogram function) [11], where it can be modeled as in Figure 3(b).

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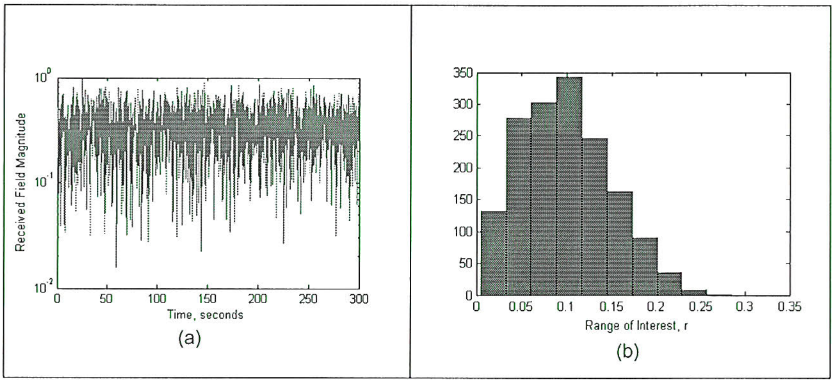

Figure 3. The measured received signal powers at position A and the corresponding histogram.

The histogram of measured S parameters really shows that how the statistical property of the received signal behaves as Rayleigh type distribution. These received signals then are applied into (8) for comparing with corresponding analytical PDF also given by (8). The result is as shown in Figure 4.

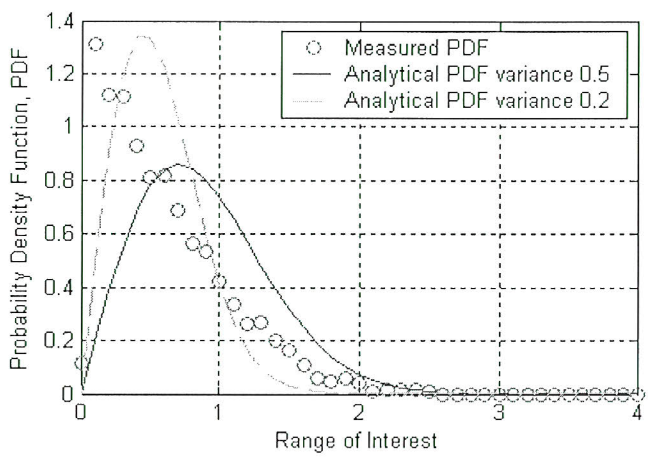

Figure 4. The Rayleigh PDF of measured received signal powers and analytical PDF at position A.

The PDF from measured received signals are slightly larger than the theoretical or analytical values proposed by (4). However, it seems that the measured PDF still in good agreement with analytical Rayleigh PDF as it goes toward zero when our range of interest, r at 2. The measured PDF has better agreement with value of variance,

$s_0^2 = 0.2$ compared to $s_0^2 = 0.5$. As a result, the reverberation chamber method which provides a multipath environment for the antenna under test shows an excellent agreement with the simulation result, where the simulated environment was in open free space area. Even the environment was perturbed by both paddles; the efficiency of this antenna was still stable and produced a good correlation with efficiencies obtained from traditional method and simulation result.

CONCLUSION

The comparative study of three different setup of measurement proves that multipath performances of antennas or terminal antennas, which particularly in this project are the antenna radiation efficiency, are comparable. Comparison between the reverberation chamber method and the calculation result using one of the best simulators in advanced electromagnetic and antennas had also proven that the antenna radiation efficiency practically should has a stable and same efficiency regardless where the antenna radiates [7]. The Rayleigh fading environment in reverberation chamber is investigated by the measurement for antenna radiation efficiency. The signals correlation between the transmitting antennas and AUT are computed from the scattering parameters at an indoor reverberation chamber. The reverberation chamber has been proven to be able to characterize both antennas and mobile terminals that are designed for use in a Rayleigh fading environment. The reverberation chamber offers in addition the possibility of a much faster measurement in an actual fading environment, with a continuously fading signal present at the terminal. This is a way of characterizing mobile terminals on reception that is very realistic compared to an actual operation of the terminal.

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