A Broadband Reference Antenna for Efficiency Measurements in a Reverberation Chamber

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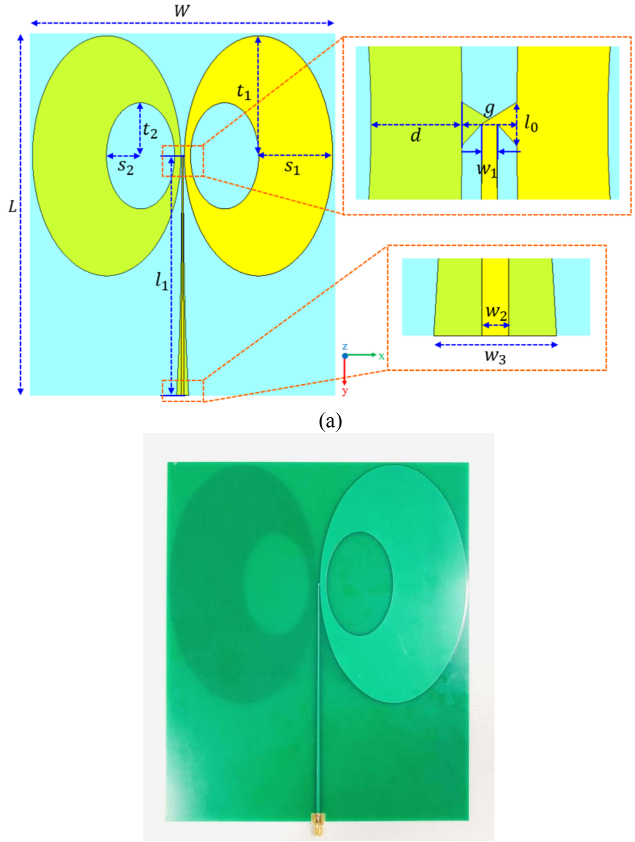
***Abstract*— A broadband reference antenna is proposed for antenna efficiency measurements in a reverberation chamber. The proposed antenna consists of two elliptical shaped dipole arms with elliptical slots etched on opposite sides of a thin FR4 substrate and fed by an exponential tapered microstrip balun. Measurements have been conducted to verify the antenna performance. It has been demonstrated that this antenna shows acceptable radiation efficiency from 200 MHz to 6 GHz.**

Keywords—antenna efficiency, broadband antenna, reverberation chamber.

I. INTRODUCTION

Broadband technology has been applied in a wide range of applications, such as high data rate short-range communication systems, ranging and geolocation sensor networks and high spatial resolution and superior penetration broadband radar systems [1]–[3]. A compact low-profile directional ultra-wideband (UWB) antenna for electromagnetic compatibility (EMC) measurements was presented in [4]. This self-grounded bow-tie antenna has a simple geometry, broadband performance with about −10 dB reflection coefficient for the frequency range of 2 GHz – 15 GHz. In [5], a broadband, ridged-guide horn (operating between 2 GHz and 18 GHz) antenna with dual polarization was designed as reference antennas; however, these antennas have relatively large electrical volumes. Planar monopole or dipole antennas have been widely studied and applied due to their unique advantages of ultra-broadband impedance characteristics, simple structure, compact size, low profile and inherent omnidirectional radiation. In [6], a planar monopole UWB antenna fed by a tapered CPW (coplanar waveguide) with an elliptical monopole patch was introduced, and this antenna can realize a ratio impedance bandwidth of 21.6:1 for S_{11} less than −10 dB and exhibit a nearly omnidirectional radiation pattern. A printed dipole antenna fed by coplanar striplines with enhanced impedance bandwidth of 2.8:1 and gain performance of 2.2 – 3.8 dBi across broadband operating between 2.12 GHz and 6 GHz was proposed in [7].

A reverberation chamber (RC) is an electrically large cavity with mechanical stirrers used to stir the field inside the chamber, which creates a statistical uniform environment that can be used as a unique test facility [8]–[9]. Initially, RCs were used as alternative test facilities in the area of EMC. Recently, there is a growing interest and demand in using RCs for a wide range of other measurement applications, such as the material electrical properties measurement, antenna radiation pattern measurement and antenna radiation efficiency measurement [8]. The methods for antenna radiation efficiency measurement, including reference antenna method and non-reference antenna method were summarized in [8]. For reference antenna method, in addition to the basic transmitted antenna and received antenna, a reference antenna is also required. In most cases, the traditional antennas used in reverberation chambers, such as a ridged-guide horn antenna, a biconical dipole antenna and a log-periodic antenna, are of types that were originally designed for other test environments [10]. These antennas are electrically large or may not have enough bandwidth.



(a)

(b)

Fig. 1. The proposed antenna: (a) Schematic plot, (b) Manufactured prototype.

In this paper, a broadband planar dipole reference antenna fed by an exponentially-tapered microstrip balun is presented. This antenna can operate between 200 MHz and 6 GHz with a decent total efficiency (better than -15 dB at 200 MHz) which cannot be obtained by simply scaling down a UWB antenna (typically from 3.1 to 10.6 GHz). The measured results are in good agreement with the simulated results.

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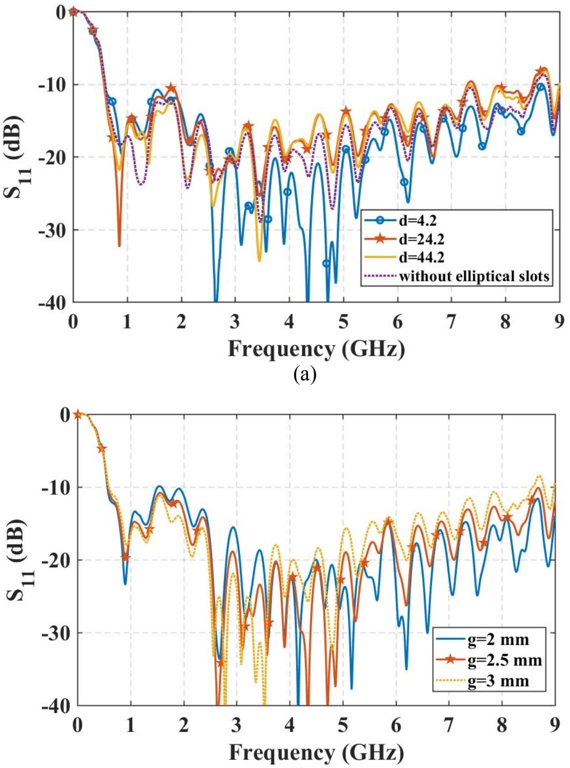


(a)

(b)

Fig. 2. Simulated S_{11} of the proposed antenna. (a) Simulated S_{11} with varying d (including the elliptical dipole antenna without elliptical slots). (b) Simulated S_{11} with varying g.

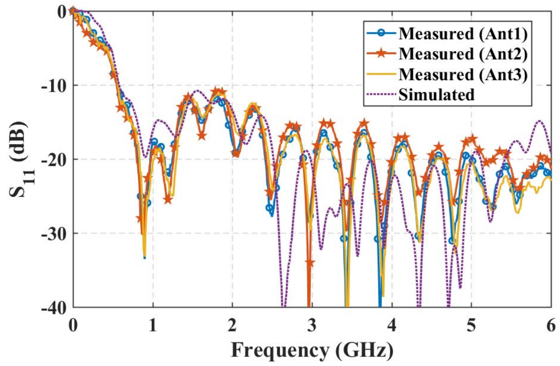


Fig. 3. Simulated and measured S_{11} of the proposed antenna.

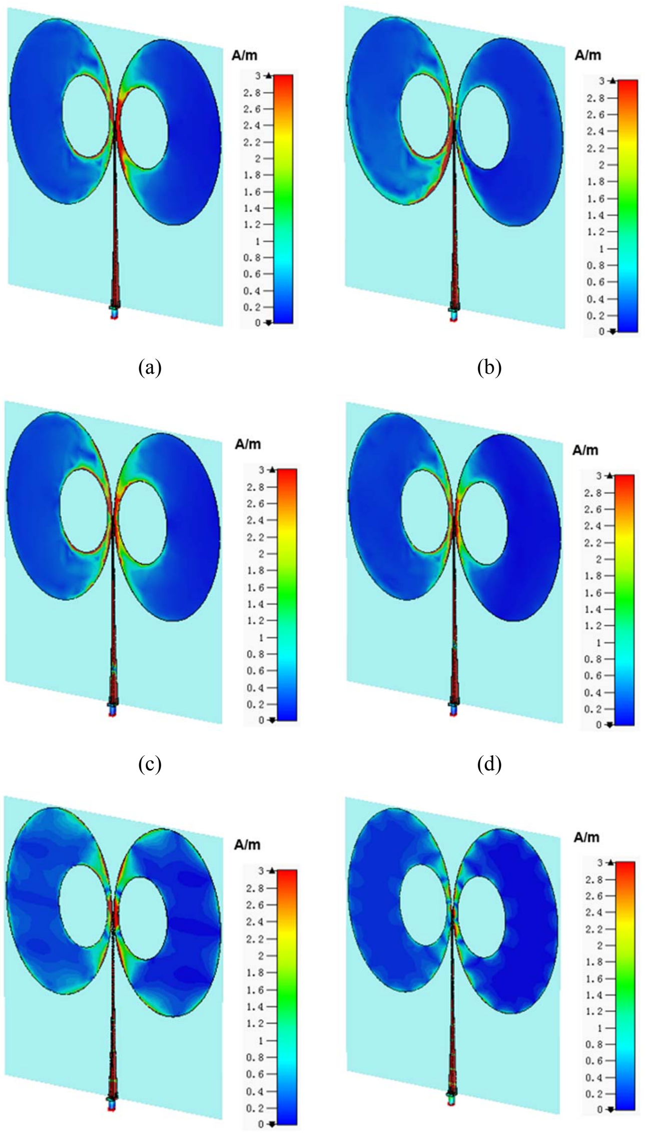
II. ANTENNA DESIGN

The configuration of the proposed antenna is shown in Fig. 1. The antenna is composed of an elliptical-shaped dipole with elliptical slots and a microstrip balun with an exponential tapered transmission line. The substrate is of 1 mm-thick with relative permittivity of 4.3 and loss tangent of 0.025. Two ellipse shape dipole patches are printed on opposite sides of the substrate to produce currents in opposite directions. The idea of etching out an elliptical region is inspired from the examination of the current distribution on the elliptical patch, where the currents are mostly concentrated on the periphery of the elliptical metal patches with a low current density in the center [11]. An exponentially-tapered microstrip balun is introduced for the impedance conversion from 85 Ω to 50 Ω in order to directly connect to a cable with a characteristic impedance of 50 Ω. The optimized parameters of the proposed antenna are presented in Table I.

TABLE I. OPTIMIZED ANTENNA DESIGN PARAMETERS

Dimension	Value	Dimension	Value
W	210	L	250
t_1	82.8	s_1	51
t_2	36.6	s_2	23.5
l_0	2	l_1	165.5
g	2.5	d	4.2
w_1	0.7	w_2	1.9
w_3	8.4		

All dimensions in mm.



(a) (b)

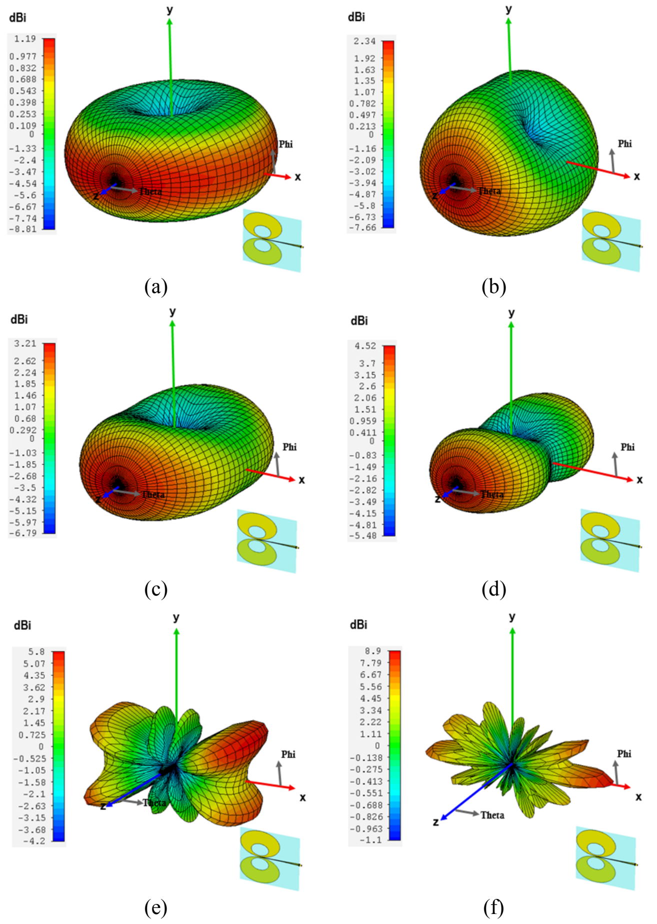
(c) (d)

(e) (f)

Fig. 4. Surface current distribution of proposed antenna at different frequencies: (a) 200 MHz; (b) 400 MHz; (c) 800 MHz; (d) 1 GHz; (e) 3 GHz; (f) 6 GHz.

III. ANTENNA PERFORMANCE

Parametric studies of the effect of the elliptical slots position on the S_{11} are shown in Fig. 2(a). By adjusting the value of the parameter d, the elliptical slot is located at different positions in the elliptical patch (see Fig. 1(a)). In



(a) (b)

(c) (d)

(e) (f)

Fig. 5. Simulated 3D radiation patterns at different frequencies: (a) 200 MHz; (b) 400 MHz; (c) 800 MHz; (d) 1 GHz; (e) 3 GHz; (f) 6 GHz.

this case, the value of *g* is 2.5 mm. The simulated results show that the best position is when the ellipse slot is at 4.2 mm away from the feed gap. For comparisons, an elliptical dipole antenna without elliptical slots is also shown. From the results shown in Fig. 2(a), the bandwidth and the S_{11} of the antenna are marginally improved by the introduction of slot in a conventional elliptical patch. When the parameter *d* is equal to 4.2 mm, the simulated S_{11} results with various feed gap *g* are presented in Fig. 2(b). It can be seen that the S_{11} is strongly affected by the parameter *g*, the antenna can achieve a frequency range for the S_{11} less than −10 dB from 540 MHz to 9 GHz when the parameter *g* is set to 2.5 mm. A comparison between the measurement and simulation results is illustrated in Fig. 3. The measured results are similar and are agree with the simulated values. Fig. 4 show the surface current distribution of the proposed antenna at different frequencies. As depicted in Fig. 4, the current is crowded towards the elliptical edge of the structure with the highest current density at the feeding gap. The current path is extended using elliptical slots, which improves the impedance bandwidth of the proposed antenna under dimension constraints. The simulated 3D radiation patterns at different frequencies are presented in Fig. 5. Although the radiation patterns are very different at higher frequencies, it is not a problem for antenna efficiency measurements inside a reverberation chamber since the antenna total efficiency is defined as the ratio of the total power radiated by the antenna to the total power supplied to the antenna [8]. The antenna efficiency was measured in a reverberation chamber by using the three-antenna method described in [9]. The three-antenna method has the advantage of minimum preconditions and no reference antenna with known efficiency is necessary. Figure 6 shows the measurement setup in the reverberation chamber. The inner dimensions of the reverberation chamber are 6 m × 3.9 m × 2.8 m. The chamber has a lowest usable frequency (LUF) of about 160 MHz on the basis of the field uniformity criteria detailed in IEC 61000-4-21 [12], and the test volume is about 10.5 m^3. The simulated and measured results are shown in Fig. 7. We have manufactured three identical antennas (note that the three-antenna method does

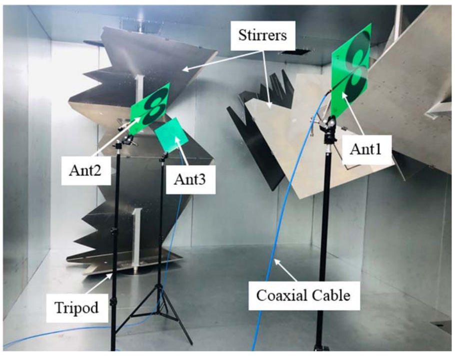


Fig. 6. Antenna efficiency measurement setup in a reverberation chamber.

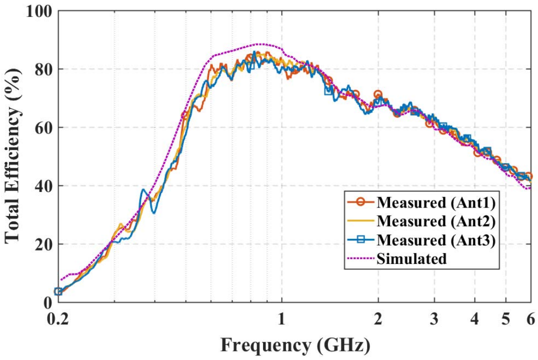


Fig. 7. Simulated and measured total efficiency of the proposed antenna.

Fig. 8. Antenna efficiency measurement (with absorbing material) in reverberation chamber.

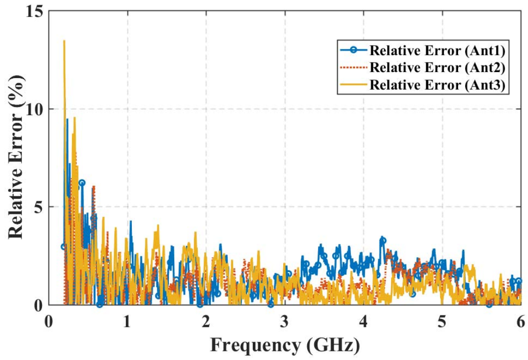


Fig. 9. The relative error of three measured antennas.

not require the three antennas are the same), the measured results using the three-antenna method are similar and are consistent with the simulated values. The efficiency decreases with the increase of frequency above 1 GHz, because the loss of transmission line, copper layer and dielectric substrate is increased at higher frequencies.

In order to identify the measurement error of the total radiation efficiency of the reference antenna, a second measurement was carried out. Compared with the first measurement, a piece of absorbing material was placed in the reverberation chamber, as shown in Fig. 8. The mean for two measurements is taken as a reference scale to calculate the relative error of three measured antennas. The results are expressed in the form of the relative error (e_r) which is defined as:

$$e_r = \frac{|\eta_{Ant} - \eta_{mean}|}{\eta_{mean}} \qquad (1)$$

where η_{Ant} is the antenna total radiation efficiency for the first or second measurement, and η_{mean} is the average efficiency for two measurements. It can be seen from Fig. 9 that the relative error of three measured antennas is mostly less than 5% within their operational frequency bands, and the larger relative error may be due to the non-uniformity of the RC at low frequencies. Note that this value agrees well with the results performed in different chambers in [13].

IV. CONCLUSIONS

A broadband dipole planar antenna fed by exponential tapered microstrip balun has been presented for measurements in a reverberation chamber. The antenna has a frequency range from 540 MHz to 9 GHz (for S_{11}<-10 dB). However, it can be used from 200 MHz to 6 GHz as a reference antenna, even the total efficiency is about -15 dB at 200 MHz. This is not a problem for using a typical vector network analyzer with a large dynamic range. In addition, the antenna efficiency was measured twice, and the results show that the relative error of the two measurements is mostly within 5% at their operational frequency band.

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