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DESIGN OF A NOVEL EXTREMELY WIDE BAND DIPOLE ANTENNA

Y. Zhang*, J. H. Qiu, S. Lin, and D. Wang

School of Electronics and Information Engineering, Harbin Institute of Technology, Heilongjiang 150080, China

Abstract—A novel extremely wide band dipole antenna with omni-directional radiation patterns is investigated experimentally and numerically. The proposed antenna comprises two groups of crossed semicircular discs. The shape of each disc is modified to broaden the working bandwidth. Measured results demonstrate that the novel antenna achieves good impedance match from 0.45 to 38.9 GHz for S_{11} lower than -10 dB, in agreement with simulated results. Omni-directional radiation patterns keep stable at the frequencies concerned. The proposed antenna is highly suitable for various wide band systems.

1. INTRODUCTION

With the development of wireless technology, many systems now work in more than one frequency band, which leads to rapid growth of broadband antenna techniques. UWB antennas are designed for applications where broad impedance bandwidth, linear phase response, constant gain, low profile, and stable radiation patterns are required [1–6]. It is challenging in practice to obtain a compromise between those requests. Furthermore, the exploitation and wide use of electromagnetic wave in various bands have greatly increased the complexity of the electromagnetic environment (EME). Therefore, in applications of electromagnetic compatibility (EMC) and electromagnetic interference (EMI), the sensing antennas are required to work in an ultrawide frequency band along with omni-directional radiation patterns at the same time. The existing equipments for EME sensing usually consist of a series of different antennas to cover a very wide frequency band, which increases the complexity of the systems.

In order to expand the operating bandwidth and earn omni-direction radiation patterns, various designs have been developed. Log

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* Corresponding author: Yang Zhang (282323531@163.com).

periodic and spiral antennas radiate different frequency components from different parts of the antenna, which causes distortion of the short impulse signals [7, 8]. Tapered slot antennas are well known to provide a very large impedance bandwidth [9, 10]. The distance between the two radiating elements changes gradually from the feed point to far-end, creating a smooth transition of impedance. It is hard for the antennas mentioned above to obtain omni-directional radiation patterns due to their operating principles. As typical omni-directional antennas, bi-conical antenna and its derived structures such as discone antenna, bowtie antenna, and monopole antennas have been widely used in wide band systems recently [11–14]. But it is very hard for them to obtain stable omni-directional radiation and very wide band characteristics simultaneously for EME sensing. With respect to all the existing wide band antennas, the lowest operating frequency is determined by the dimension of the main radiating body.

This paper presents a novel extremely wide band dipole antenna, which has outstanding wide operating bandwidth and stable omni-directional radiation characteristics at the same time. Several measures are introduced to improve the performances of the antenna. Results show that the proposed antenna operates well from 0.45 to 38.9 GHz with S_{11} lower than -10 dB. The omni-directional radiation patterns keep stable within the whole working band. Simulated and measured data agree well. The proposed antenna is highly suitable in various wide band systems.

2. ANTENNA CONFIGURATION

The geometry and configuration of the proposed antenna is shown in Fig. 1. The antenna consists of two vertical-direction approximately symmetric parts. Each part comprises four semi-circular metal discs crossing at the center, and the radius R is 100 mm. There is a small circular arc with the radius r of 40 mm embedded into each crossing disc. The antenna is fed by a coaxial cable with a SMA connector. The diameter of the cable is 3 mm. The cable penetrates through the axis of the upper part to connect with the lower part. The outer metal layer connects with the upper part while the inner conductor connects with the top of the lower part. The feed gap between the two parts is 0.8 mm.

3. DESIGN PROCEDURE

To design a wide band antenna with stable radiation patterns is very challenging and complicated. It is impossible to have all

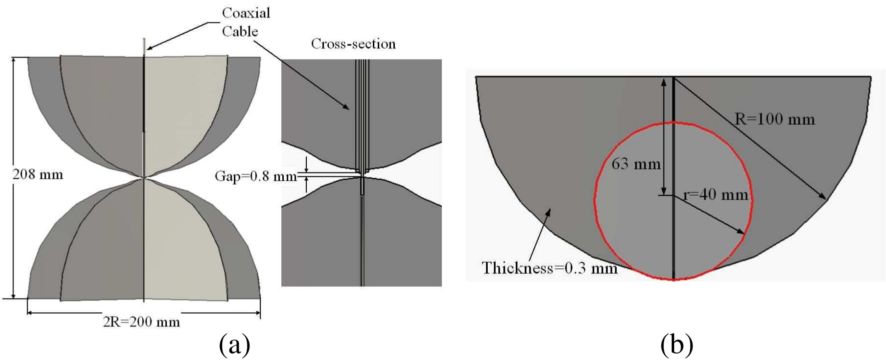


Figure 1. Geometry of the proposed antenna. (a) Global view with cross-section, (b) radius and location of the arc.

the characteristics optimized simultaneously. Therefore, an optimal balance should be made among these characteristics by studying the structure and parameters. The design procedure is based on a circular disc dipole antenna. The proposed antenna is modeled and calculated in the CST microwave studio software, which is mainly based on the finite integration time domain (FITD) method. This software has great advantages in electrically large antenna and ultrawide band antenna design. Limited by the computer hardware, the simulation of higher frequency is at 30 GHz.

The circular disc antenna is a deformation of bi-conical antenna or tapered slot antenna, whose input impedance is constant over a wide frequency range, and can be considered as a highpass filter. Its lowest working frequency can be calculated according to formula (1). In order to realize miniaturization, the circular disc is usually replaced by a semicircular disc. Then the formula is modified as formula (2) [15], where the units of fl and r are GHz and cm, respectively. The radius of the proposed antenna equals 10 cm, so the lowest frequency is 0.49 GHz.

$$fl = \frac{3.2}{r} \tag{1}$$

$$fl = \frac{4.9}{r} \tag{2}$$

3.1. Radiation Patterns

The circular disc antenna is of great characteristics, such as simplicity of fabrication, stable phase center, and very wide operating band, but the radiation patterns are not stable due to its planar structure. The

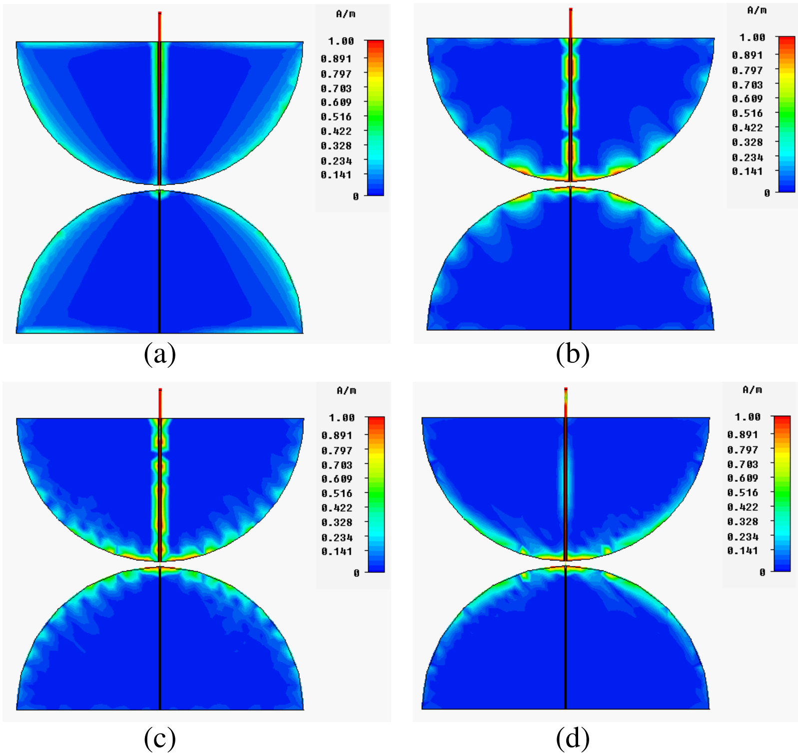


Figure 2. Surface current at 0 degree, (a) 0.5 GHz, (b) 5 GHz, (c) 10 GHz, (d) 20 GHz.

omni-directional radiation will deteriorate into bidirectional radiation as frequency rises. Fig. 2 shows the surface currents distribution at different frequencies. It can be found that the current at high frequencies mainly concentrates at the outline of the circular disc which can be considered as two current lines separated at a certain distance. Therefore, these two current lines comprise a two-element array which excites the majority of radiation. As the frequency rises, it is the interference effect of array elements' radiation that leads to a deterioration of the omni-directional characteristic.

A spatial axisymmetric structure can be chosen to enhance the omni-directional radiation [13]. As shown in Fig. 1, there are four semicircular discs crossed at the center, and the current distribution on each disc is exactly the same, so the radiation pattern can be considered as a rotation and repeated addition of each disc's radiation by four times. The comparison of the H plane radiation patterns is given in

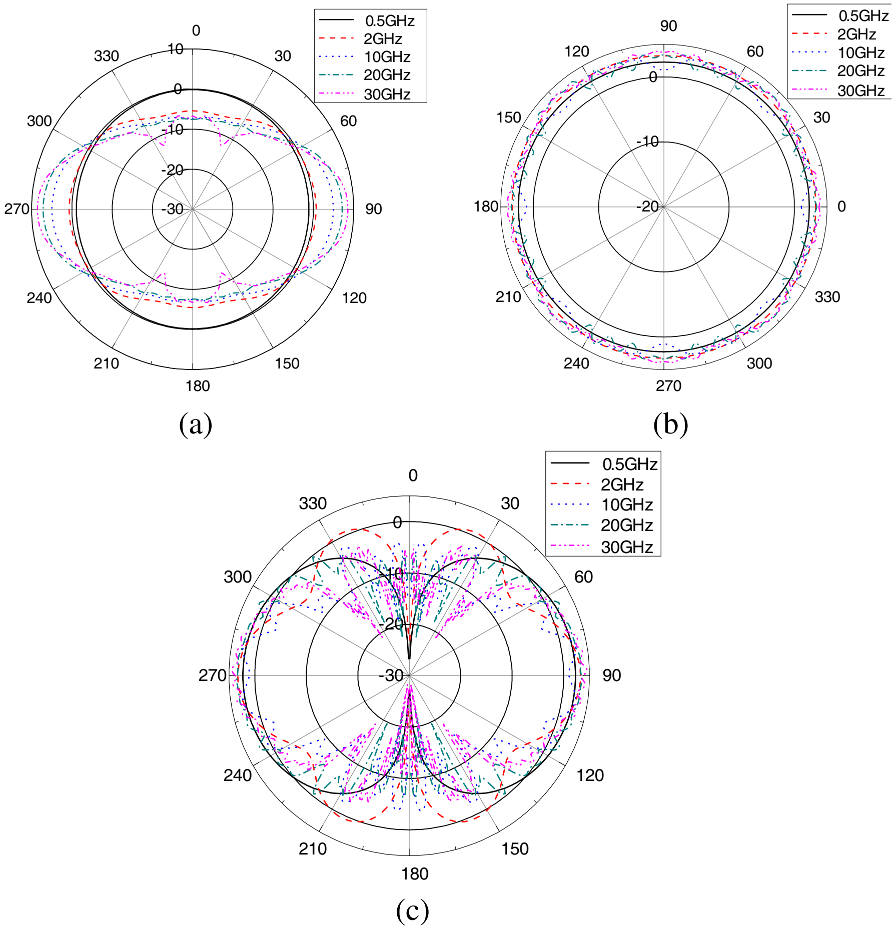
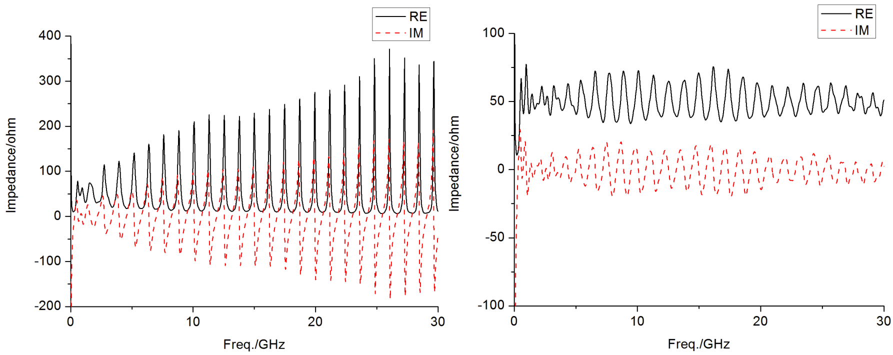


Figure 3. Radiation patterns in dB. (a) H plane of circular disc antenna, (b) H plane of crossing discs antenna, (c) E plane of crossing discs antenna.

Figs. 3(a), (b). It can be seen that the omni-directional pattern is enhanced greatly. Fig. 3(c) shows the simulated E plane radiation pattern of the crossing discs.

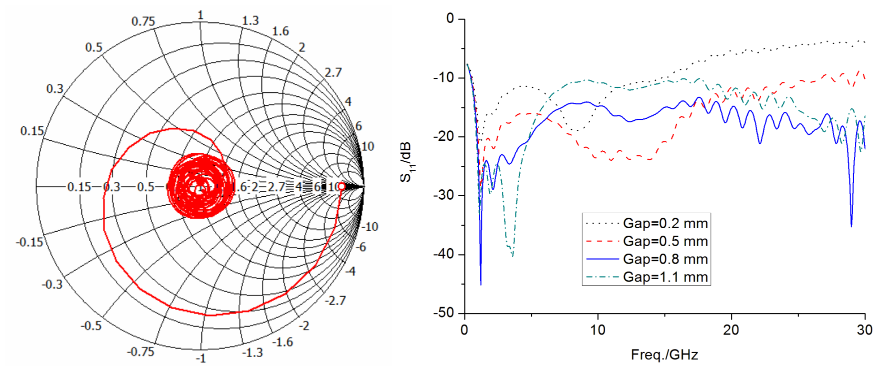
3.2. Impedance Match

It is found that the input impedance changes greatly in the concerned frequency band compared with circular disk antenna. Since the structure close to the feed influences the impedance greatly, a modification is introduced by embedding a small circular arc into



(a) (b)

Figure 4. Input impedance. (a) Crossing disc antenna, (b) crossing disc antenna with small arc.



(a) (b)

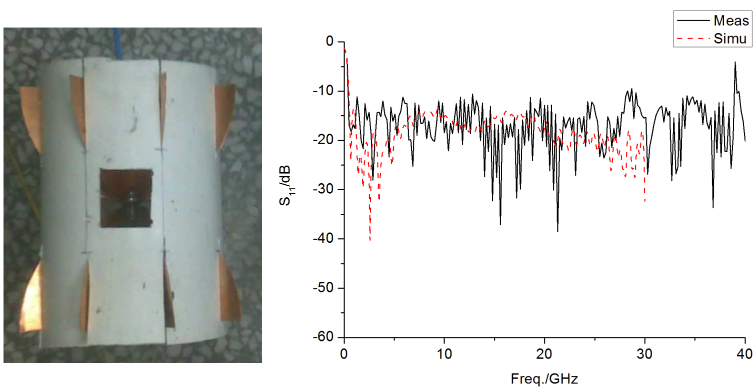
Figure 5. Impedance characteristics. (a) Smith chart of antenna impedance, (b) S_{11} versus frequency with different feed gaps.

each disc. (The radius of the arc is optimized by simulation with the optimum value of 40 mm.) It is meaningful to make the change for a better impedance transition from the input coaxial cable to free space. The improved impedance characteristics are shown in Fig. 4. It is seen that the real and imaginary parts fluctuate around 50 ohm and 0 ohm within the whole band. Those changes produce multiple resonant loops on the Smith chart in Fig. 5(a), demonstrating a wide band characteristic. The feed gap is a key parameter for impedance match over the whole band. By simulation, it is found that the optimized gap is 0.8 mm, as shown in Fig. 5(b).

Based on the analysis and simulation above, we can conclude a designing principle: the lowest working frequency is determined by the dimension of the antenna; the highest frequency is up to the small circular arc, and the optimized impedance match can be obtained by tuning the feed gap.

4. RESULTS AND DISCUSSION

The proposed antenna was manufactured manually and fixed by a PVC pipe with the diameter of 160 mm and length of 245 mm, as shown in Fig. 6(a). The antenna is made of copper with the thickness of 0.3 mm. The antenna was measured with the help of Agilent E8363B vector network analyzer (10 MHz–40 GHz) in an anechoic chamber. Fig. 6(b) shows the simulated and measured S_{11} against frequency. It is seen that the proposed antenna exhibits an outstanding wide band performance from 0.45 to 38.9 GHz with S_{11} lower than -10 dB, and the bandwidth ratio achieves 86 : 1. Considerable differences are found between the simulated and measured S_{11} results within 1–6 GHz and 24–30 GHz, as shown in Fig. 6. The simulated S_{11} is mainly lower than -20 dB, while the measured result is mostly between -10 dB and -20 dB. The reasons for these differences are as follow: the feed connector used in the antenna is the normal SMA connector, whose upper working frequency is about 30 GHz. Because of the uncertainty of the connector's quality, great impedance match (lower than -20 dB) cannot be acquired within such a wide frequency range. The precision



(a) (b)

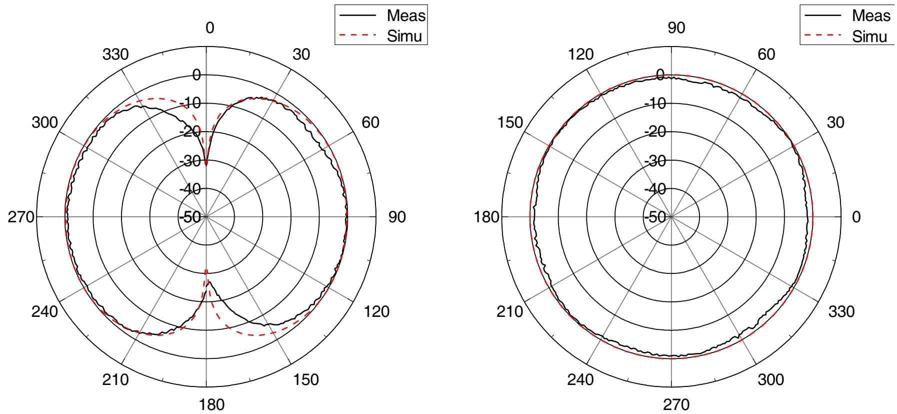
Figure 6. Photograph and S_{11} results of the proposed antenna. (a) Photograph, (b) S_{11} data

limit of handwork will also deteriorate the performance, especially in the higher frequency range. Another reason is that the dimension of the proposed antenna is somehow large, so the surrounding stuff (such as the metal shell of the measured equipment) will affect the measurement. The reflection caused by the metal shell may result in a slight rise of the S_{11}. The results indicate that the modification of the feed structure proposed in this paper extremely extends the upper limit of the operating band.

The measured radiation patterns of the antenna, at 0.8 GHz, 8 GHz, 13 GHz, are shown in Figs. 7, 8, and 9, respectively. Table 1 shows the simulated and measured gains at these frequency points. Due to restrictions of the measure condition, radiation patterns at frequencies higher than 13 GHz cannot be acquired. It is seen that the antenna has omni-directional radiation patterns at all the frequencies. The ripple level waxes at higher frequencies due to the rotational asymmetry, which is mainly caused by the carelessness of hand-fabrication.

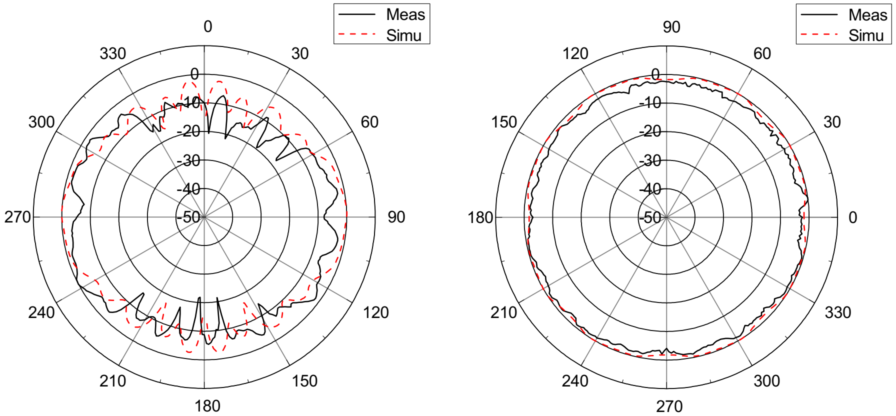
Table 1. The H plane max gain of the proposed antenna.

	0.8 GHz	8 GHz	13 GHz
Simulated result/dB	1.0	3.3	3.6
Measured result/dB	0.7	2.8	3.3



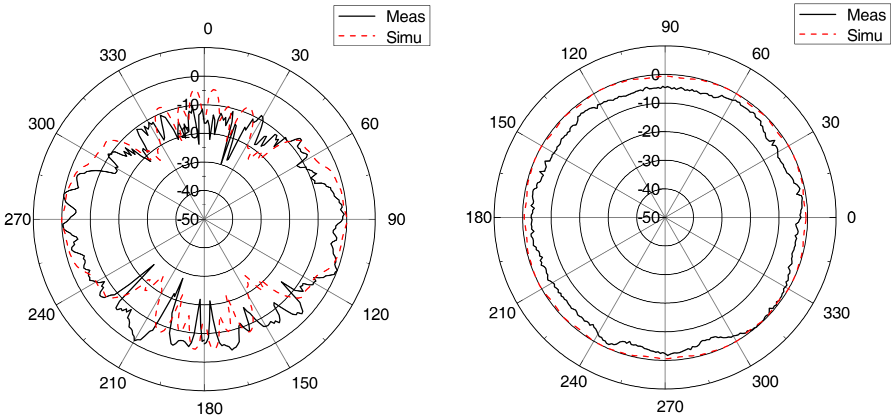
(a) E plane (b) H plane

Figure 7. Measured and simulated radiation patterns at 0.8 GHz /dB.



(a) E plane (b) H plane

Figure 8. Measured and simulated radiation patterns at 8 GHz /dB.



(a) E plane (b) H plane

Figure 9. Measured and simulated radiation patterns at 13 GHz /dB.

5. CONCLUSION

A novel extremely wide band dipole semi-circular disc antenna is presented in this paper. Each pole consists of four discs crossed to improve the omni-directional radiation patterns. The shape of the disc is modified by embedding a small circular arc to increase the highest operating frequency. Simulated and measured results agree well. Measured results show that the proposed antenna achieves very wide bandwidth in the frequency range of 0.45–38.9 GHz with S_{11} lower than -10 dB. Although there are ripples on the H plane curves, the omni-directional radiation patterns keep stable at the frequencies concerned. The proposed antenna is highly suitable for various UWB systems.

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