# A Cone Loaded Ultra-Broad Band Antenna For Electric-Field Measurement

Ziqian Zeng and Hongfu Guo
*School of Physics and Optoelectronic Engineering, Xidian University, Xi'an, Shaanxi, China*
*zqzeng@stu.xidian.edu.cn*

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Abstract: The design of sensing antennas in electric-field probes is the key to measure electromagnetic radiation accurately. In this paper, the cone dipole antenna and its dimension parameters are simulated by Ansoft HFSS. Meanwhile, the impact of dimension parameters on the performance of antennas is analysed. In order to improve the flatness of probe, the loaded dipole is adopted. Combining with the detection characteristics of diodes, the relationship between performance of loaded antennas and the flatness of electronic-field probes is discussed. Finally, the 1-40GHz ultra-broad band antenna for electric-field measurement is developed by optimizing these parameters of the antenna.

## 1 INTRODUCTION

The electromagnetic waves has provided unlimited convenience for people's lives. However, the problem caused by electromagnetic radiation is also highlighted gradually. Now electromagnetic radiation has risen to a new source of pollution, the electromagnetic pollution (Hou, 2011). Electromagnetic environment monitoring is an extremely effective way to reduce the harm caused by electromagnetic radiation to human. And electric-field probe is the core component of electromagnetic environment monitoring (Li, 2016).

In recent years, many experts have developed various electric-field probes and sensing antennas. Lv (2014) developed a broadband electric-field probe based on the fractal structure which improved the low frequency response of an ordinary electric-field probe, composed by the straight dipole. Then, Togo (2014) developed a metal-free electric-field probe based on photonics. Its frequency response is flat within a 6 dB range at frequencies from 100kHz to 10GHz. Later, Ohoka *et al.* (2015) developed an electric-field probe that combined a small dipole antenna with a high input impedance differential input amplifier circuit. This probe significantly improved sensitivity at low frequency. Nevertheless, now because the frequency needed by electronic systems becomes increasingly high and the upper limit of frequency range is already more than 40GHz, the existing antennas in electric-field probes no longer apply it. The antenna is the main component of the probe (Harasztosi, 2002). Therefore, the design of ultra-broad band sensing antennas in electric-field probes becomes the crux of the design of electric-field probes (Sun, 2008).

Based on the characteristic of antennas that the conventional dipole antenna is highly frequency sensitive (Kanda and Driver, 1987), the tapered structure and the loaded dipole have been used to solve above problem. In this paper, cone loaded dipole antennas are simulated and the impact of its parameters on the frequency response is analysed. Finally, the cone loaded ultra-broad band dipole antenna which the useful frequency range is up to 1-40GHz is realized by optimizing parameters.

## 2 DESIGN CONSIDERATIONS FOR THE ANTENNA IN THE ELECTRIC-FIELD PROBE

The electric-field probe consists of an electrically short dipole antenna and detector diode connected to an instrumentation amplifier via a high impedance line (Kalyanasundaram and Arunachalam, 2011). The performance of electric-field probes is mainly influenced by both the receiving antenna and the detector diode. The detection characteristic of ideal diode circuits is non-linear that the higher the

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frequency is, the worse the performance of the detected output is, as shown in Fig. 1. Therefore, to attain an electric-field probe with flat frequency response, the efficiency of the receiving antenna and the detector diode should be complementary that the performance of the receiving antenna increases with increasing frequency, as shown in Fig. 1. If using reflection coefficient (S11) to discuss the performance of the antenna, S11 should decrease with increasing frequency, as shown in Fig. 2.

In the paper, we want to attain an ultra-broad band antenna with useful frequency range of 1-40GHz. Therefore, the efficiency of the antenna should increase with increasing frequency within the frequency range of 1-40GHz.

# 3 SIMULATION FOR ANTENNAS IN THE PROBE

According to the antenna theory, the relationship between the frequency and reflection coefficient (S11) of the tapered antenna is similar to the one we need. In practical engineering applications, there are different kinds of tapered antennas, such as cone dipole antennas, pyramid dipole antennas and so on. In the paper, the cone dipole antenna is selected because it's easy to process. In order to facilitate simulate and design, the cone unloaded antenna is simulated first, and the relationship between the frequency and its parameters is analysed. Then by simulating the loaded antenna and optimizing parameters, the optimal parameters is obtained.

## 3.1 Simulation and Design for the Unloaded Dipole Antenna

Fig. 3 shows the simulation model of cone dipole antenna whose material is copper. The performance of antennas is analysed by changing its parameters. Final, the optimal antenna is obtained.

### 3.1.1 The Impact of Antenna Length on the Antenna Performance

In the simulation, the antenna length is changed from 3mm to 8mm and the step size is 1mm. Besides, the cone radius of the dipole and the dipole gap are set as 0.1mm and 0.5mm respectively. The simulation results shown in Fig. 4 indicates that the impact of the antenna length on resonant frequency is obvious. It can be observed that resonant frequency decreases with increasing antenna length.

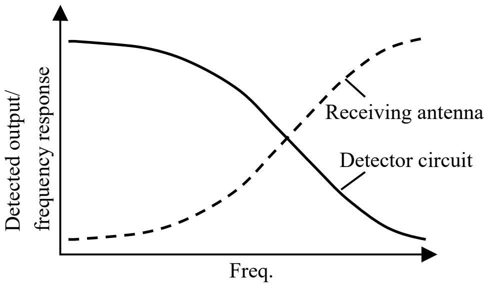

Figure 1: The efficiency of detected circuit and receiving antenna.

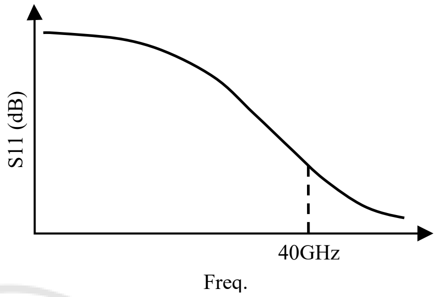

Figure 2: S11 versus frequency in the receiving antenna.

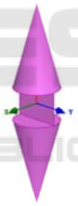

Figure 3: Cone dipole antenna model.

Besides, the 4-mm dipole antenna whose resonant frequency is 40GHz meets the requirement that the efficiency of the antenna should increase with increasing frequency within the range of 1-40GHz.

### 3.1.2 The Impact of the Dipole Gap on the Antenna Performance

Based on the above length optimization, the length is set as 4mm. And the dipole gap ranges from 0.1mm to 1mm and the step size is 0.1mm. Besides, the cone radius of the dipole is set as0.1mm. Figure 5 shows that the dipole gap has slight influence on antenna performance. When the dipole gap is 0.7mm, the efficiency around 40GHz is highest.

### 3.1.3 The Impact of Cone Radius on the Antenna Performance

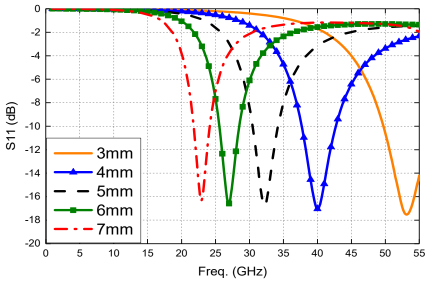

Figure 4: S11 versus frequency for varying antenna length.

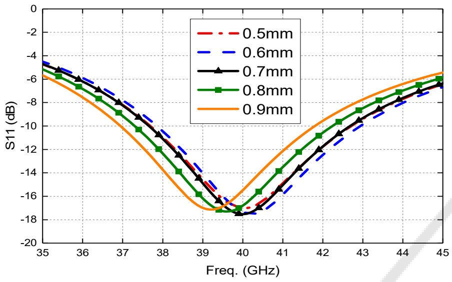

Figure 5: S11 versus frequency for varying dipole gap.

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Here the antenna length and the dipole gap are set as 4mm and 0.7mm respectively. And the cone radius of the dipole is changed from 0.1mm to 0.7mm. In Fig. 6, with cone radius increasing, reflection coefficient (S11) of resonant frequency point decreases first and then increases. When the cone radius of the dipole is 0.5mm, the efficiency of the antenna is highest.

According to above simulation, when antenna length, the dipole gap and cone radius are 4mm, 0.7mm and 0.5mm respectively, the performance of antenna is best. However, compared with ideal antenna shown in Fig. 2, the performance of above antenna has huge difference from the one we need. Its resonant characteristic is too prominent.

## 3.2 Simulation and Design for loaded Dipole Antennas

According to antenna theory and above analysis, the bandwidth of the dipole with pure metal is very narrow. Its resonant characteristic is prominent. While loaded antennas have flatter frequency response and wider bandwidth. Therefore, loaded antennas are used to improve the performance of antennas in probes (Yang *et al.*, 2014).

In last section we know that the impact of antenna length on resonant frequency is obvious, so the length and the loaded surface resistance are mainly changed to optimize the performance of antennas in this section. Here the dipole gap and cone radius are set as the optimal results which are 0.7mm and 0.5mm, and the substrate material of dipoles is aluminium-oxide ($Al_2O_3$). In the loaded antenna design, the resistance and the excitation probably have poor contact when the dielectric and the excitation are directly connected. So a sheet metal (gold) with 0.1-mm thickness is added between the dielectric and the excitation.

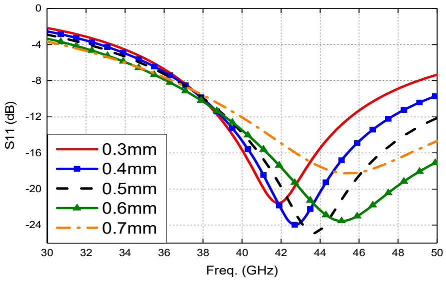


Figure 6: S11 versus frequency for varying cone radius.

### 3.2.1 Optimization for Antenna Length

First, we optimize the length of loaded antenna. In the process, based on that free space intrinsic impedance is 377Ω, the surface resistance of single arm of the dipole is set as 400Ω (Kraus, 2011). Meanwhile, antenna length is changed from 3mm to 30mm. From the simulation results in Fig. 7, we can know that short loaded antennas have low efficiency, especially in the range of 1-30GHz. Then, the efficiency becomes high and the flatness becomes good by increasing antenna length. And the 25mm loaded dipole antenna has the best performance.

### 3.2.2 Optimization for Surface Resistance

In order to obtain the optimal loaded antenna, the surface resistance is changed in this section. Antenna length is set as optimal value, 25mm. Fig. 8 depict the frequency response with different resistance. First, we change the resistance around 400Ω, as shown in Fig. 8(a). It can be seen that there are several resonance points within 1-40GHz, and resonance characteristic becomes weak by increasing resistance. Then, we continue to increase resistance. Fig. 8(b) shows that the efficiency becomes low within the range of 1-30GHz and becomes high within the range of 30-40GHz when the resistance increases. And now the trend of S11 curves is close to the ideal antenna.

By simulating unloaded and loaded antennas, we obtain the optimal antenna whose size is 25-mm antenna length, 0.7-mm dipole gap and 0.5-mm cone radius. And when the surface resistance is 4000Ω, its performance is closest to our need. Compared with the ideal antenna, the frequency response of the above optimal antenna can fit it well, as shown in Fig. 9. So it can be used in the probe.

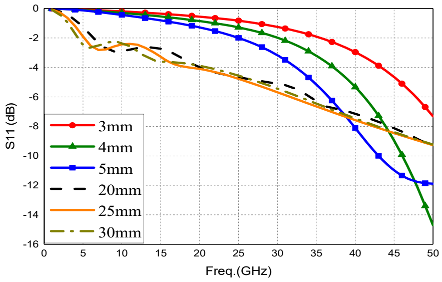
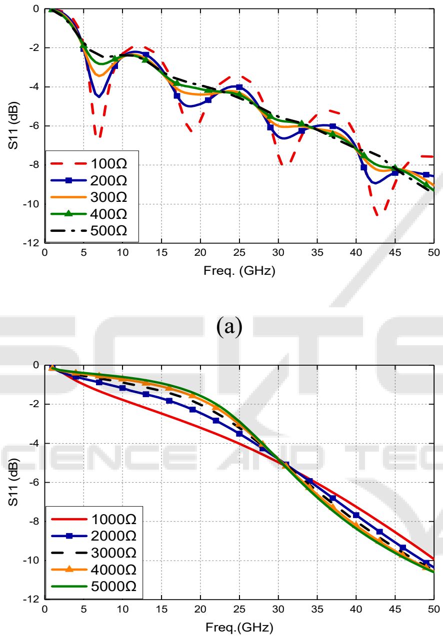


Figure 7: S11 versus frequency for varying antenna length.



(b)

Figure 8: (a) S11 versus frequency for resistance of 100-500Ω. (b) S11 versus frequency for resistance of 1000-5000Ω.

## 4 CONCLUSIONS

In the paper, we analyse cone unloaded and loaded antennas. The results indicate: 1) Loading resistance has a great influence on S11 curve of the antenna. 2) Loading resistance can obviously improve the flatness of the antenna in electric-field probe.

In this work, the broad-band antenna in probes for electric-field measurement with working frequency of 1-40GHz is presented by using cone structure and loaded dipole. And the method in the paper can be used to design antennas with wider bandwidth.

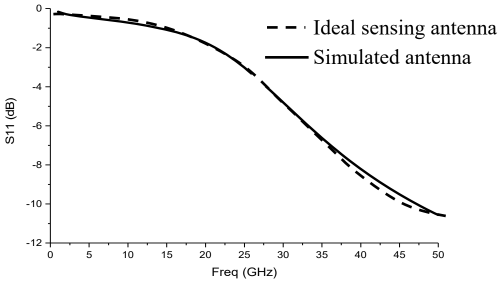


Figure 9: The comparison of ideal and simulated antenna.

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