Miniaturization Design of Monopole Antenna Based on Capacitive Loading

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Abstract - In this paper, three new structures of monopole antenna are proposed, which can greatly reduce the size of monopole antenna under the premise of ensuring omnidirectional radiation, high gain and high efficiency. The structures of the antenna adopt the innovative technology of capacitive loading. The performance of the proposed antennas can be obtained in three-dimensional electromagnetic field simulation. In order to understand the working mechanism of the innovative monopole antennas, the equivalent circuit model of the antennas is proposed and analyzed in this paper. The miniaturized monopole antennas can be used in short-range communication, radio communication and other equipment. The simulated and measured results of the antennas show that the innovative structures play a very significant role in miniaturizing the size of monopole, as well as in impedance matching, gain and efficiency.

I. INTRODUCTION

In the last decade, with the rapid development of modern wireless communication technology and miniaturization of communication systems, the demand for kinds of miniaturized antennas, which play an important role in wireless communication, is increasing. Monopole antennas, one kind of electrically small antennas, get more and more attention for its symmetric structure, omnidirectional radiation and high radiation efficiency [1]-[2]. This kind of antennas have the characteristics of omnidirectional radiation on the horizontal plane, which makes it possible to be used in short-distance communication and radio communication equipment. This kind of antennas have high radiation efficiency and gain. In fact, this type of antenna often has the problem of too large size in low frequency communication, so this paper focuses on the introduction of miniaturized antenna technology on the premise of ensuring high-performance radiation of antenna [3]-[4].

To miniaturize the size of the monopole antenna, a new proposed structure has been simulated as in [5]. But, The innovative structure proposed in this paper can reduce the antenna size to 0.015λ, but only 0.5λ in [5]. Similarly, the structure proposed in [6] only gets a size reduction to 0.22λ (but uses high dielectric constant material). But in this paper, the designs show more advantages in gain and miniaturization. In this paper, the designs innovatively use capacitive loading technology to realize the miniaturization of antenna size, and the dielectric constant of the capacitors is 4.4 or 8.84.

II. ANTENNA DESCRIPTION

The proposed antennas in this paper operate at 460MHz with an omnidirectional radiation, small size and high gain. As shown in Fig. 1, three structures have been simulated in three-dimensional electromagnetic field simulation software HFSS. Note that the external conductor of the coaxial feed line is connected to the bottom metallic ground when the inner conductor feeds radiator through field coupling by parallel plate capacitor.

![Diagram](image)

Figure 1. Three different structures

As shown in Fig. 1, some parallel plate coupling capacitors are used in the antenna structure to reduce the size of the...
antenna. The dielectric constant of the dielectric used for capacitors is 4.4 for antenna 1 and 3 when 8.84 for antenna 2 that allows us to manufacture on a large scale in production. Structure 1 can also theoretically achieve high gain and miniaturization of antenna, but in order to enhance the mechanical performance of antenna and reduce the height, structure 2 is proposed. In order to obtain better mechanical properties, eight capacitive-loaded structure 3 is proposed.

Structure 1 consists of ground, 50 ohm coaxial feed port, \(C_{\text{bottom}}\) monopole, \(C_{\text{upper}}\) metal plane. The radius and height of \(C_{\text{bottom}}\) are 15mm and 0.7mm, respectively, while \(C_{\text{upper}}\) are 45mm and 1mm respectively. The radius and height of the monopole conductor are 0.5mm and 25mm, respectively, and the plane radius of the upper metal and ground is 59.9mm.

The differences between structure 2 and structure 1 are that structure 2 removes \(C_{\text{upper}}\) and adds four dielectric-filled capacitive pillars. The radius and height of the monopole are 0.435 mm and 10mm, respectively, while \(C_{\text{bottom}}\) are 18 mm and 0.7 mm respectively. And the radius of the \(C_{\text{circle}}\) is 6mm. The distance between the center of the capacitors and the center of the ground is 52mm while the radius of ground is 70mm.

Structure 3 is to be a further improvement of structure 2. As shown in Fig. 1, the radius and height of the monopole are 4.3mm and 10mm, respectively, while \(C_{\text{bottom}}\) are 34mm and 0.7mm respectively. And the radius of the \(C_{\text{circle}}\) and ground is 14.5mm and 59.9mm, respectively. The distance between the center of the capacitors and the center of the ground is 50mm.

The equivalent circuit model of the antenna which is helpful for us to understand the working mechanism of the antenna can be shown as Fig. 2. As shown in the Fig. 2, capacitor \(C_1\) represents the coupling capacitance at the feed port while capacitor \(C_2\) represents the capacitance of \(C_{\text{upper}}\) in structure 1 or \(C_{\text{circle}}\) in structure 2 and 3, and \(R_{\text{mono}}\) and \(L_{\text{mono}}\) belong to monopole radiator. According to the equivalent circuit in Fig. 2, we can know that the input impedance of the antenna is given as follow:

\[
Z_{\text{in}} = R_{\text{mono}} + j(\omega L_{\text{mono}} - \frac{1}{\omega C_1} - \frac{1}{\omega C_2}).
\]  

(1)

When we adjust the antenna to a resonant state, the resonant frequency \(f_r\) of the antenna can be obtained and we can know the influence factors of the resonant frequency. The \(C^V\) refers to the equivalent capacitance of \(C_1\) and \(C_2\). As an consequence, \(L_{\text{mono}}\) will decrease when we increase the value of \(C^V\) at resonant frequency. It means that we can reduce the height of the antenna with this method.

### III. SIMULATED AND MEASURED RESULTS

Through the commercial full-wave simulation computing software HFSS, the simulated Return Loss can be seen in Fig. 3 which shows that the proposed antenna has a good impedance matching at resonant frequency 460MHz. This means that we can directly use 50 ohm coaxial line to feed the antenna. There is no doubt that the efficiency of antenna can not reach 100%, but higher than 90% because of the existence of metal conductors.

As shown in Fig. 4 (only antenna 2 for brevity), the innovative monopole antenna 2 designed in this paper has the characteristics of omnidirectional radiation, high gain and high radiation efficiency. For structure 1, it has the characteristics of high gain, simple structure and high efficiency, but its anti-
falling performance is poor, installation is difficult. For structure 2, it has compact structure, strong fall resistance, high gain and it is easy to install. Structure 3 is an improvement of structure 2. The performance of these three structures is listed in Table 1.

As shown in Table 1, the installation of structure 2 and 3 is less difficult. Structure 3 is the optimum design of structure 2. Structure 2 and 3 can reduce the size of antenna to a greater extent (0.015λ, totally), at the cost of reducing gain, on the premise of ensuring omnidirectional radiation and high efficiency.

<table>
<thead>
<tr>
<th>Structure</th>
<th>Freq (MHz)</th>
<th>Dielectric Constant</th>
<th>Gain (dBi)</th>
<th>Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>460</td>
<td>4.4</td>
<td>1.80</td>
<td>0.038λ</td>
</tr>
<tr>
<td>2</td>
<td>460</td>
<td>8.84</td>
<td>1.15</td>
<td>0.015λ</td>
</tr>
<tr>
<td>3</td>
<td>460</td>
<td>4.4</td>
<td>1.23</td>
<td>0.015λ</td>
</tr>
</tbody>
</table>

In order to prove the feasibility of this method to miniaturize the size of the monopole antenna, we fabricate and measure the performance of the antenna structure 2, as showed in Fig. 5. The measured Return Loss and VSWR can be seen in Fig. 6. As we can see, the frequency of the antenna shifts from 460 MHz to 450 MHz. Because the assembly of antenna is done by hand, the frequency error can be predicted. Moreover, because of the limitation of processing accuracy, measurement errors will also occur. In the parametric study, the radius of \( C \) is varied from 5mm to 7mm and we keep the other parameters constant as mentioned above. As we can see from Fig. 7, the radius of \( C \) called \( R_{via} \) has much more effect on resonant frequency. To a certain extent, the frequency shifting of the antenna is caused by this.

IV. CONCLUSION AND FUTURE WORK

Three new structures for monopole antenna have been proposed in this paper which can effectively reduce the size of the antenna and perform well in gain and radiation efficiency. Simulated and measured results show that the proposed antennas are small enough to be used in short-range communication and radio communication equipment. The measured radiation patterns and gain will be obtained in our next work.

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