A Novel Printed Folded Dipole Antenna Used for Modern RFID System*

Bin Lin, Jianhua Zhou**, Baiqiang You
Electronic Engineering Department, Xiamen University
Xiamen, Fujian, PR of China, 361005

***Abstract*—For the minimization of RFID tag antenna, we designed a printed folded dipole antenna working at 2.4 GHz. And a mirror compensation technology was introduced to improve the radiation feature of antenna with better return loss characteristic and directivity. The simulated results show that when VSWR (Vertical Standing Wave Ratio) is less than 2, the antenna bandwidth is up to 0.39 GHz absolutely and to 15.48% relatively. Considering engineering processes, the influences of dielectric constant ε_r, board thickness, folding degree and other parameters on the properties of this antenna are particularly studied. On the basis, a dual-frequency folded dipole antenna is proposed, which can work in two main frequency for RFID system, i.e. 915 MHz and 2.4 GHz. Moreover, an antenna sample made on this novel structure has been tested and the results show that the bandwidth of antenna is improved in further, along with hemisphere directional radiation characteristics.**

Keywords-radio frequency identification; tag antenna; folded dipole antenna; minimization

I. Introduction

The design of RFID (radio frequency identification) antenna is one of the key techniques that decide RFID system's functions. RFID tag antenna is needed to be placed in the tag with size limitation, and face development trends of minimization, low cost and low exhaust. Therefore, the design optimization of tag antenna plays a very important role in whole RFID system design [1-2]. The current hot points of study on RFID technique and its application involve in many aspects, such as realization of minimization, acquirement of larger bandwidth, realization of multi-bands and compatibility with other communication systems. For example in 2006, Ahmed Ibrahiem's team designed a printed dipole antenna that can work at 900 MHz. The antenna size reaches 60 mm × 40 mm which can also be decreased further, but its return loss characteristic isn't very ideal [3]. M.Stupf's team designed two antennas working at 900 MHz with superior function and small size, but the structure is complicated inconvenient for progressing [4]. Namhoon Kim's team used printed metal wreath for feeding to a printed dipole antenna to improve its performance. Nevertheless, the size is very difficult to be reduced further due to the feeding wreath [5]. Very differently, Kihun Chang's team designed the arm of printed dipole antenna as in wreath type which realized minimization, but with too narrow bandwidth [6].

The printed dipole antenna, usually applied for middle to long range RFID systems, has strong radiation ability and whole direction radiation characteristic, together with simple fabrication process, low cost and absolute advantages compared with normal antennas. So in this paper, a novel mirror compensation structure is put forward to improve the radiation characteristic for basic printed dipole antenna. Then along with the practical design work of this antenna, its performance simulation and analysis have been carried on in detail.

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** To whom correspondence should be addressed, E-mail: eezhoujh@xmu.edu.cn

II. Radiation Analysis of Dipole Antenna

In middle to long range RFID system, the most commonly used tag antenna is the dipole antenna with the length of arm equal to a quarter of the working wavelength ($\lambda/4$), as shown in Fig.1.

For calculating radiation field of basic dipole antenna, the antenna can be divided into many infinitesimal line segments, by each of which taken as a Hertz-dipole. Since it is very far from the observation point in Fig.1, the distance vector $\vec{r}'$ almost runs parallel to the distance vector $\vec{r}$, all along the direction of θ. The former is given from one line-segment unit of antenna at z position with length Δz to the observation point, while the latter is from the coordinate origin to the observation point. Thus, we have

$$r' = r - z\cos\theta \tag{1}$$

For the electric current segment $I(z)\Delta z$, the radiation electric field ΔE at z position along the same direction as $\vec{r}$ or $\vec{r}'$ is given as

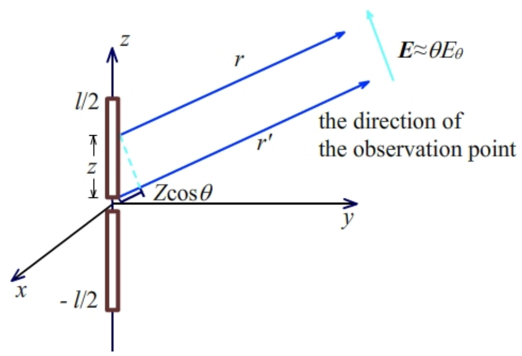


Figure 1. The radiation characteristic of basic dipole antenna

$$\Delta\vec{E} \approx \vec{\theta}\eta \frac{\mathrm{j}kI\Delta z}{4\pi r'} \sin\theta \mathrm{e}^{-\mathrm{j}kr'}$$

i.e.

$$\Delta\vec{E} \approx \vec{\theta}\eta \frac{\mathrm{j}kI\Delta z}{4\pi r} \sin\theta \mathrm{e}^{-\mathrm{j}kr} e^{\mathrm{j}kz\cos\theta} \tag{2}$$

Doing integral operation in the antenna length, the total radiation electric field is found as

$$\vec{E} = \vec{\theta}\eta \frac{\mathrm{j}k\sin\theta}{4\pi r} \mathrm{e}^{-\mathrm{j}kr} \int_{-l/2}^{l/2} I(z) \mathrm{e}^{\mathrm{j}kz\cos\theta} \mathrm{d}z = \vec{\theta} E_\theta \tag{3}$$

in which E_θ is the radiation electric field strength given by

$$E_\theta = \eta \frac{\mathrm{j}k\sin\theta}{4\pi r} \mathrm{e}^{-\mathrm{j}kr} \int_{-l/2}^{l/2} I(z) \mathrm{e}^{\mathrm{j}kz\cos\theta} \mathrm{d}z$$

Similarly, the radiation magnetic field of the antenna can be found as follows

$$\vec{H} = \vec{\phi} \frac{1}{\eta} E_\theta \tag{4}$$

Solving the integral in Eq. (3), we have

$$E_\theta = \eta \frac{\mathrm{j}I_0 \mathrm{e}^{-\mathrm{j}kr}}{2\pi k \sin\theta} \left[\cos\left(\frac{kl}{2} \cos\theta \right) - \cos\left(\frac{kl}{2} \right) \right] \tag{5}$$

Since the arm length of dipole antenna is assumed as

$$l/2 = \lambda/4$$

So we have

$$|E_\theta| = \frac{\eta I_0}{2\pi r \sin\theta} \cos\left(\frac{\pi}{2} \cos\theta \right) \tag{6}$$

III. STRUCTURAL DESIGN OF FOLDED DIPOLE ANTENNA

In structural design of printed dipole antenna, the antenna's arm was made folded to further let up its size. For improving the performance, we introduced a mirror compensation structure under the antenna creatively. The simulation results show that the new structure can improve the radiation feature of antenna obviously.

Taking the antenna used for RFID system working in ISM frequency section with bandwidth request of 2.4 ～ 2.4835 GHz as an example, FR4 dielectric board of thickness h = 0.8 mm and dielectric constant ε_r = 4.4 was used. The structure scheme of designed antenna is shown in Fig.2.

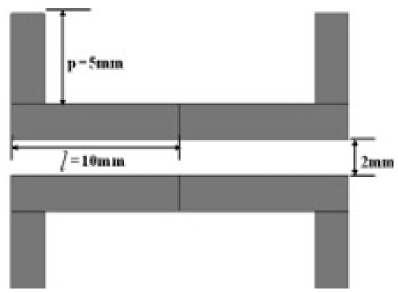


Figure 2. The structure scheme of printed folded dipole antenna with mirror compensation structure

Because of the original arm length equal to $\lambda/4$, the arm length after folded should satisfy the following condition

$$l + p = \frac{\lambda}{4} = \frac{c}{4f\sqrt{\varepsilon_r}} \tag{7}$$

Assigning the velocity of light $c = 3.0 \times 10^8$ m/s and the working frequency f = 2.4 GHz, the arm length after folded should be as

$$l + p = 15 \text{ mm} \tag{8}$$

Here, the horizontal length is taken as l = 10 mm, the longitudinal length as p = 5 mm.

IV. PERFORMANCE SIMULATION AND ANALYSIS OF FOLDED DIPOLE ANTENNA

A. *Performance simulation*

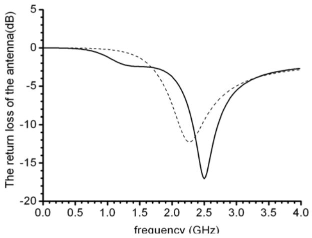
For the discussion of the electromagnetic radiation characteristic of folded dipole antenna, finite difference time domain method (FDTDM) is widely applied, combined with the grid method put forward by K. S. Yee in 1966 [7]. Simulating and analyzing the performance of designed printed folded dipole antenna, the return loss and directional characteristics of antenna are given in Fig.3 (a), (b) and (c) respectively. In Fig.3 (a), the solid line and the dotted line apartly present the return loss of the antenna with and without mirror compensation structure. It is obvious that the mirror compensation structure can improve the radiation feature of antenna greatly. The operating center frequency is 2.52 GHz, at which the return loss S_{11} is −17.03 dB. Based on the following formula

$$|\Gamma| = \frac{\mathrm{VSWR} - 1}{\mathrm{VSWR} + 1} \tag{9}$$

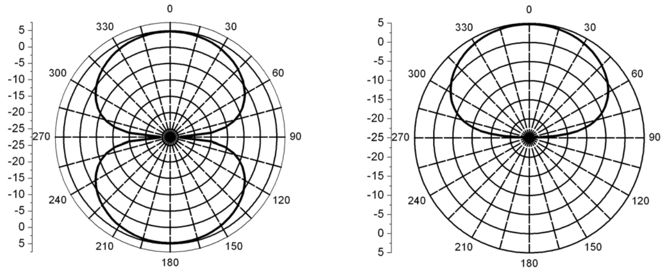
in which Γ is the reflection coefficient and VSWR is the vertical standing wave ratio, |Γ| is less than 1/3 when VSWR is less than 2. From the formula of return loss given by

$$S_{11} = 20\lg|\Gamma| \tag{10}$$

loss value S_{11} there all let up gradually that means the return loss characteristic getting better gradually. Moreover, the bandwidth and relatively bandwidth of antenna enlarge gradually for VSWR less than 2. In short, the circuit board with adequacy higher dielectric constant selected for practical processing will improve antenna performance obviously.



(a) The return loss characteristic



(b) H patterns (c) E patterns

Figure 3. The return loss and directional characteristics of folded dipole antenna working at 2.4 GHz

it can be found that S_{11} is less than −10 dB. Under such condition, the antenna bandwidth is up to 0.39GHz absolutely (2.342 GHz ~ 2.732 GHz) and 15.48% relatively. Thus, the return loss characteristic is better and the bandwidth meets the fundamental request for modern RFID system. From H and E patterns, it is obvious that this folded dipole antenna has hemisphere directional radiation characteristic.

B. Influence of dielectric constant on antenna performance

Although taken as $\varepsilon_r = 4.4$ in design, the dielectric constant of substrate will be deviated during the making process of antenna. Through a series of simulation, the influence of different dielectric constant on the performance of folded dipole antenna has been discussed, the results of which are listed in Table 1.

TABLE 1. INFLUENCE OF DIELECTRIC CONSTANTS ON ANTENNA PERFORMANCE TABLE TYPE STYLES

ε_r	**working center frequency (GHz)**	**S_{11} (dB)**	**bandwidth (GHz)**	**relatively bandwidth (%)**
4.0	2.58	-15.86	0.385	14.92
4.1	2.56	-16.24	0.388	15.16
4.2	2.54	-16.48	0.389	15.31
4.3	2.54	-16.74	0.389	15.31
4.4	2.52	-17.03	0.390	15.48
4.5	2.50	-17.28	0.390	15.60
4.6	2.50	-17.56	0.390	15.60
4.7	2.48	-17.87	0.390	15.73
4.8	2.46	-18.10	0.390	15.85
4.9	2.46	-18.46	0.390	15.85
5.0	2.44	-18.75	0.390	15.94

It can be seen from Table.1 that with a little increase of dielectric constant, the working center frequency and return loss value S_{11} there all let up gradually that means the return loss characteristic getting better gradually. Moreover, the bandwidth and relatively bandwidth of antenna enlarge gradually for VSWR less than 2. In short, the circuit board with adequacy higher dielectric constant selected for practical processing will improve antenna performance obviously.

C. Influence of the thickness of circuit board on antenna performance

The influence of different thickness used for circuit board on the performance of folded dipole antenna has also been discussed, the results of which are listed in Table 2. It can be seen that with a little increase of the thickness, the working center frequency and return loss value S_{11} there of antenna all let up gradually that means the return loss characteristic getting better gradually. But for VSWR less than 2, the bandwidth and relatively bandwidth of antenna enlarge gradually first, then let up gradually. For improving antenna performance, it is necessary to choose adequacy thickness of circuit board in practical processing to make the return loss characteristic and working bandwidth of antenna all meet the requirement.

D. Influence of folding degree on antenna performance

According to Eq. (7), the sum of the horizontal length l and longitudinal length p of antenna arm should be constant to keep the working center frequency invariant. Thus, longer longitudinal length means higher folding degree of dipole antenna arm.

Keeping the arm length based on Eq. (8), the antenna has been simulated by enlarging the longitudinal length gradually. The simulated working center frequency, S_{11} value, working bandwidth and its relatively one of antenna are shown in Fig.4 (a), (b), (c) and (d) respectively. The figure displays that the progressively enlarged length makes the working center frequency let up gradually at first and then increase gradually. Meanwhile, S_{11} value at the working center frequency presents the regulation just as in periodic variety. Moreover, the bandwidth and relatively bandwidth of antenna enlarge gradually for VSWR less than 2.

TABLE 2. INFLUENCE OF THE THICKNESS OF CIRCUIT BOARDON ANTENNA PERFORMANCE

***h* (mm)**	**working center frequency (GHz)**	**S_{11} (dB)**	**bandwidth (GHz)**	**relatively bandwidth (%)**
0.4	2.56	-11.70	0.280	10.94
0.5	2.56	-12.87	0.329	12.85
0.6	2.54	-14.12	0.359	14.13
0.7	2.52	-15.47	0.378	15.00
0.8	2.52	-17.03	0.390	15.48
0.9	2.52	-18.77	0.396	15.71
1.0	2.52	-20.78	0.400	15.87
1.1	2.5	-23.30	0.399	15.96
1.2	2.5	-26.67	0.397	15.88
1.3	2.5	-31.57	0.394	15.76
1.4	2.5	-37.84	0.388	15.52

In a whole, bigger folding degree and longer longitudinal length of antenna arm will make its working center frequency migrate to higher frequency section, to which special attention should be paid.

V. DESIGN AND SIMULATION OF DUAL-FREQUENCY DIPOLE ANTENNA

The working frequency sections around 868 ～ 870 MHz, 902 ～ 928 MHz and 2.4 ～ 2.4835 GHz have greatest application foreground for modern RFID system, which need a novel antenna covering these frequency sections. So we have special research on dual-frequency folded dipole antenna.

Based on the principle of mirror compensation structure applied in folded dipole antenna, two longitudinal arms are added on the horizontal arm of dipole antenna. This antenna can work in different frequency sections separately, similar to the combined-action effect of two printed folded dipole antennas. In the design, FR4 dielectric board is used, the thickness and dielectric constant of which are taken as $h = 0.8$ mm and $\varepsilon_r = 4.4$ respectively. The structure scheme of the antenna is shown in Fig.5.

According to the above discussion, the arm length as in Fig.5 should satisfy the following condition

$$l_1 + p_1 = \frac{\lambda_{g1}}{4} = \frac{c}{4 f_1 \sqrt{\varepsilon_r}} \qquad (11a)$$

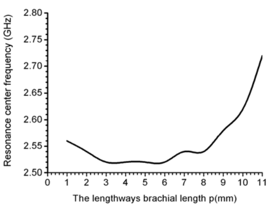
$$l_2 + p_2 = \frac{\lambda_{g2}}{4} = \frac{c}{4 f_2 \sqrt{\varepsilon_r}} \qquad (11b)$$

where the working frequencies f_1 and f_2 of two folded dipole ante nnas are set as 900 MHz and 2.4 GHz respectively.

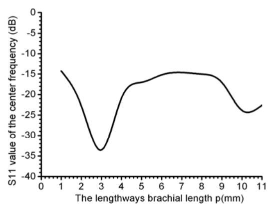
Thus, we have

$$l_1 + p_1 = 40 \text{ mm} \qquad (12a)$$

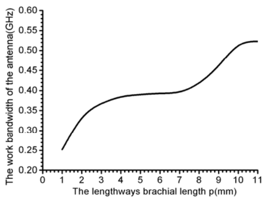
$$l_2 + p_2 = 15 \text{ mm} \qquad (12b)$$



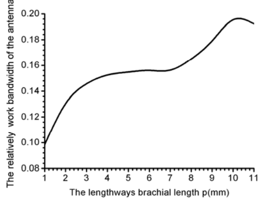
(a) Working center frequency



(b) S_{11} at working center frequency



(c) working bandwidth



(d) relatively working bandwidth

Figure 4. Influence on antenna function by the fold degree

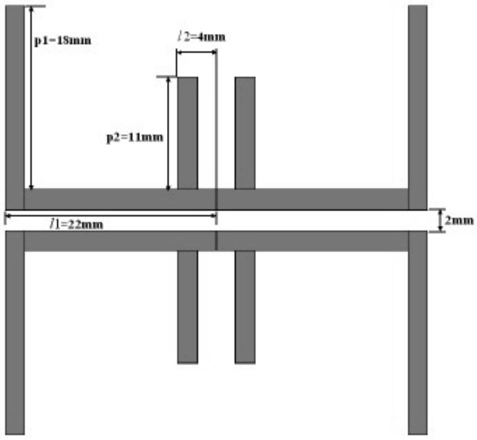
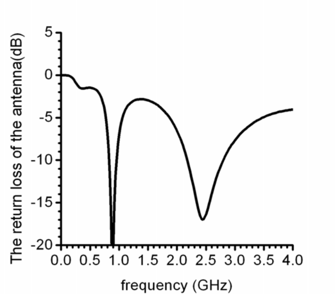
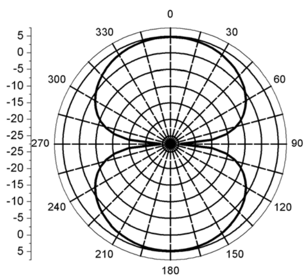


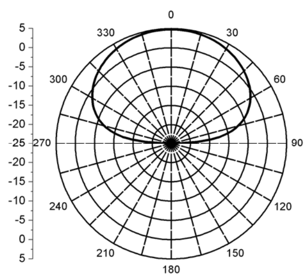
Figure 5. The structure scheme of dual-frequency folded dipole antenna working at 915 MH and 2.4 GHz



(a) The return loss characteristic



(b) H pattern



(c) E pattern

Figure 6. The return loss characteristic and patterns of dual-frequency antenna working at 915 MHz and 2.4 GHz

Taking the lengths f_1 and f_2 of two horizontal arms as 22 mm and 4 mm, it can be obtained that the lengths p_1 and p_2 of two longitudinal arms are 18 mm and 11 mm respectively.

The return loss characteristic and patterns of dual-frequency folded dipole antenna designed are simulated and analyzed, with the results as shown in Fig.6 (a), (b) and (c) respectively.

It can be seen from Fig.6 that the working center frequency in lower frequency section is 0.88 GHz, at which the return loss value S_{11} is −22.14 dB. And when VSWR is less than 2, the antenna bandwidth is up to 0.129 GHz (0.828 GHz ~ 0.957 GHz) and 14.66% relatively. On the other hand, the working center frequency in higher frequency section is

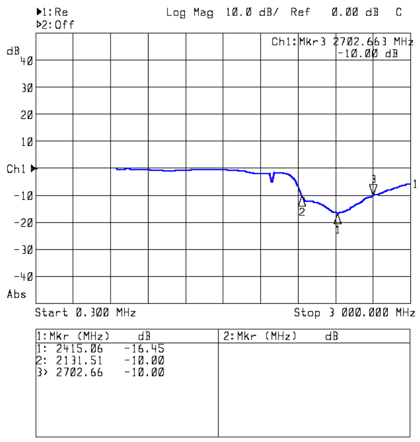
2.44 GHz, at which the return loss value S_{11} is 16.98 dB. And when VSWR is less than 2, the antenna bandwidth is up to 0.619 GHz (2.179 GHz ~ 2.798 GHz) and 25.37% relatively.

On the whole, this dual-frequency folded dipole antenna has better return loss characteristic and its bandwidth can satisfy the basic requirement of covering a wide working frequency section. Also, H and E patterns of antenna show hemisphere direction radiation characteristic.

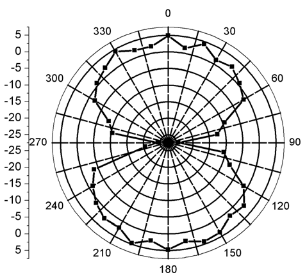
VI. TESTED RESULT ANALYSIS OF FOLDED DIPOLE ANTENNA

Analyzing the actual working characteristic of this novel antenna, we made an antenna sample working at 2.4 GHz and tested its return loss and directional characteristics with resistance match, by a vector network analyzer (VNA) and a microwave field strength analyzer (MFSA).

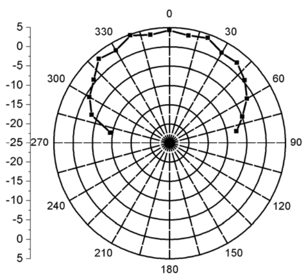
The experimental data are given in Fig.7 (a), (b) and (c) respectively, from which it can be found that the return loss value S_{11} is −16.45 dB at 2.415 GHz, the working center frequency. And when VSWR is less than 2, the antenna bandwidth is up to 0.571 GHz (2.131GHz ~ 2.702 GHz) and 23.64% relatively. According to H and E patterns, this folded dipole antenna facilitates hemisphere directional radiation characteristic.



(a) The return loss characteristic



(b) H pattern



(c) E pattern

Figure 7. The return loss and directional characteristics of the folded dipole antenna sample working at 2.4 GHz

VII. CONCLUSION

In this paper, a printed folded dipole antenna with mirror compensation structure has been designed. The simulated and analyzed results show that its return loss characteristic is better than that without mirror compensation structure. The basic requirement for bandwidth is satisfied and hemisphere direction radiation characteristic is presented.

It can also be known that the working center frequency of antenna is determined by the key parameters of circuit board and antenna arm. More specifically, adequacy higher dielectric constant and larger thickness will improve the antenna performance, which is also affected obviously by the folding degree of antenna arm.

For a dual-frequency antenna designed successfully based on this folded dipole antenna, the working center frequencies in lower and higher frequency sections apartly are 0.88 GHz and 2.44 GHz, at which its return losses are −22.14 dB and −16.98 dB separately. Moreover, the corresponding antenna bandwidth and relative bandwidth for VSWR less than 2 present that the performance of antenna can be improved greatly, all with hemisphere direction radiation characteristic.

Finally, an actual antenna sample with this novel structure has been researched. The results show that when VSWR is less than 2, the bandwidth of the antenna working at 2.4 GHz is up to 0.571GHz absolutely and to 23.64% relatively, also with hemisphere directional radiation characteristic.

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