A Ceramic Spiral Antenna used for Modern RFID System*

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***Abstract*—For the requirements of wideband RFID antenna, we designed a ceramic spiral antenna working at 915 MHz. The simulated results show that when VSWR (Vertical Standing Wave Ratio) is less than 2, the antenna bandwidth is up to 1.22 GHz (0.57 ～ 1.79 GHz) absolutely and to 133.21% relatively at the central frequency of 0.9 GHz. Considering engineering processes, the influence of dielectric constant ε_r and thickness of circuit board are particularly studied. On this basis, a dual-frequency ceramic spiral antenna is proposed, which can work with respect to all the main frequencies of RFID system, i.e. 915 MHz and 2.4 GHz.**

***Keywords*-radio frequency identification; ceramic spiral antenna; photonic bandgap**

I. Introduction

RFID (radio frequency identification) is a kind of no-touch identifying automatically technique, which is realized by radio frequency communication and gets in more and more realms physically applied now. The design of RFID antenna is one of the key techniques that decide the performances of RFID system, for example, RFID tag antenna to be placed in the tag with size limitation. Along with the quick development of RFID technique, there are more and more requests for RFID antenna, such as wideband in frequency, minimization in size, low cost for sell and low exhaust in properties [1-2].

In 1963, Ramsey put forward a frequency-independent antenna whose radiation characteristic wouldn't change along with frequency variation, working within ultra-wide frequency band [3]. In 1964, Smith put forward a two-arm spiral antenna. Being one of numerous application topics in frequency-independent antenna, the spiral antenna has absolute advantages compared with normal antennas, such as strong radiation ability and whole direction radiation characteristic, simple fabrication process and low cost. It had been studied in detail before [4-5] and also appeared in our initial research work focused on RFID antenna [6]. Here taking ceramic material with high dielectric constant as dielectric board substrate, a special spiral antenna for RFID system is designed to get better properties with its size decreased in further.

II. Structural Design of Ceramic Spiral Antenna

The reason why the characteristics of antenna change with the frequency is its electricity size change of its occurrence [7]. If a kind of antenna with electricity size independent of the frequency can be constructed, its bandwidth will be not restricted theoretically. The spiral antenna looks like to meet this request. For some applications in very wide frequency, the characteristic of spiral antenna almost has nothing to do with its working frequency.

A spiral line is shown in Fig.1. Familiarly, the spiral line square distance is given as

$$r = r_0 e^{\alpha(\varphi - \varphi_0)} \tag{1}$$

where r is the vector radius and r_0 is the one when $\varphi = \varphi_0$, φ is the turn cape, α is a constant influencing the spiral line's open speed. The value of α satisfies the following condition

$$\varepsilon = e^{2\pi\alpha} \tag{2}$$

If two spiral lines are assumed working at wavelengths λ_1 and λ_2, and relying on formulae $r_1 = r_0 e^{\alpha(\varphi_1 - \varphi_0)}$ and $r_2 = r_0 e^{\alpha(\varphi_2 - \varphi_0)}$ respectively, we have

$$\lambda_2 / \lambda_1 = e^{\alpha(\varphi_2 - \varphi_1)} \tag{3}$$

This formula shows that the same spiral lines can work on the different frequencies. Their shapes and sizes can be thought as the same, only involved in the angle difference $\varphi_2 - \varphi_1$. Obviously, this kind of structure has a very wide working bandwidth.

According to RFID stands, the antenna used for RFID system working in UHF frequency section is made a request of bandwidth as 840 ~ 845 MHz and 920 ~ 925 MHz. We designed a kind of spiral antenna using ceramic dielectric board, with dielectric constant $\varepsilon_r = 40$ and thickness $h = 1$ mm. The whole profile size is only 30 mm × 30 mm, and the structure scheme of designed antenna is shown in Fig.2.

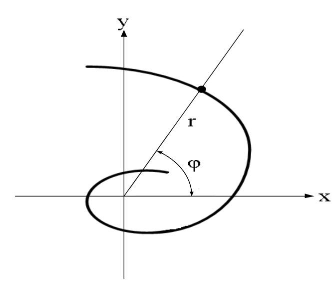


Figure 1. The radiation characteristic of spiral line

* This work is supported by the Fujian Provincial Key Project (2007H0036) of China.

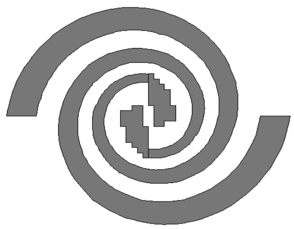


Figure 2. The structure scheme of the spiral antenna

The spiral antenna is constituted by two symmetry spiral arms, with each formed by two spiral lines inside and outside separately and initiated from opposite side. The square distances of two spiral lines inside and outside the first spiral arm apartly are

$$r_1 = r_0 e^{\alpha\varphi}, \quad r_2 = r_0 e^{\alpha(\varphi+\delta)} \tag{4}$$

Another spiral arm can be gotten through revolving the above spiral arm by 180°, with the square distances of its two spiral lines inside and outside apartly being

$$r_3 = r_0 e^{\alpha(\varphi-\pi)}, \quad r_4 = r_0 e^{\alpha(\varphi+\delta-\pi)} \tag{5}$$

In equations (4) and (5), $r_0 = 3$ mm, $\alpha = 0.588$, and $\delta = \pi/2$.

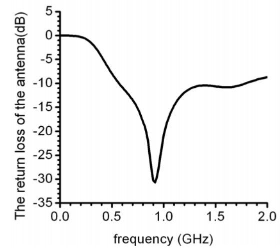
III. Performance Simulation and Analysis of Ceramic Spiral Antenna

A. Performance simulation

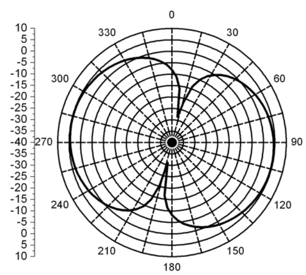
For the discussion of the electromagnetic radiation characteristics for ceramic spiral antenna, finite difference time domain method (FDTDM) is widely applied, combined with the grid method put forward by K. S. Yee in 1966 [8]. Simulating and analyzing the performance of designed ceramic spiral antenna, we have the return loss and directional characteristic of antenna as given in Fig.3 (a), (b) and (c) respectively. It is known that S_{11} is less than 10 dB correspond to VSWR (vertical standing wave ratio) less than 2. Under such condition, the operating center frequency is determined as 0.92 GHz, at which the return loss S_{11} is 32.56 dB and the bandwidth is 1.22 GHz（0.57 ～ 1.79 GHz）absolutely and 133.21% relatively. The results show that the return loss characteristic is much better and the bandwidth can satisfy the basic request. From H and E patterns, it is obvious that this ceramic spiral antenna has hemisphere directional radiation characteristic.

B. Influence of dielectric constant on antenna performance

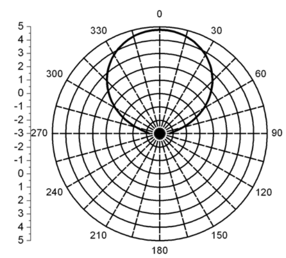
Although given $\varepsilon_r = 40$ in design, the dielectric constant of substrate will be deviated during the making process of antenna. Through a series of simulations, the influence of different dielectric constant on the performance of ceramic spiral antennae has been discussed in detail, the results of which are listed in Table 1.



(a) The return loss characteristic



(b) H patterns



(c) E patterns

Figure 3. The return loss and directional characteristics of ceramic spiral antenna working at 915 MHz

It can be seen that with a little increase of dielectric constant, the working center frequency and return loss value S_{11} of antenna all let up gradually that means the return loss characteristic being improved gradually. Moreover, the bandwidth of antenna decreases gradually for VSWR less than 2, but the relatively bandwidth enlarges gradually. So, choosing an adequacy substrate with higher dielectric constant in practical processing can improve the antenna performance obviously.

C. Influence of the thickness of substrate on antenna performance

Due to the similar reason, the influence of different thickness of substrate on the performance of spiral antenna has also been discussed, the results of which are listed in Table 2.

TABLE 1. Influence of Dielectric Constant on Antenna Performance

ε_r	center workworking frequency (GHz)	S_{11} (dB)	bandwidth (GHz)	relatively bandwidth (%)
35	0.95	-26.05	1.2405	130.58%
36	0.94	-27.16	1.2393	131.84%
37	0.93	-28.27	1.2362	132.92%
38	0.93	-29.58	1.2333	132.61%
39	0.92	-30.93	1.2289	133.58%
40	0.92	-32.56	1.2255	133.21%
41	0.91	-34.18	1.2211	134.19%
42	0.91	-36.54	1.2132	133.32%
43	0.91	-38.45	1.2092	132.88%
44	0.90	-42.41	1.2022	133.58%
45	0.90	-47.30	1.1953	132.81%

TABLE 2. INFLUENCE OF THE THICKNESS OF SUBSTRATE ON ANTENNA PERFORMANCE

h (mm)	center working frequency (GHz)	S_{11} (dB)	bandwidth (GHz)	Relatively bandwidth (%)
0.5	0.90	-17.64	0.5797	64.41%
0.6	0.90	-20.25	0.6562	72.91%
0.7	0.90	-22.97	0.7330	81.44%
0.8	0.90	-25.82	1.0796	119.96%
0.9	0.91	-28.94	1.1792	129.58%
1.0	0.92	-32.56	1.2255	133.21%
1.1	0.93	-37.13	1.2531	134.74%
1.2	0.94	-42.34	1.2719	135.31%
1.3	0.94	-49.92	1.2836	136.55%
1.4	0.95	-52.08	1.2912	135.92%
1.5	0.95	-53.19	1.2969	136.52%

It can also be seen that with a little increase of the thickness of the substrate, the working center frequency enlarges gradually and the return loss value S_{11} reduces gradually that means the return loss characteristic getting better significantly. Moreover, the bandwidth and relatively bandwidth of antenna enhance gradually for VSWR less than 2. For improving antenna performance in practical processing, it is necessary to choose adequacy thickness of substrate to make the return loss characteristic and working bandwidth of antenna meet all the requirements.

IV. DESIGN AND SIMULATION OF DUAL-FREQUENCY CERAMIC SPIRAL ANTENNA

A. Antenna design and performance simulation

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 special antenna covering all these sections. So we have done detail research on a dual-frequency ceramic spiral antenna.

Making use of PBG structure to constitute a new kind of dielectric material is a known way to improve the properties of various devices, which develops quickly in recent years. With this technique, we can improve the characteristics of our microstrip antenna in further. After the electromagnetic wave in a band gap is scattered by periodic dielectric, its intensity in some band will exponentially decay because of the destructiveness interference. So it is unable to propagate in that structure, and then forms band gap on the frequency spectrum. If these characteristics can be applied in reasonable, the microstrip antenna with excellent performance may be fabricated with the key fraction lying in the structure material parameters of PBG [9].

To obtain a dual-frequency antenna, a ceramic dielectric board of thickness h =1 mm and dielectric constant ε_r = 15 is used with sample size of 30 mm×30 mm. On the other side, a spiral antenna is designed by using the structure as shown in Fig.2, which has been optimized based on the above discussion. And we apply a rectangle PBG structure arrays on the connect floor opposite to the radiation spiral antenna, the profile of which is shown in Fig.4.

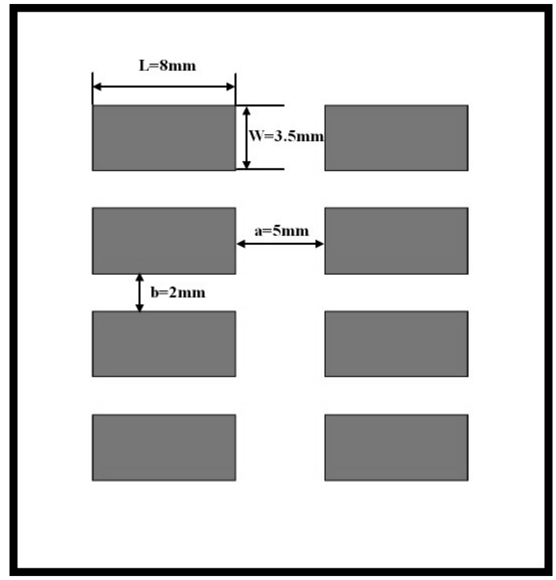
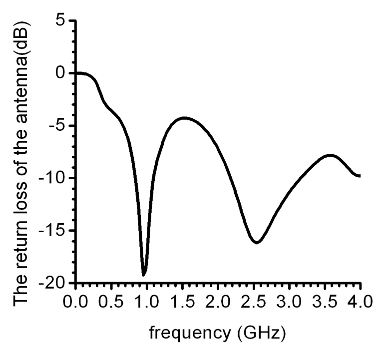
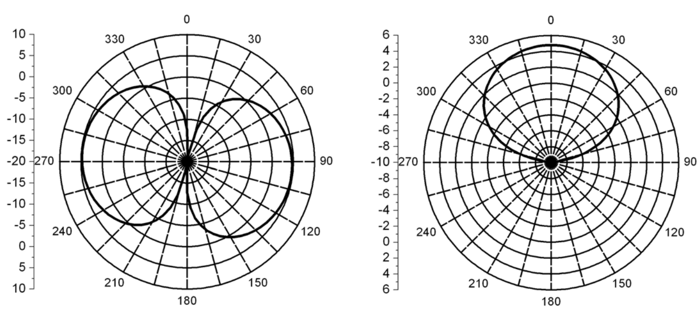


Figure 4. The structure scheme of rectangle PBG structure array on the connect floor



(a) The characteristic of return loss



(b) H pattern (c) E pattern

Figure 5. The characteristic of return loss and patterns of dual-frequency ceramic spiral antenna

The characteristics of return loss and the patterns of designed dual-frequency ceramic spiral antenna are simulated and analyzed, with the results presented in Fig.5 (a), (b) and (c) respectively.

From Fig.5, the working center frequency in lower frequency section is 0.95 GHz, at which the return loss value S_{11} is 19.13 dB. And for VSWR less than 2, the antenna bandwidth is up to 0.258 GHz (0.837 ~ 1.095 GHz) absolutely and 27.16% relatively. On the other hand, the working center frequency in higher frequency section is 2.55 GHz, at which the return loss value S_{11} is 16.16 dB. And for VSWR less than 2, the antenna bandwidth is up to 0.981 GHz (2.177 GHz ~ 3.158 GHz) and 38.47% relatively.

Obviously, this dual-frequency ceramic spiral antenna has better return loss characteristic with its bandwidth satisfying the basic requirement of covering a wide working frequency section. Also, H and E patterns of antenna show hemisphere direction radiation characteristic.

B. *Influence of rectangle array in PBG structure*

As discussed above, the change of rectangle array in PBG structure will bring great improvement to the characteristic of dual-frequency antenna. Through a series of simulation and analysis, the influence of the rectangle array in PBG structure is summarized in Table 3.

With the increase of the rectangle array number in PBG structure, the center working frequency, the return loss S_{11}, the bandwidth and relatively bandwidth in both frequency sections all present the same regulation just as in periodic variety. When the row number of the rectangle array in PBG structure is an even, the return loss characteristic and working bandwidth of antenna all meet the requirements with better properties than that of odd one.

V. CONCLUSION

The structure design method of ceramic spiral antenna has been discussed in this paper, for which approximate formula is given. A ceramic spiral antenna is designed with the center working frequency as 0.92 GHz, at which the return loss value S_{11} is −32.56 dB. The simulated results show that the characteristic of return loss is adequate and the bandwidth can satisfy the basic requirements, together with a hemisphere direction radiation characteristic quite fitting RFID use.

Analyzing the known sensitive parameters of antenna, we found that more specific higher dielectric constant and a bit increase on thickness can improve the antenna's performance greatly.

Aiming at the development requirements of modern RFID system, a dual-frequency antenna is designed successfully based on this ceramic spiral antenna. Its working center frequencies in both lower and higher frequency sections are 0.95 GHz and 2.55 GHz, at which S_{11} are −19.13 dB and −16.16 dB separately. Moreover, the simulated results with respect to antenna bandwidth and relative bandwidth for VSWR less than 2 present that the performance of antenna can also be improved obviously, all with hemisphere direction radiation. On the other hand, the variation of the rectangle array in PBG structure has a full impact on the dual-frequency characteristic of antenna.

ACKNOWLEDGMENT

The authors gratefully acknowledge the staff members of Microwave Library and Electronic Engineering Library for helpful supports.

TABLE 3. INFLUENCE OF RECTANGLE ARRAY IN PBG STRUCTURE ON ANTENNA PERFORMANCE

PBG structure	**center working frequency 1 (GHz)**	**S_{11} (dB)**	**bandwidth (GHz)**	**relatively bandwidth (%)**
1×2	1.0	-13.12	0.231	23.1%
2×2	0.95	-23.22	0.254	26.78%
3×2	1.05	-14.32	0.223	21.2%
4×2	0.95	-19.13	0.258	27.16%
5×2	1.05	-13.57	0.226	21.54%
6×2	0.95	-18.57	0.25	26.27%

PBG structure	**center working frequency 2 (GHz)**	**S_{11} (dB)**	**bandwidth (GHz)**	**relatively bandwidth (%)**
1×2	2.75	-25.8	1.24	45.09%
2×2	2.55	-15.98	1.02	40%
3×2	2.65	-24.95	1.243	46.91%
4×2	2.55	-16.16	0.981	38.47%
5×2	2.65	-24.83	1.237	46.68%
6×2	2.55	-16.20	0.985	38.63%

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