Passive UHF RFID with Ferrite Electromagnetic Band Gap (EBG) Material for Metal Objects Tracking

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Abstract

Passive UHF (Ultra High Frequency) RFID (Radio Frequency Identification) is a promising technology for products tracking in logistics or routing packages in supply chain. However, passive UHF RFID tag suffers a lot when it is placed on conductive plane or water surface. Many designs like microstrip antenna and ferrite antenna have been used to solve this metal-water problem. But their use is limited by narrow bandwidth and low antenna gain. The Electromagnetic band gap (EBG) material which exhibits a unique forbidden band gap at certain frequency offers a potential solution to solve the problem of backside objects effects. Previous research paper indicated that the dipole RFID antenna above three-layer mushroom like EBG material exhibited a good antenna gain and long read range. However, the complicated structure and high material cost greatly limit the application of tag. In this paper, we developed a new type of EBG material which uses ferrite film to reduce size and lower forbidden frequency. A commercial ferrite film which has a high permeability is applied to form two-layer mushroom like EBG material for UHF RFID. This two-layer mushroom like EBG material is a two-layer structure with a ground plane. The design of EBG material for UHF RFID which operates at 915MHz was discussed in this paper. An EBG tag on metal with a gain of 7 dBi was achieved in simulation. The simulation results showed that the RFID tag still could be read on EBG substrate with a good gain (~7dBi).

I. Introduction

The recent development of radio frequency identification (RFID) technology for item-level tracking has been accelerated due to pressing industry demand. RFID technology is an automatic identification method which can be used conveniently for product tracking. It has the advantage that the track process requires only minimal human input and thus further reduces the labor cost in logistics operation. RFID has many potential applications in different areas such as item identification and retail management. It makes it possible to locate the items at the right place. Passive UHF RFID tags are commercially used in cases such as pallet and container tracking because of its low cost.

A RFID system typically consists of transponders and transceivers such as tag and reader. The objectives of RFID system is enabling the tag be read by a RFID reader. Usually, there is no power source inside the passive RFID tag, so the voltage needed to power RFID COMS chip is obtained from reader via remote activation. The reader transmits a modulated signal to the tag and the tag backscatters a signal with identification data to reader at the same time. A passive UHF RFID tag usually includes an antenna and a RF chip which has a memory to store identification data.

The antennas used for passive UHF RFID are usually dipole based antenna which is a directional antenna. But the dipole based antenna is highly degraded by the backside objects. The dipole based UHF antenna even cannot work when it is attached on a metal substrate because the circuitry is shorted by the metal ground plane. However, there are many products made by metal or other conductive material such as container and metal cans that require proper identification and tracking. In order to make the passive UHF RFID tag usable for metallic objects tracking, a lot of research works has been conducted over the last decade and several types of RFID antenna are developed specially for metallic objects [1][2]. In general, there are always two approaches to design the RFID tag on metal substrate: novel antenna design rather than dipole based and adoption of ferroelectric material to insulate the tag from metal. Although many methods have been developed to solve the problem, there are still a lot of outstanding issues resulting in expensive products. The novel RFID antenna design often has a large thickness that is inconvenient for flat conductive objects and the read range of tag with ferroelectric material is quite short compare to traditional dipole based RFID tag. EBG material is a kind of metamaterial known to have a selective suppression of surface electromagnetic wave and would be a potential material for ground plane substrate for the dipole antenna [3].

The conductive surface can reflect electromagnetic wave with 180˚ phase change. This reflected electromagnetic wave influences the performance of antenna including gain and the radiation frequency. This effect weakens the antenna performance strongly when antenna is near it. Electromagnetic band gap (EBG) material also called as photonic band gap (PBG) material exhibits unique properties that it has a forbidden band gap at certain frequencies. The phase of reflected electromagnetic from an EBG plane varies continuously from -180˚ to 180˚ related to the frequency. With this reflected phase, the dipole-based antenna can still work when it is positioned near the EBG material [3]. The effects of an EBG structure on the performance of dipole antenna have been studied by Fan Yang [4]. Further studies of the reflection phase characteristics of a mushroom like EBG material have revealed 90˚±45˚ for a low profile wire antenna to obtain a good return loss and antenna gain. In this thesis, we also selected printed dipole antenna as RFID tag antenna, so the forbidden gap is the frequencies at which EBG has a reflection phase between 90˚±45˚. For the application of UHF

RFID which operates at 915MHz, a mushroom like EBG was design with a forbidden frequency at around 915MHz.

This paper describes the theory, design, and implementation of UHF RFID tag with two-layer mushroom like ferrite EBG. Simulations in HFSS were conducted to evaluate the performance of the RFID tag. This UHF RFID tag includes a RFID antenna and an EBG substrate which matches with the frequency of the antenna. This EBG substrate has a forbidden frequency band gap at 915 MHz which is the operation frequency of UHF RFID antenna. With this EBG material, the antenna placed on it exhibits a better performance than in the free space.

II. Ferrite Electromagnetic Bandgap (EBG) substrate design and simulation

The basic theory of mushroom like EBG is simple lumped circuit model as shown in figure 1. The forbidden band gap is determined by the inductance and capacitance of the unit cell. In order to get a wideband EBG material and low forbidden frequency, the thickness of the EBG material design in previous paper is about 2 mm thick with a forbidden band of 30 MHz [5]. However, this thick and rigid EBG material might limit the application of RFID tag and the cost of the EBG RFID tag is higher than commercial general purpose tag. So there is an increasing demand on low cost, thin and even flexible RFID tag for metallic objects tracking.

There are generally two methods to achieve a low cost and thin EBG RFID tag. One is increasing unit cell capacitance and the other is increasing inductance. The forbidden frequency of EBG material is determined by the equation below and the bandwidth of forbidden band is proportional to the ratio between inductance and capacitance.

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

$$BW \propto \frac{L}{C} \tag{2}$$

where L is inductance of unit cell, C is the capacitance of unit cell, and BW is the forbidden bandwidth.

Because the bandwidth of EBG material is determined by the ratio of inductance and capacitance, a large loading inductance would achieve a low forbidden frequency and large bandwidth. In contrast, a large capacitance would reduce the bandwidth of EBG material. The inductance of EBG material is determined by the equation below.

$$L = \mu t \tag{3}$$

where μ is the permeability of bottom layer material and t is the thickness of bottom layer.

As discussed above, the method of designing a thin and large bandwidth EBG material is applying a large unit cell inductance. However, the large thickness of bottom layer would limit the application of the tag and increases the cost of tag. To reduce cost and thickness, high permeability material should be used as bottom layer material. Ferrite which is a common ferrite core material for passive component is selected. The commercial available ferrite film has a permeability of 10 and a dielectric constant of 4 [6]. A large inductance layer could be fabricated by this ferrite film and a two layer mushroom like EBG material could be design based on this high permeability material. The model of two layer mushroom like EBG is the same with three layer mushroom like EBG. The difference between them is that the capacitance of three layer mushroom like EBG is parallel capacitance and the capacitance of two layer mushroom like is formed by edge capacitance as shown in figure below.

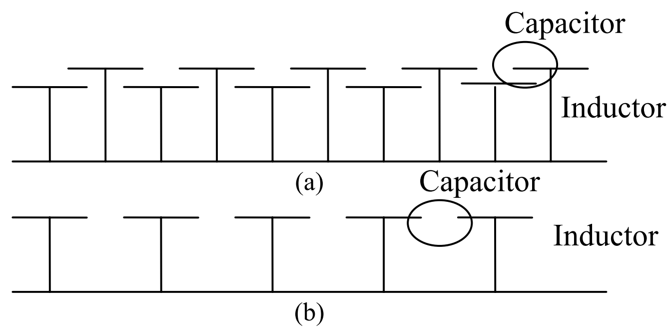

Figure.1 Schematics of EBG material (a) Cross-sectional view of three-layer EBG and (b) Cross-sectional view of two-layer EBG

A large permeability material is selected and a large loading inductance, two-layer EBG material could be used for low forbidden frequency band gap. The capacitance of two-layer mushroom like EBG is determined by the equation below.

$$C = \frac{w(\varepsilon_1 + \varepsilon_2)}{\pi} \cosh^{-1}\left(\frac{a}{g}\right) \tag{4}$$

where w is the width of plates, ε_1 is the dielectric constant on one side, ε_2 is the dielectric constant on the other side, a is the distance between two vias and g is the gap size.

Based on the equations (1) – (4), we could finally calculate the forbidden frequency of the two layer mushroom like ferrite EBG. However, the equations above are only an approximating nature of the EBG design method. There are many parameters are not considered like the gap size, the material conductivity, via diameters, and so on. In order to predict the forbidden frequency more precisely, finite element method (FEM) simulation software, Ansoft HFSS (High Frequency Structure Simulator), is used. The band gap features of EBG material are revealed by two methods either the surface wave suppression or reflection phase [7]. The reflected electromagnetic wave has effects on antenna impedance and resonance frequency. It is also used to determine the frequency forbidden band gap. A unit cell of EBG material was applied to simulate the reflection phase of mushroom-like EBG as shown in figure 2. Using Ansoft HFSS, the reflection phase resulting from an incident wave excitation can by calculated with respect to incident wave frequency. Master and slave boundaries were used to simulate periodic boundary conditions and perfectly matched layers (PMLs) which are fictitious materials that fully absorb the electromagnetic fields impinging upon them is placed one half wave length above EBG surface to ensure it was in far field. An incident wave illuminated the EBG and the average reflection phase is calculated from the scattered field.

Assuming that the reflected signal is evaluated at a distance d away from the reflection plane, the expected reflection phase from a perfect metal ground plane could be

$$\Phi = 180 - (\frac{d}{\lambda} \bullet 360) \quad (5)$$

If the EBG surface is placed with a distance of d away from the evaluation plane, the equation to calculate the reflect phase at the surface is [7]

$$\phi_{EBG} = \frac{\int_s Phase(E_{Scattered})ds}{\int_s ds} \quad (6)$$

The design of an ultrathin ferrite EBG material is simulated in Ansoft HFSS as shown in figure 2. The width is 22 mm, thickness is 0.5 mm, and the gap size is 1 mm.

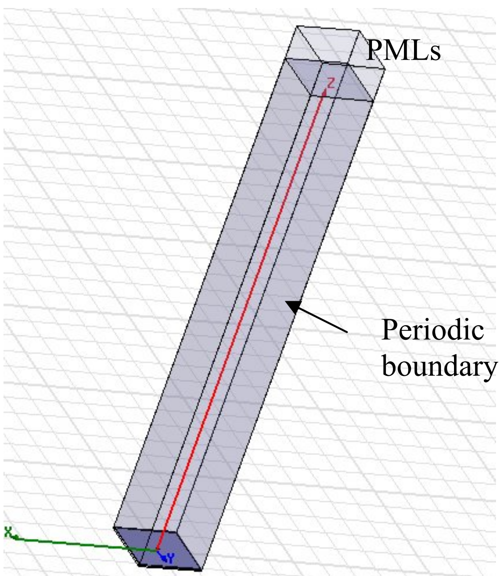

Figure.2 Simulation of ferrite EBG in HFSS

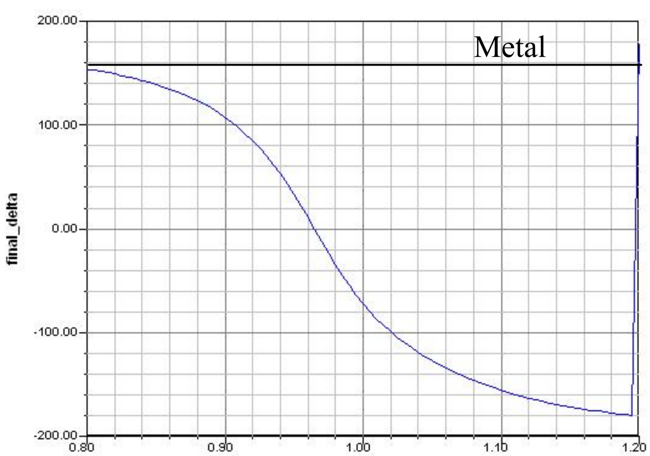

Figure.3 Refection phase of ferrite EBG

The simulation result is shown in figure 3. It is clearly found that the reflection phase from EBG surface changed consistently from 180 degree to -180 degree and there is a forbidden band gap at 915 MHz. As discussed in introduction, the folded dipole antenna could radiate effectively when it is placed on EBG material. Due to the thin and two-layer structure, the cost of this RFID EBG tag would be lower.

III. Ferrite EBG UHF RFID on metal tag simulation

The antenna used on ferrite EBG material is a simple folded dipole antenna. The folded dipole antenna is constructed by two dipole antennas and two shorting stubs to match with RFID strap. The reason for choosing this type of antenna is that it is easy to tune and fabricate and the antenna gain of dipole antenna is better than microstrip antenna like patch antenna and inverted-F antenna. The schematic representation of the folded dipole antenna with shorting stubs is shown below with parameters designated in table 1. The L is the length of the antenna which is fixed to 148 mm in this design and D is the distance from the shorting stubs to the lumped port. Due to the complex impedance of RFID tag, the RFID antenna is not a 50 ohm antenna and this antenna should match with RFID chip without adding external matching network. The two shorting stubs are used to tune the antenna impedance as shown in figure 5.

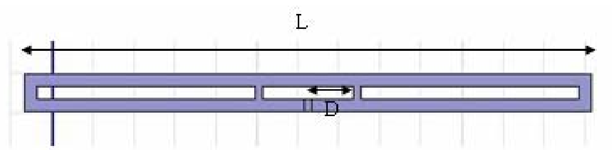

Figure.4 Folded dipole antenna

Parameter	Description
L	Length of antenna
D	Distance between shorting stubs and port

Table.1 Notations for folded dipole antenna

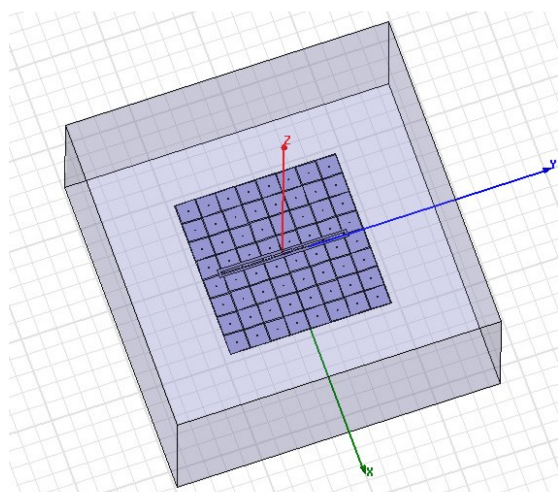
Figure.5 Simulation of ferrite EBG RFID tag in HFSS

Patch size	Gap size	Via diameter	Thickness of EBG
22 mm	1 mm	1mm	0.5mm
Dielectric Constant	Permeability	Distance between antenna and EBG	Driven dimension
4	10	3 mm	184mm x 184mm x 3.5mm

Table.2 Ferrite EBG UHF RFID tag design

The far field radiation patterns of the folded dipole antenna on the three different EBG materials are shown in figure 6. The radiation pattern refers to the directional dependence of radiation from the antenna or other source. The peak antenna gains on the ferrite EBG material is 7 dBi. It is clear found that the antenna on ferrite EBG material exhibits a good antenna gain and a directional radiation pattern than it in free space. The received power of the antenna is reflected to enhance the antenna performance. This result indicates that the ferrite EBG could suppress the surface wave effectively at forbidden frequency.

A folded dipole antenna with two shorting stubs is placed on EBG material to match with Alien's RFID strap which has an impedance of 30 – 110j. In order to achieve the maximum power transmission, an antenna with impedance of 30 + 110j should be designed. By changing the position of shorting stubs, the antenna impedance could be tuned. The 148 mm long folded dipole antenna with shorting stubs placed with a distance (D) of 18 mm to center shows a good match with Alien's RFID strap. [See figure 7].

Figure 7 displays the simulated impedance of the RFID antenna is 20+120j at 915 MHz which was matched with Alen's RFID strap (30 – 110 j). The calculated return loss values on 30 – 110 j RFID strap is -11dB. The return loss is calculated using

$$|S|^2 = \left|\frac{Z_L - Z^*_S}{Z_L + Z_S}\right|^2, \quad 0 \le |S|^2 \le 1 \qquad (7)$$

where Z_L is the antenna impedance and Z_S is the chip impedance from which we can calculate the bandwidth for a -10dB return loss. In this calculation, we assume the chip impedance is constant across the band, while in the real practice, the chip impedance will be slightly increasing with frequency. The -10 dB power transmission bandwidth of antenna is 30 MHz which covers the operation frequency of North American standard, Hong Kong standard and China standard.

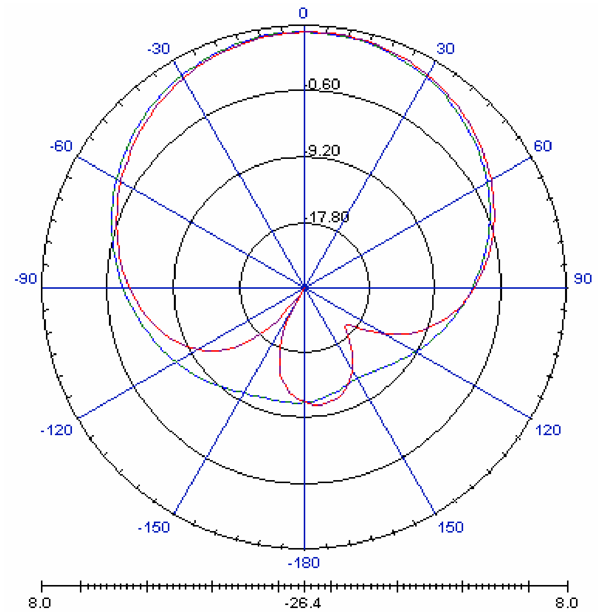

Figure.6 Radiation pattern of ferrite EBG RFID tag antenna

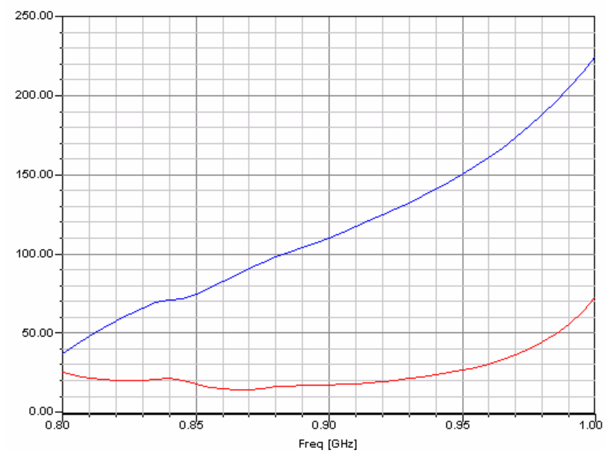

Figure.7 Impedance of ferrite EBG RFID tag antenna

IV. Conclusions

The motivation of this paper is to show that RFID tag with two-layer mushroom like ferrite EBG substrate performs well for metallic objects tracking. The EBG material is a material which does not exist in nature. Its unique property that it has a forbidden band gap at certain frequency exhibits a potential application for UHF RFID tag. Due to the requirements on low profile, small size and low cost, two-layer mushroom like ferrite EBG material is selected as tag substrate.

The EBG material is implemented and evaluated by reflection phase. The reflection phase is calculated by a unit cell of EBG material in Ansoft HFSS. The effects of different design parameters on folded dipole antenna gain are evaluated by simulation. The design with thickness of 0.5 mm exhibits a forbidden frequency at 915 MHz and a folded dipole antenna placed on it is tuned to match with Alien's RFID strap with an antenna gain of 7 dBi and a bandwidth of 30 MHz (from 890 MHz to 920 MHz).

Based on the simulation results, the novel passive UHF RFID on-metal tag is explored that it could overcome the problems associated with the current design. A comparative low cost and high performance tag which uses ferrite film is found to have an ultrathin thickness and simple structure. It is also noted that the development of simulation tools to predict the effects of various parameters values on the RFID antenna performance is necessary along with a high thorough understandings of EBG material.

Acknowledgments

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