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920MHz 帯における薄型電波吸収体の研究

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あらまし 920 MHz 帯における薄型電波吸収体を設計し，その特性を数値解析によって明らかにする．設計した電波吸収体は金属反射板の上に損失性の誘電体を装荷したものであり，誘電体の表面にはループ状の導体が周期的に配置されている．数値シミュレーションを行い，表面のループ状導体の構造や誘電体の厚さ，電気特性が反射特性に及ぼす影響を明らかにする．さらに，パッチやクロスダイポール状の導体を誘電体表面に配置した電波吸収体との反射特性の比較を行う．最後に， 920 MHz 帯の電波吸収体を設計し，入射角60°以下の TE 波，TM 波に対してその反射係数が-10 dB 未満となることを示す．

キーワード　電波吸収体，周波数選択性表面

Study on Thin Microwave Absorber at 920 MHz Band

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Abstract A thin microwave absorber in the 920 MHz band is designed and its characteristics are clarified by numerical analysis. The designed absorber consists of a lossy dielectric loaded on a metal reflector, and loop-shaped conductors are periodically arranged on the surface of the dielectric. Numerical simulations are performed to clarify the influence of the structure of the surface loop conductors, the thickness of the dielectric, and the electrical properties on the reflection characteristics. In addition, the reflection characteristics are compared with those of a microwave absorber with patch and cross dipole conductors on the dielectric surface. Finally, the microwave absorber in the 920 MHz band is designed and its reflection coefficient is shown to be less than -10 dB for TE and TM waves with incident angles less than 60°.

Keywords Microwave Absorber, Frequency Selective Surfaces

1. INTRODUCTION

In recent years, RFID (Radio Frequency Identification) systems, which are automatic identification technology using wireless communication, have become popular in factories and hospitals for the purpose of automatic inventory control. ISM bands such as 920 MHz band and 2.4 GHz band are often used for RIFD systems. In particular, RFID systems using the 920 MHz band (915~930 MHz)[1] have advantages over those using the 2.4 GHz band, such as a longer communication distance and the ability to read tags outside of the line-of-sight due to the easy penetration of electromagnetic waves.

On the other hand, in the 920 MHz band RFID system, there is a problem of false detection due to the propagation of microwaves emitted from the reader antenna outside the desired detection area. In order to solve this problem, the use of microwave absorbers to reduce unwanted reflections and limit the detection area has been studied[3][4], and the need for microwave absorbers in the 920 MHz band for RFID systems is increasing. The characteristics required for such a microwave absorber are that it should operate in the 920 MHz band (915~930 MHz), absorb microwave from a wide angle, and be thin.

One example of a microwave absorber that can be made thinner is the FSS (Frequency Selective Surfaces) type microwave absorber. FSS-type microwave absorber consists of three layers: a metallic reflector, a lossy dielectric spacer, and a conductor periodic structure. The conductor periodic structure is designed to match the impedance between the dielectric with reflector and the free space, and can absorb microwaves [5]. The disadvantage of the FSS absorber is its narrow bandwidth, but the advantage is that the absorber can be made thinner. Therefore, such FSS-type microwave absorber is considered to be effective as a microwave absorber for RFID systems using narrow-band electromagnetic waves in the 920 MHz band.

Previous studies have reported FSS-type microwave absorbers with periodic structures consisting of crossed dipoles [6], circular loops [7], and square patches [8] as the surface conductor periodic structure. In these studies, all the microwave absorbers were designed to be thin compared to the free-space wavelength of the design frequency. It has also been shown that the absorber is highly effective in absorbing electromagnetic waves from incident angles up to 45°. In addition, it has been shown in these studies that the periodic structure of the circular loop in particular shows a high absorption effect for both TE and TM waves.

In this paper, FSS-type microwave absorber in the 920 MHz band is designed and its effectiveness is clarified. The proposed microwave absorber has a periodic structure consisting of loop-shaped conductors. First, a model for numerical simulation of FSS-type microwave absorber is described. Then, the relationship between the periodic structure of the looped conductor on the surface of the microwave absorber and the reflection characteristics is clarified by numerical simulation. Next, the reflection characteristics of the proposed FSS-type microwave absorber are compared with those of FSS-type microwave absorbers with periodic structures of patch and crossed dipole conductors. Finally, a design example of a 920 MHz-band FSS-type microwave absorber with a reflection coefficient of -10 dB or less for electromagnetic waves from an incident angle of 60° or less is presented to clarify its effectiveness.

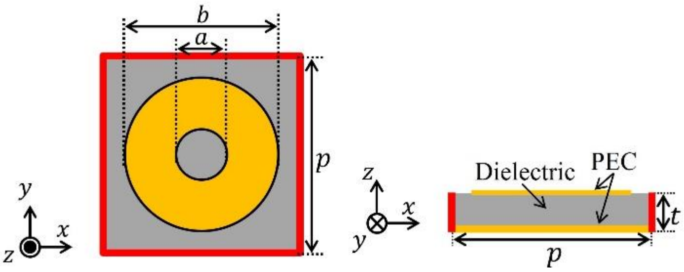
2. REFLECTION CHARACTERISTICS OF FSS-TYPE MICROWAVE ABSORBER

In this chapter, relations between the loop structure, electrical properties of the spacer and reflection properties are clarified for FSS-type microwave absorbers with looped surface conductor structure. Also, the relationship between the shape of the surface conductor and the microwave absorption characteristics is clarified by comparing the reflection characteristics with those of an FSS-type microwave absorber with a periodic structure consisting of patch or cross dipole-shaped conductors.

2.1. NUMERICAL ANALYSIS MODEL

The analytical model is shown in Figure 1. It is a three-layered structure consisting of a metal reflector, a lossy dielectric, and a conductor periodic structure on the surface. The reflection coefficient at plane wave incidence was analyzed using an infinite periodic structure consisting of an infinite number of unit cells with a single element conductor loop. As shown in the unit cell, the inner diameter of the loop is a, the outer diameter is b, the distance between elements is pitch p, and the thickness of the spacer is t. The relationship between these six parameters, including the relative dielectric constant ε_r and the loss tangent $\tan\delta$, and the reflection characteristics will be discussed in the following sections.

In this study, numerical analysis was carried out using the method of moments with the electromagnetic field analysis software FEKO.

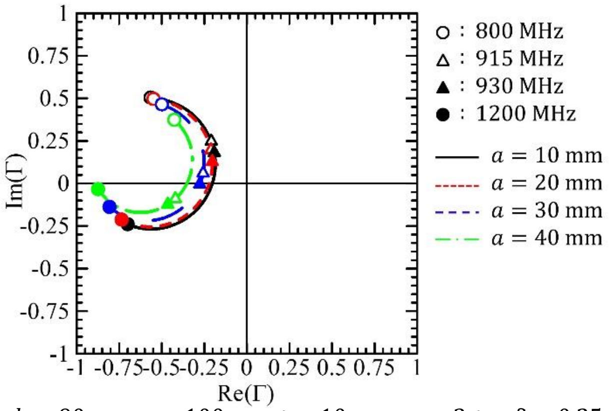


(a)Top View (b)Side View

Fig.1. Numerical Analysis Model (Unit Cell)

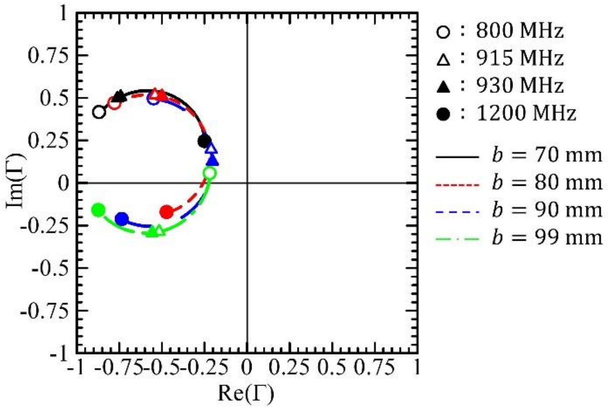
2.2. RELATIONSHIP BETWEEN PARAMETERS OF LOOP STRUCTURE AND REFLECTION CHARACTERISTICS

The reflection coefficients for normal incidence were analyzed for each case where the surface structure (inner diameter of the loop a, outer diameter b, and inter-element distance p) was varied. The results are shown in Figures 2(a), (b), and (c). For these three parameters, the change in the minimum value of the reflection coefficient is small. In addition, the change in the trajectory of the reflection coefficient is the largest when the outer diameter b of the loop is varied. This is probably because the current flows around the periphery of the loop and the change in surface current is the largest when the outer diameter b, which changes the length of the periphery, is varied, greatly affecting the impedance of the surface.



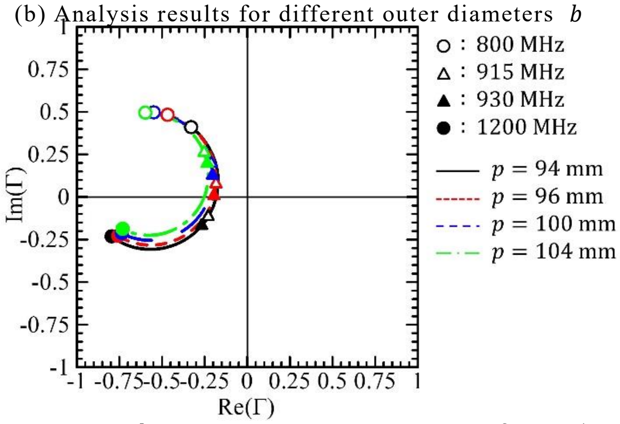
$b = 90$ mm, $p = 100$ mm, $t = 10$ mm, $\varepsilon_r = 3$, $\tan\delta = 0.25$

(a) Analysis results for different inner diameters a



$a = 20$ mm, $p = 100$ mm, $t = 10$ mm, $\varepsilon_r = 3$, $\tan\delta = 0.25$

(b) Analysis results for different outer diameters b



$a = 20$ mm, $b = 90$ mm, $t = 10$ mm, $\varepsilon_r = 3$, $\tan\delta = 0.25$

(c) Analysis results for different inter-element distance p

Fig.2. Relationship between parameters of loop structure and reflection characteristics.

Moreover, the frequency at which the reflection coefficient is minimized is lower for larger values of the loop inner diameter a and outer diameter b, and higher for larger values of the inter-element distance p. From these results, it can be said that the frequency at which the reflection coefficient is minimized can be adjusted by the surface structure.

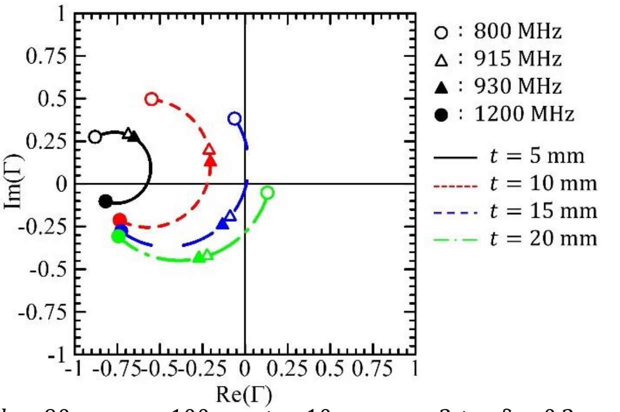
2.3. RELATIONSHIP BETWEEN SPACER PARAMETERS AND REFLECTION CHARACTERISTICS

The reflection coefficients for normal incidence were analyzed for different values of the spacer thickness t, relative permittivity ε_r, and loss tangent $\tan\delta$. The results are shown in Figures 3(a), (b) and (c).

The minimum value of the reflection coefficient (the magnitude of the reflection coefficient closest to $\mathrm{Re}(\Gamma) = \mathrm{Im}(\Gamma) = 0$ in the trajectory of the reflection coefficient) varies greatly with thickness and loss tangent. The larger the thickness, the more the trajectory moves toward the positive real part of the graph, and conversely, the larger the value of the loss tangent, the more the loss tangent changes toward the negative real part of the graph. From the results, it can be said that the minimum value of the reflection coefficient can be adjusted by the thickness and dielectric loss tangent. In addition, as the loss tangent increases, the trajectory of the reflection coefficient becomes shorter overall. The short trajectory means that the change in reflection characteristics with frequency is small, and it is thought that designing a microwave absorber with a material that has a larger dielectric loss tangent will result in a wider bandwidth.

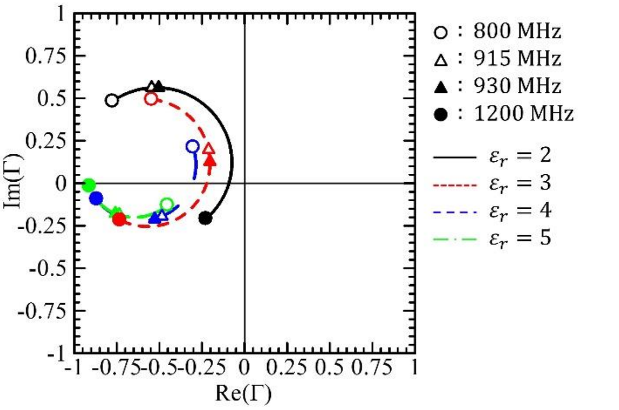
The larger the value of relative permittivity, the more the overall trajectory of the reflection coefficient shifts to the higher frequency band, and the minimum reflection coefficient is obtained in the lower frequency band. This change is similar to the change with the outer diameter of the loop in Figure 3(b). The reason for this is that the larger the relative dielectric constant, the shorter the wavelength in the dielectric material, and relatively the outer diameter of the loop seems larger.

Thus, it can be concluded that the minimum reflection coefficient depends mainly on the thickness and dielectric loss tangent, the frequency band depends on the relative permittivity, thickness, and structure of the surface conductor (inner diameter, outer diameter, and inter-element distance in the case of loops), and the bandwidth depends on the dielectric loss tangent.



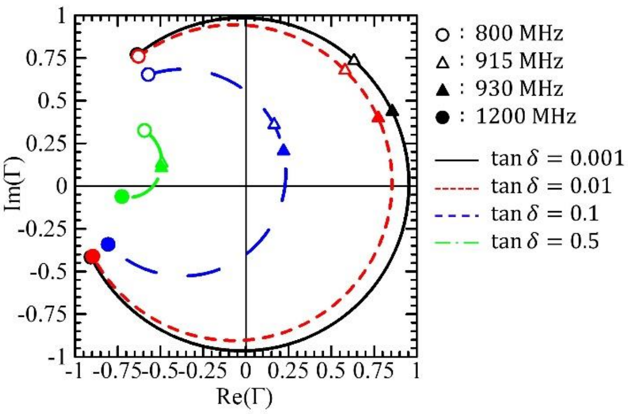
$b = 90\ \mathrm{mm}, p = 100\ \mathrm{mm}, t = 10\ \mathrm{mm}, \varepsilon_r = 3, \tan\delta = 0.2$

(a) Analysis results for different thickness t



$a = 20\ \mathrm{mm}, b = 90\ \mathrm{mm}, p = 100\ \mathrm{mm}, t = 10\ \mathrm{mm}, \tan\delta = 0.25$

(b) Analysis results for different relative permittivity ε_r



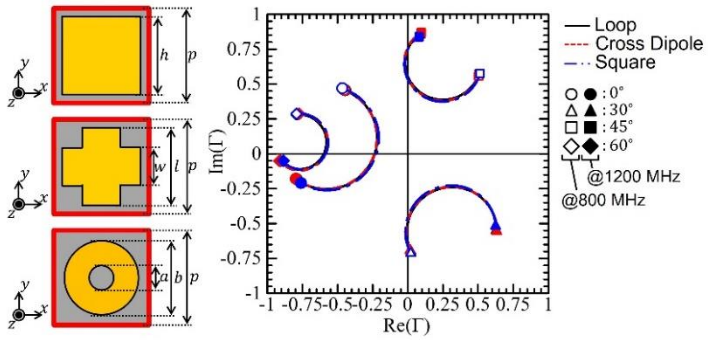
$a = 20\ \mathrm{mm}, b = 90\ \mathrm{mm}, p = 100, t = 10\ \mathrm{mm}, \varepsilon_r = 3$

(c) Analysis results for different loss tangent $\tan\delta$

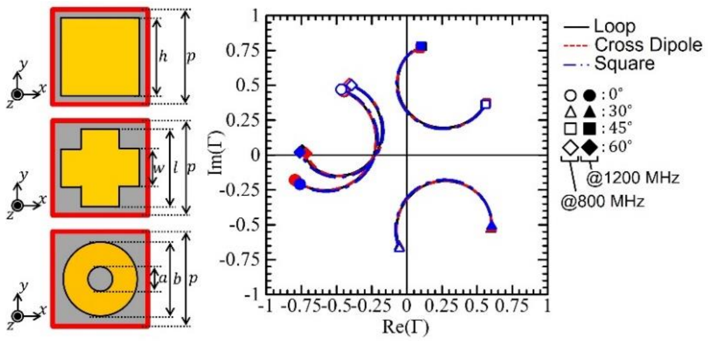
Fig.3. Relationship between spacer parameters and reflection characteristics.

2.4. Comparison with other surface structures

This section describes the results of the comparison between the loop structure and the structure where the surface structure is replaced by a crossed dipole and a square patch without changing the thickness of the spacer, the electrical characteristics ($\varepsilon_r, \tan\delta$), or the inter-element distance p. Each absorber was designed to have



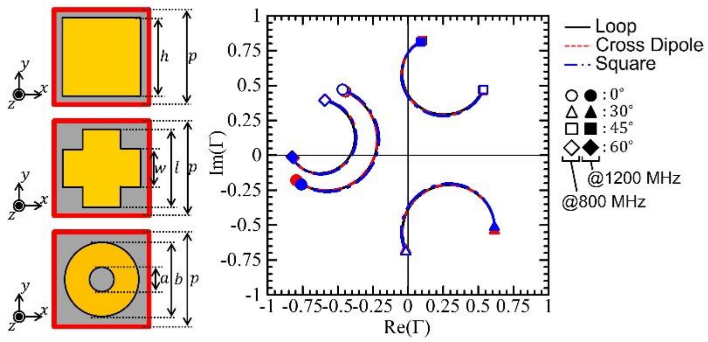
(a)TE wave



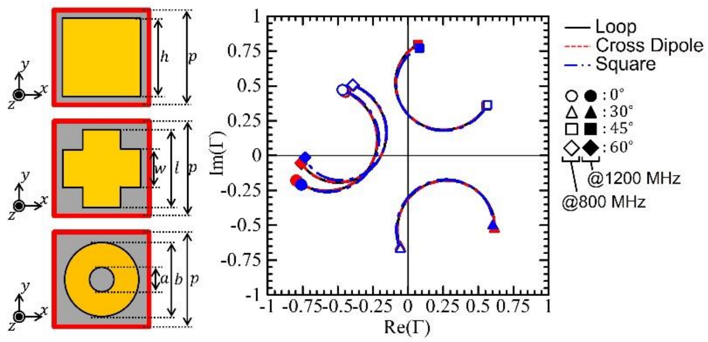
(b)TM wave

$a = 24\ \mathrm{mm}, b = 92\ \mathrm{mm}, p = 100\ \mathrm{mm}, w = 46\ \mathrm{mm},$
$l = 90\ \mathrm{mm}, h = 80\ \mathrm{mm}, t = 10\ \mathrm{mm}, \varepsilon_r = 3.0, \tan\delta = 0.25$

Fig.4. Comparison with other surface structures ($\phi = 0°$)



(a)TE wave



(b)TM wave

$a = 24\ \mathrm{mm}, b = 92\ \mathrm{mm}, p = 100\ \mathrm{mm}, w = 46\ \mathrm{mm},$
$l = 90\ \mathrm{mm}, h = 80\ \mathrm{mm}, t = 10\ \mathrm{mm}, \varepsilon_r = 3.0, \tan\delta = 0.25$

Fig.5. Comparison with other surface structures ($\phi = 45°$)

the minimum reflection coefficient in the 920 MHz band for normal incidence. First of all, the reflection characteristics of TE and TM waves are shown in Figure 4 when the incident angle $\theta = 0°$, 30°, 45°, and 60°. From the results, it can be seen that the approximate shapes of the analytical results are almost the same regardless of the surface structure.

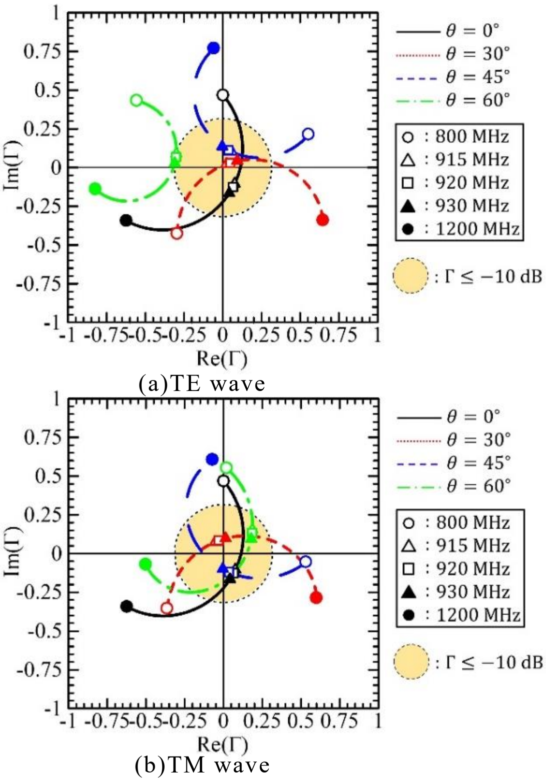
Looking at the reflection characteristics for oblique incidence, it can be observed trajectory of the reflection coefficient of the TE wave generally moves away from the origin (the reflection coefficient increases) as the angle of incidence increases. In contrast, for TM waves, the distance from the origin (the magnitude of the reflection coefficient) changes little. This can be considered as the effect of the Brewster angle of the TM wave is also acquired in the FSS-type microwave absorber.

Next, the same analysis was performed by rotating the polarization by 45° around the z-axis ($\phi = 45°$), and the results are shown in Figure 5. The results show that there is no significant difference between the loop structure and the other structures. These results show that the reflection characteristics are equal for the three shapes considered in this study. This is thought to be due to the small size of the surface conductors relative to the free-space wavelength of the design frequency. Therefore, it is thought that there is a difference according to the structure of the surface in the previous study, but each difference in the previous study is due to the electrical characteristics and thickness of the spacer.

Accordingly, the reflection characteristics do not depend on the shape of the surface conductor, and the change in the minimum reflection coefficient due to the surface structure is small. Therefore, when designing an FSS-type microwave absorber, it is important to optimize the thickness if the material to be used is predetermined, and it is important to select the optimum material if the thickness is limited. Specifically, the greater the loss of the material used, the thicker the material needs to be, and the thinner the design, the smaller the loss of the material needs to be.

3. DESIGN EXAMPLE OF FSS-TYPE MICROWAVE ABSORBER

In this chapter, based on the results of Chapter 2, the design of the 920 MHz band is discussed so that the reflection coefficient is always less than -10 dB at an incident angle of 60° or less, which is the target.



$a = 18$ mm, $b = 85$ mm, $p = 100$ mm, $t = 18$ mm,
$\varepsilon_r = 3.0, \tan\delta = 0.25$

Fig.6. Design with lossy polypropylene foam

3.1. DESIGN WITH LOSSY POLYPROPYLENE FOAM

In this section, the design of the microwave absorber which can achieve the target of reflection coefficient less than -10 dB at incident angle less than 60^∘ is studied by using lossy foamed polypropylene ($\varepsilon_r = 3.0, \tan\delta = 0.25$) as a spacer, which was also used in the design of section 2.5. Since the value of the dielectric loss tangent is fixed, the reflection characteristics must be adjusted according to the thickness. Also, from Section 2.4, it is known that the minimum reflection coefficient for TM waves is independent of the angle of incidence, while for TE waves, the reflection property worsens as the angle of incidence increases. Therefore, it is considered that the material can be designed to show high absorption effect against oblique incidence by designing the material so that the reflection property is best at oblique incidence of TE wave instead of normal incidence. From the results of Fig. 3(a) in Section 2.4, it is considered that the minimum value of the reflection coefficient for oblique incidence can be reduced by increasing the thickness t. Figure 6 shows the results of the design based on these design principles to obtain the best reflection characteristics at an incident angle of 30°~45° in the 920 MHz band. The results show that the target reflection coefficient of less than -10 dB is achieved at 915~930 MHz for all incident angles of 0°, 30°◦, 45°, and 60°.

Thus, it was shown that by optimizing the thickness, it is possible to improve the reflection characteristics and design a microwave absorber that can absorb microwaves in a wide angle.

3.2. DESIGN WITH OPTIMIZED DIELECTRIC LOSS TANGENT

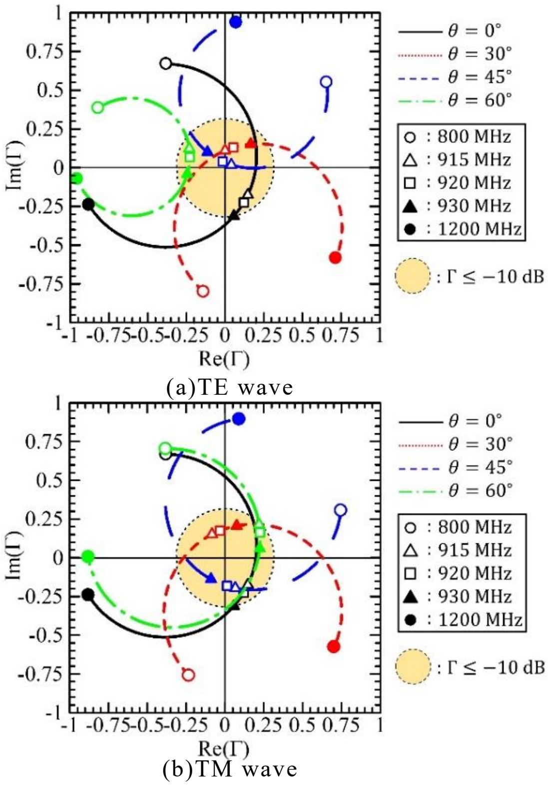
In this paper, a radio wave absorber that can achieve the target with a thickness of 10 mm (about 1/33 of the free-space wavelength at 920 MHz) is studied and an example of the design is shown.

In the previous section, the material was 18 mm thick and had a dielectric loss tangent of 0.25. Therefore, when designing a material with a thickness of 10 mm, the dielectric loss tangent should be smaller than 0.25. As in the previous section, the design was carried out so that the reflection coefficient becomes small for oblique incidence of TE waves. The results are shown in Figure 7. Compared with the design in Section 3.1, the trajectory of the reflection coefficient is longer and the bandwidth is narrower due to the smaller loss.

Thus, it was shown that by optimizing the dielectric loss tangent, it is possible to design a microwave absorber that can absorb a wide angle microwave at any thickness.

4. CONCLUSION

In this paper, the relationship between the characteristics and the structure of the FSS-type microwave absorber, which is designed to reduce false detections by suppressing the propagation of microwaves outside the desired area in the 920 MHz band RFID system, is clarified by numerical analysis. In addition, a practical design example is described, and it is shown by numerical analysis that a high absorption effect can be obtained with a reflection coefficient of -10 dB or less for angles of incidence of 60° or less.



(a)TE wave

(b)TM wave

$a = 27$ mm, $b = 92$ mm, $p = 100$ mm, $t = 10$ mm,

$\varepsilon_r = 3.0, \tan\delta = 0.1$

Fig.7. Design with optimized dielectric loss tangent

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