

Microstrip Reflectarray Using Crossed-Dipole with Frequency Selective Surface of Loops

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1. Introduction

A microstrip reflectarray is a flat low-profile reflector consisting of an array of microstrip patch elements, reflecting a beam in a specified direction when illuminated by a primary source. It has been applied to radar and communication systems because of its advantages, such as surface mountable with low mass and volume, easily deployable, low manufacturing cost, steerable beam, and integratable with a solar array, etc [1]-[3]. In the wireless communication applications such as a large-scale indoor base station of wireless local area network (WLAN) system, planar reflectarray antennas can be mounted on ceiling or embedded into walls to reflect beams covering different areas, especially those blind areas to the primary source. Meanwhile, it is desirable that the reflectarrays should not have effect on the propagation channel of other communication systems working at other frequency bands.

In this paper, a new idea for reflectarray design is presented that the reflectarray can work as a reflector and produce desired reflection beam shape and direction for a primary wave source, but be partially transparent for other wave sources. A microstrip reflectarray using crossed-dipole elements with frequency selective surface (FSS) of square loops is designed to demonstrate the effectiveness of the present idea. An infinite periodic model is used to analyze the reflection and transmission coefficients of the new crossed-dipole elements. The results show that the square-loop FSS can be used to replace the metal ground plane of a conventional microstrip reflectarray under certain conditions. The reflection phase curve is estimated from the case of normal plane incidence on a periodic infinite array. Using this approach a design of 3×5 reflectarray of variable size crossed dipoles with square-loop FSS is presented. The properties of the new reflectarray is discussed and compared with a conventional microstrip reflectarray.

2. Crossed-Dipole Element with Square-Loop FSS

An FSS is a surface which exhibits different reflection and/or transmission properties as a function of frequency [4]. An array of loops acts as a band-stop filter, which are characterized by their fundamental resonance when the circumference of the elements is about one wavelength in the dielectric surrounding them. An infinite periodic model using HFSS simulation [5] was performed to analyze the reflection and transmission coefficients of a square-loop FSS, as shown in Fig. 1. The period in both x and y directions is $D=7$ mm and the circumference of the square loop is 12 mm. The array of square-loop is attached on the surface of a dielectric substrate with a thickness of $t=1.5$ mm and relative permittivity of $\epsilon_r = 2.5$. The properties of the square-loop FSS versus frequency at normal incidence of plane wave are shown in Fig. 1. It can be found that a complete reflection occurs at the resonant frequency of the one-wavelength loop. In view of this feature, the metal ground plane of a microstrip reflectarray can be replaced with the loop-FSS in a certain frequency band.

In this work, a new reflectarray composed of printed crossed-dipole array and square-loop FSS on the opposite surface of the dielectric substrate is proposed and designed. First, the effect of crossed-dipole on the square-loop FSS is considered. Figure 2 shows the reflection coefficient of the composite element versus the length of crossed-dipole element for different incidence angles and

polarization. It can be seen that the variation of reflection loss is within 2dB when the length of crossed-dipole varies from the minimum length of 0.2 mm to the maximum length of 6.8 mm. The performance is favourable for designing a reflectarray of varying dipole length.

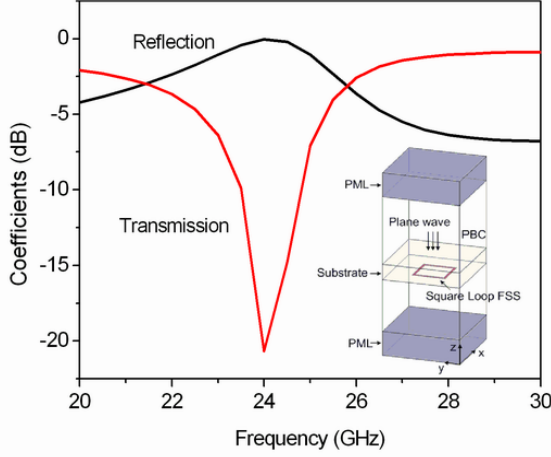


Figure 1: Reflection and transmission coefficients of square-Loop FSS.

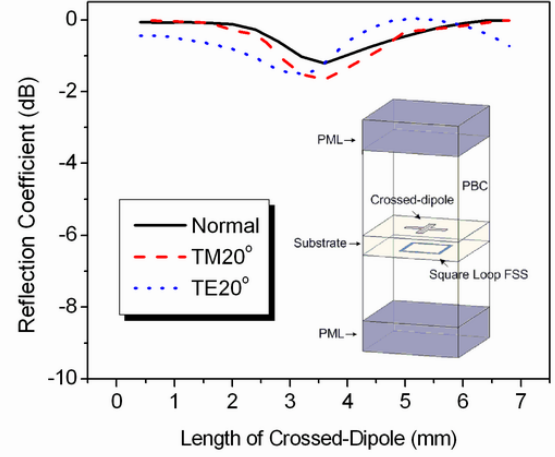


Figure 2: Reflection coefficients versus length of crossed-dipole at 24GHz.

3. Design of Crossed-Dipole Reflectarray with Loop-FSS

The key technique in the design of a reflectarray is how the individual element is designed to scatter the incident wave with the proper phase shift necessary to produce a beam in a specified direction. The configuration of a standard microstrip reflectarray is shown in Fig. 3. The condition for an array aperture distribution to be cophase in the desired direction is given by

$$\phi_{mn} - k_0(R_{mn} + \vec{r}_{mn} \cdot \hat{u}_0) = 2p\pi, \quad p = 0, \pm 1, \pm 2, \dots \quad (1)$$

where R_{mn} is the distance from the feed source to the mn_{th} array element, ϕ_{mn} is the phase of the scattered field from the mn_{th} element, \vec{r}_{mn} is the position vector at mn_{th} element measured from the center of the array and \hat{u}_0 is the unit vector of the direction of the main beam of the reflectarray.

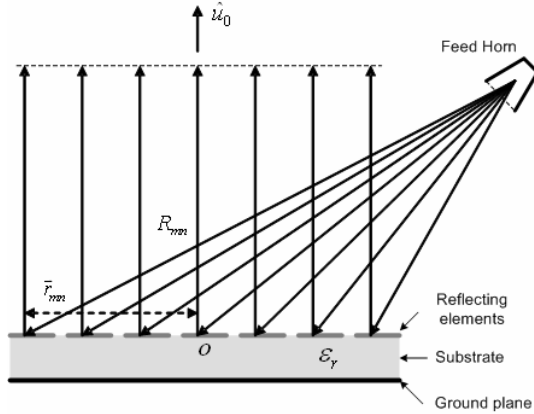


Figure 3: Configuration of a microstrip reflectarray.

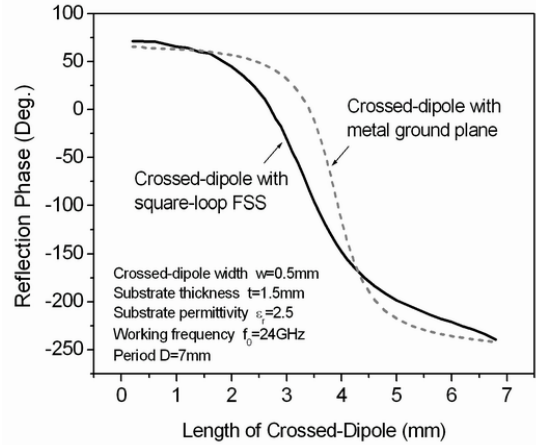


Figure 4: Comparison of Reflection phase of crossed-dipole with square-loop FSS and metal ground plane.

In the design of microstrip reflectarray, the dimension or the shape of the reflecting element needs to be changed in order to obtain the required phase. The compensated phase curve can be calculated by an analysis of infinite periodic array of identical microstrip elements [5]. After obtaining the phase curve, the resonant length of the mn_{th} element is determined to produce a phase shift ϕ_{mn} in the field scattered from the element. Figure 4 shows the reflection phase curve of the

crossed-dipole element with square-loop FSS. Compared to the reflection phase curve of the crossed-dipole with conventional ground plane, it can be found that the proposed element structure has a slowly varying phase curve, which yields a reduction of phase error caused by fabrication error in element size in practice. In general, the phase of the reflection coefficient is dependent not only on elements size but also on the angle of incidence of plane wave. However, it has been shown that the phase variation is small when the incidence angle is less than about 40° [6]. When an incidence angle or a scan angle is larger than 40° , the design concept based on the normal incidence in this study will be invalid. Therefore, as a test example here, a reflectarray design is restricted to scan angles smaller than 40° .

In order to validate the element structure of crossed-dipole with loop-FSS, a 35° -beam-steering reflectarray along x -axis operating at 24GHz is designed. Figure 5 shows the basic geometry of the reflectarray using 3×5 crossed dipoles of variable size. The spacing of elements is 0.56λ in both x and y directions. The substrate thickness and relative permittivity are assumed to be $t=1.5\text{mm}$ and $\epsilon_r=2.5$, respectively. The feed may be positioned at an arbitrary angle and distance from the reflectarray, but should be far enough from the reflectarray so that the incident wave can be treated as a plane wave. In the present design, the incident plane wave is coming from the direction of $(\theta_i, \phi_i) = (20^\circ, -90^\circ)$. The polarization of the incidence plane wave can be either TM or TE polarization. The dimensions of the elements were determined based on Eq. (1) and Fig. 4. Radiation patterns of xz plane for TM and TE polarized incidence were simulated by HFSS and shown in Fig. 6(a) and (b), respectively. Both results demonstrate that the main beam is directed to 35° , which agrees with the design requirement. Thus, the reflectarray using crossed dipoles with square-loop FSS satisfies the requirements on the main beam position very well.

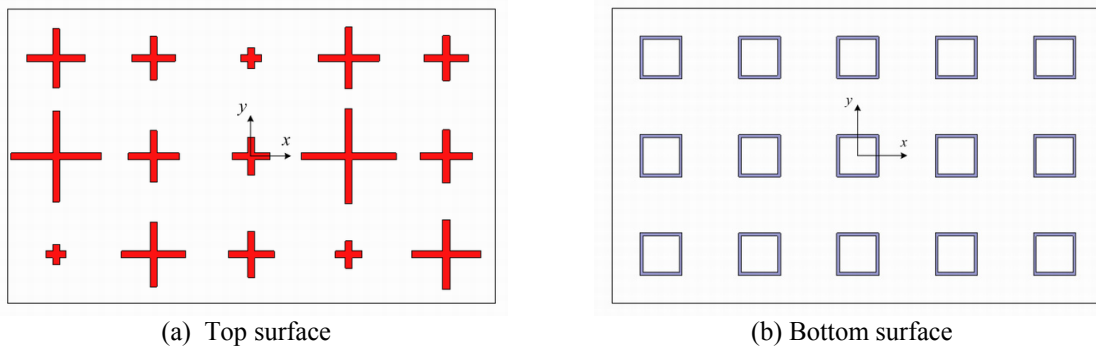


Figure 5: (a) Crossed-dipole array on the top of designed reflectarray, (b) Square-loop FSS on the bottom of designed reflectarray.

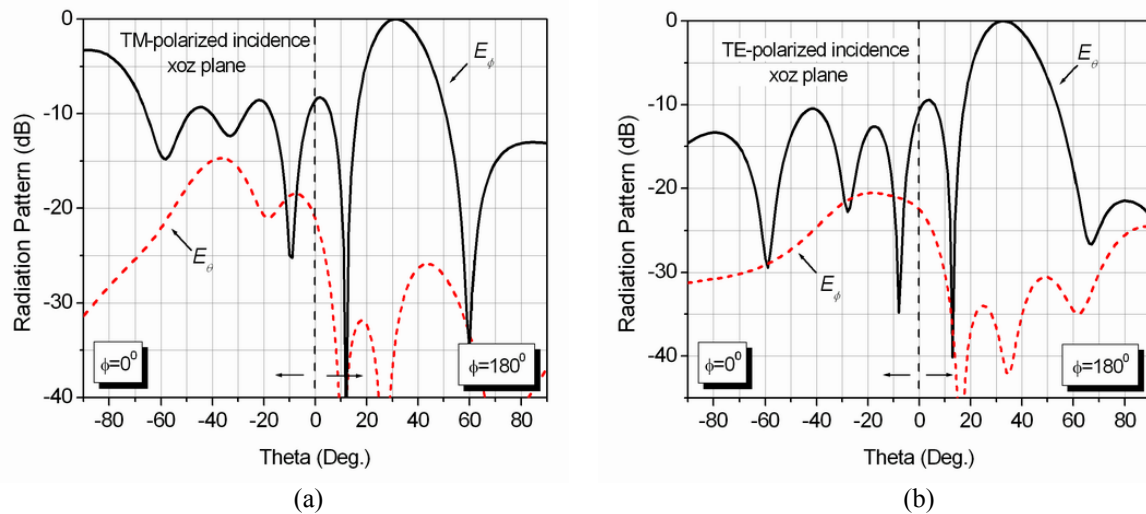


Figure 6: Radiation patterns of xoz plane of the crossed-dipole reflectarray in (a) TM-polarized plane wave incidence, (b) TE-polarized plane wave incidence

To make a comparison of directivity bandwidth between the loop FSS reflectarray and the conventional metal ground plane reflectarray, a design of 3×5 crossed dipoles with metal ground plane was also designed and simulated. Figure 7(a) and (b) show the computed directivity against frequency for the two reflectarrays at TM- and TE-polarized plane wave incidences, respectively. Directivity of the reflectarray is defined as the ratio of the scattered intensity in a main beam direction from the reflectarray to the scattered intensity averaged over all directions. As shown in this Figure, below the working frequency of loop FSS, the directivity of the designed reflectarray is very small, which shows that the incidence waves are partly penetrated through the reflectarray. In other words, the reflectarray is partially transparent for frequency-band waves lower than the operating frequency, resulting in reduction of the blockage effect on other communication systems. The -1dB directivity-drop bandwidth of 10.1% for TE-polarization and 7.1% for TM-polarization are achieved by the crossed-dipole reflectarray with loop FSS.

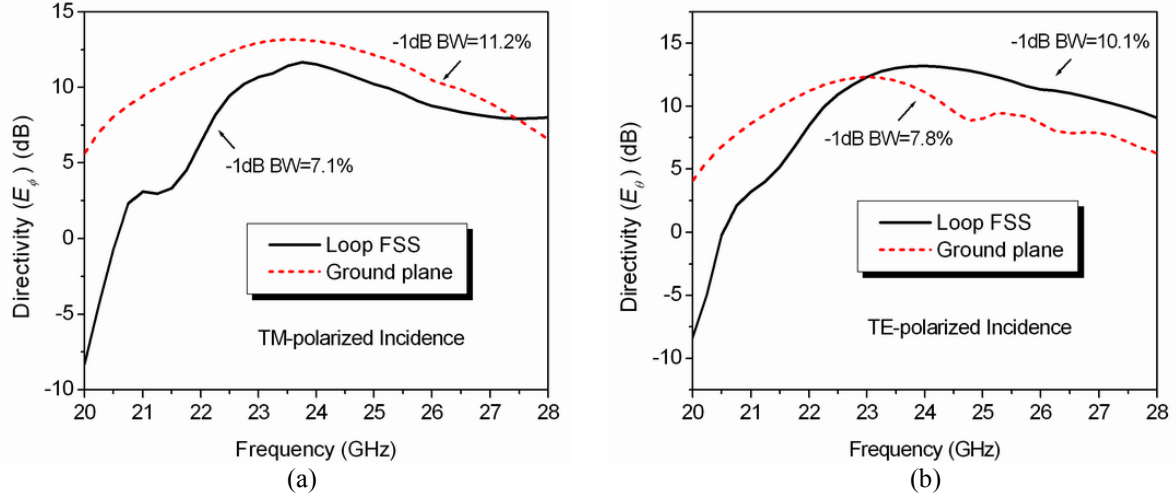


Figure 7: Comparisons of Directivity versus frequency for the crossed-dipole reflectarray with square-loop FSS and ground plane. (a) TM-polarized incidence, (b) TE-polarized incidence.

4. Conclusion

This paper presents a new idea for designing a frequency-selective reflectarray, which has an ability to work as a reflector and steer reflected beam for a special frequency-band wave, meanwhile, which will be partially transparent for other frequency-band waves. A simple example of reflectarray is proposed to demonstrate the realizability, which consists of printed crossed-dipole array with a square-loop FSS on the opposite surface of the dielectric substrate.

Acknowledgments

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