Dual–frequency reflectarray design using sandwiched FSS

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***Abstract* — A concept using sandwiched frequency selective surface(FSS) as a frequency selective reflection plane is proposed for dual-frequency reflectarray system. The reflection phase range of a reflectarray relies on the thickness of the substrate. Usually, we need a tradeoff between the wide phase range and the smooth linear level, especially for dual-frequency system. By inserting an FSS between the reflectarray element layer and the metal ground plane, an additional reflecting plane for the upper frequency band is provided. For lower frequency band, the FSS layer is transparent and the reflecting plane is changed into the real metal ground plane. A 30° scattering angle reflectarray is designed to validate this concept.**

***Index Terms* — Reflectarray, frequency selective surface, dual-frequency.**

I. INTRODUCTION

Reflectarray has been developed for several decades since the 1980s, and achieved wide applications for its advantages, such as surface-mountable, low mass and volume and easy deployment[1]. Most recent researches have been focused on additional features to basic reflectarray function such as dual-band/polarization, beam scanning and so on [2-5].

For a reflectarray, designing reflection phase of the reflectarray is the basic role during the design procedure. However, the phase range relies on the thickness of the substrate. For a single-layer substrate, the achievable reflection phase range of a traditional reflectarray is approximated $360^{\circ}\times(1.0-kh/\pi)$, where k is a wavenumber in the substrate and h is the substrate thickness[6]. It can be seen from this formula that a thinner substrate offers a wider reflection phase range. However, this is achieved at the cost of a high nonlinear relationship between the reflection phases versus element size. A rapid variation around the patch resonance makes the design difficult due to manufacturing errors. On the other hand, by increasing the substrate thickness, a much smoother phase variation can be achieved. However, the phase range becomes narrow, which makes practical designs unfeasible.

Thus, for a dual-frequency system (wavelength is different at two operating frequency), a substrate may be too thin to have smooth phase range at lower frequency resulting slope; on the other hand, it may be too thick at higher frequency to obtain an enough phase range. Usually, we need a tradeoff between the wide phase range and the smooth linear level.

In this paper, a novel concept is proposed to solve this problem. To simultaneously obtain a smooth reflection phase curve, a larger reflection phase range and dual operating frequency bands, an FSS layer is sandwiched between the reflectarray element layer (RA layer) and the metal ground plane in our design. The FSS layer can provide an additional reflecting plane for the upper frequency band. For lower frequency band, the FSS layer is transparent for the incident field and the reflecting plane is changed into the real metal ground plane. Moreover, a dual-band and dual-polarization reflectarray which comprises cross dipole elements and sandwiched FSS layer is designed to validate the concept. Smooth and wide reflection phase ranges are achieved at both lower and higher frequency bands (12GHz and 16GHz). A 7 × 11-element reflectarray is designed to demonstrate the performance, which has a maximum directivity at the desired scattering angle.

II. DESIGN OF NARROWBAND FSS

The configuration of the FSS sandwiched reflectarray is shown in Fig.1. The distance from FSS layer to metal ground plane and reflectarray element layer are h_1 and h_2, respectively. The substrate has a thickness of H and a permittivity of ε_r. To properly provide an additional reflection plane for upper frequency and a transparent plane for lower frequency, a suitable FSS should be designed firstly.

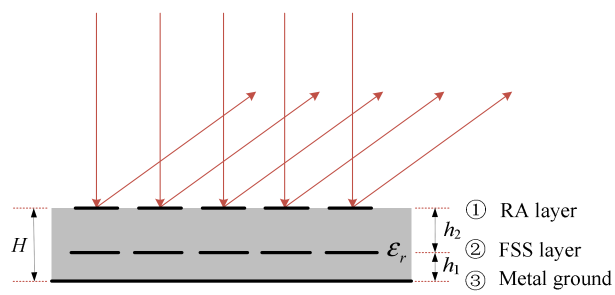


Fig.1. Dual-frequency reflectarray using sandwiched FSS.

A Frequency Selective Surface (FSS) is any surface construction designed as a 'filter' for plane waves [7]. A typical band stop behavior FSS comprises loop elements, as depicted in Fig.2.(a). The size of each unit cell is 10mm×10mm ($0.4\lambda\times0.4\lambda$ for 12GHz， $0.53\lambda\times0.53\lambda$ for 16GHz). The other detailed dimensions are also given in this figure (resonating at 16GHz). The permittivity of the substrate is selected as 2.5. The equivalent circuit of the loop FSS is shown in Fig.2. (b). It resonates at $f_r = 1/2\pi\sqrt{LC}$, where L and C are inductance and capacitance respectively.

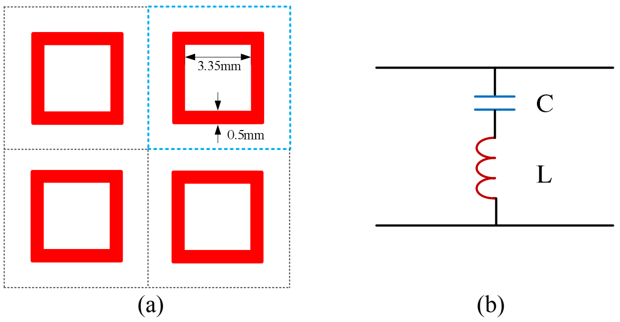


Fig.2. Loop-element FSS (a) Geometry of typical loop-element FSS. (b) Equivalent circuit of the loop-element FSS.

As can be found in Fig.3, the amplitude is about 0 dB and the reflection phase is about -180° at 16GHz. Thus a PEC-like plane can be realized at the upper operating frequency. However, as observed in Fig.3.(a), the -10dB S11 band of the loop-element FSS is too wide that the reflection coefficient is only -3.5dB at 12GHz. In order to achieve a high transparent performance at the lower operating frequency, a modified narrow band stop FSS is design firstly.

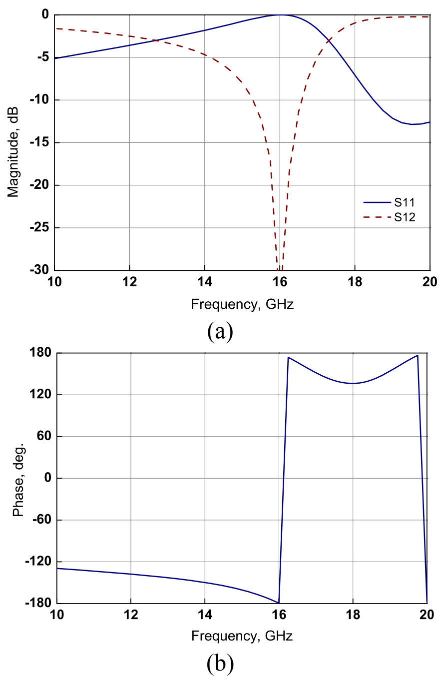


Fig.3. Loop-element FSS (a). S parameters with various frequencies. (b). Reflection phase with various frequencies.

The new modified FSS element geometry is sketched in Fig.4. (a). To obtain a narrow band stop performance, the adjacent loop elements are connected by a strip line which is equivalent to shunt an inductor as depicted in Fig.4.(b). The unit cell still keeps the size of 10mm×10mm. The width of the loop element and the strip line are both 0.5mm. The inner length of the loop is tuned to 4.25mm ant the length of the strip line is the distance between the adjacent loop elements, which is optimized as 4.75mm for resonating at the upper operating frequency.

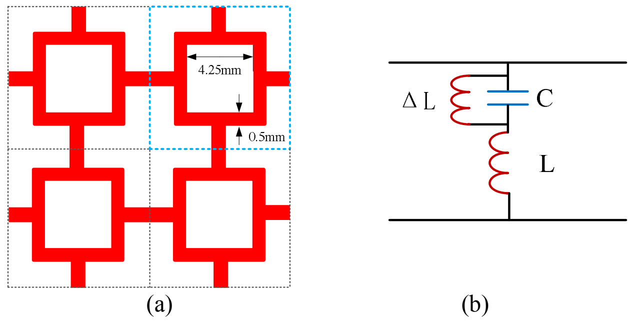


Fig.4. Modified FSS (a) Geometry of typical loop-element FSS. (b) Equivalent circuit of the loop-element FSS.

The bandwidth of a band stop filter is related to $\sqrt{L/C}$, which depends on the dimension of unit cells[7]. By adding a strip line with the loop element, the inductor is changed into $L^{'} = L/(1+(L/\Delta L))$, which is smaller than that of the loop-element FSS. To keep the resonant frequency, when the inductance becomes smaller, a bigger capacitance $C^{'}$ is needed. The value of $\sqrt{L^{'}/C^{'}}$ is obviously smaller than $\sqrt{L/C}$, thus a narrow band stop FSS is obtained.

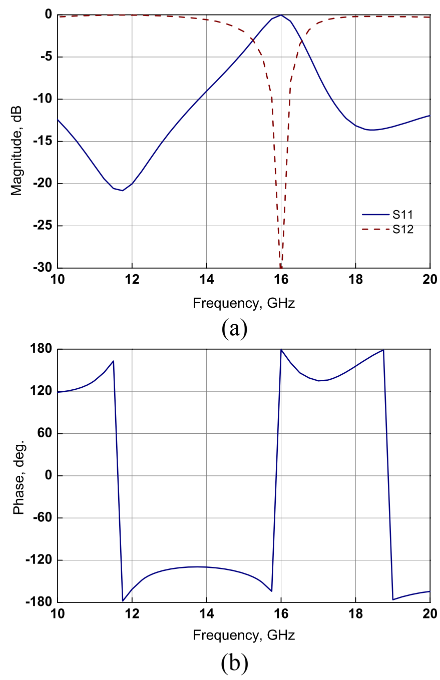


Fig.5. Modified FSS (a). S parameters with various frequencies. (b). Reflection phase with various frequencies.

As demonstrated in Fig.5, the -10dB S11 band is only 3.2GHz and the reflecting amplitude is -20dB at 12GHz. The reflection amplitude is about 0 dB and the reflection phase is about 180° at 16GHz. Excellent transparent and reflection performances are obtained at lower and upper frequency bands, respectively.

III. DESIGN OF REFLECTARRAY

To meet the dual-frequency and dual-polarization requirements, cross-dipole elements of variable sizes are used for the present design. For each cross dipole element, the horizontal dipole(x-direction) are designed to obtain the required phase correction for the horizontally polarized incident wave at 12GHz; the vertical dipole(y-direction) deals with the vertically polarized incident wave at 16GHz. The configuration of the FSS sandwiched reflectarray is shown in Fig.6. The reflectarray element layer is composed with 7×11 elements with a size of 70mm×110mm. The distance from FSS layer to metal ground plane and reflectarray element layer are $h_1 = 0.8mm$, $h_2 = 1.6mm$, respectively. The permittivity of the substrate is selected as 2.5.

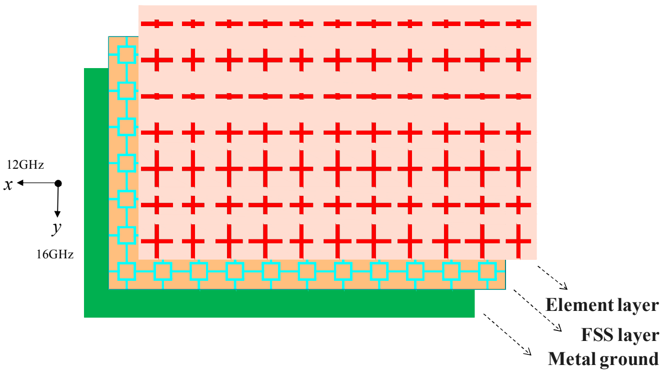
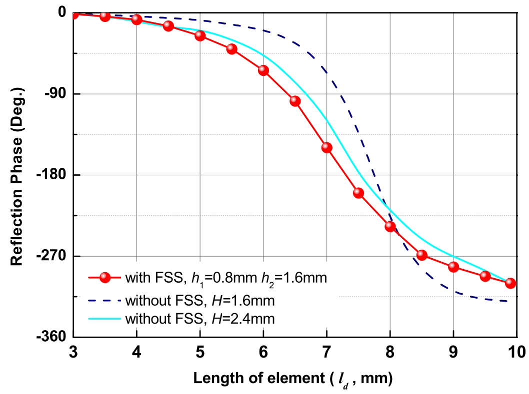


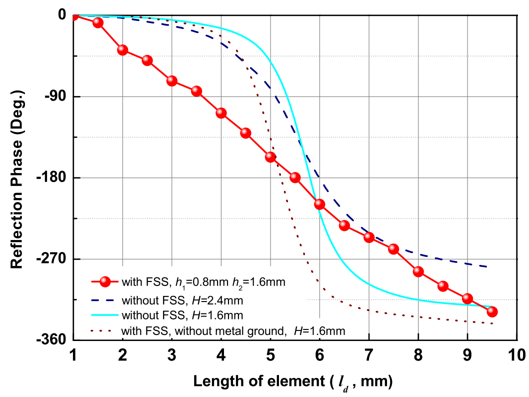
Fig.6. Configuration of the FSS sandwiched reflectarray.

An infinite periodic model was performed to analyze the reflection phase characteristics of the unit cell using HFSS simulation with normal incidence. For lower operating frequency (12GHz), as can be seen in Fig.7. (a), if there is a metal ground plane at a distance of 1.6mm (H=1.6mm) from the reflectarray element layer (RA layer), the curve of the reflection phase shows a rapid variation around the resonance and slow variation off resonance. When the metal ground is set at the distance of 2.4mm (H=2.4mm), a smoother phase variation phase range can be obtained. However, on the other hand, the distance of 2.4mm is too thick for 16 GHz. As depicted in Fig.7. (b), for the case of H=2.4mm without FSS, the phase variation is smooth but phase range is limited to less than 300° .

When the modified FSS is inserted between the element layer and the metal ground plane, the reflectarray has a frequency depended reflection ground. Thus for lower operating frequency (12GHz), the FSS is invisible and the reflection ground is the real metal plane. For upper operating frequency (16GHz), the FSS is a PEC-like layer, from which the incidence field is directly reflected. From Fig.7, it can be observed that smooth phase ranges (more than 300 degree) are obtained at both lower and upper frequency. At 12GHz, the reflectarray element has similar reflection phase with or without FSS (the distance between the RA layer and the real metal ground plane is H=2.4mm), i.e., the FSS is invisible. At 16GHz, the reflectarray element with FSS has a wider phase range than that without FSS. For the case of H=1.6mm, If the metal ground plane is instead by FSS, similar phase response can be obtain. However, for the actual case (H=2.4), FSS and the ground plane comprise a whole reflection structure. Due to the interaction between them, the FSS design should be properly tuned to optimize the phase behavior of the complete backing structure with metal ground plane. The final optimized inner loop length is 3mm. And more linear performance is obtained with FSS at the higher operating frequency.



(a)

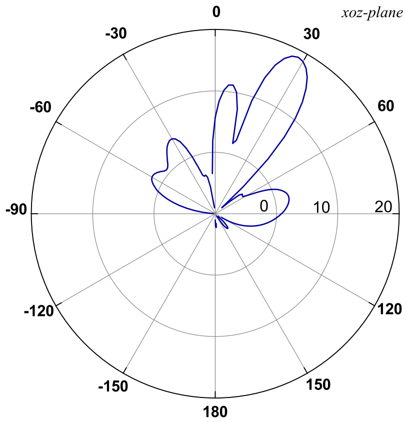


(b)

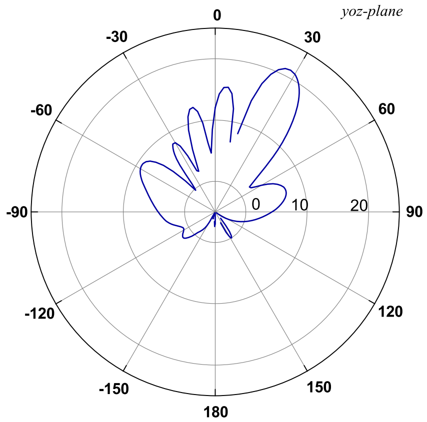
Fig.7. Reflection phase versus the dipole length (a). At 12GHz. (b). At 16GHz

It is also noted that this concept is especially effective for dual-frequency system with a large frequency interval such as 12GHz and 24GHz system because the wavelengths at the two frequencies are very different. Thus a single substrate is unsuitable. By properly inserting an FSS (resonating at upper frequency), the reflection phase performance can be greatly improved.

By using the reflection phase response with the elements size depicted in Fig.7, a 7 × 11 elements reflectarray operating at 12GHz (H-Polarization) and 16 GHz (V-Polarization) is designed to validate the performance (normal incidence and 30° desired scattering angle). The geometry of the designed reflectarray is shown Fig.6. Since the main beam is scanned only in the *xoz*-plane (for 12GHz)/*yoz*-plane (for 16GHz), the dimensions of the cross dipole length in *x/y* direction are the same within each column/row.



(a)



(b)

Fig.8. Scattering pattern of 11×7 elements reflectarray. (a). At 12GHz. (b). At 16GHz

The scattering pattern of the proposed reflectarray is depicted in Fig.8. The direction of the maximum directivity points at 29° at both operating frequencies, which shows a small shift from the design angle (30°). This angle shift attributes to both simulation errors and mutual coupling. The maximum directivities are 18.9dB and 21.2dB at 12GHz(*xoz*-plane) and 16GHz(*yoz*-plane), respectively.

IV. Conclusion

This paper presented a new concept for dual-frequency and dual-polarization reflectarray by sandwiching a narrow band FSS, which exhibits wide smooth phase bands at both lower frequency and upper operating frequencies. A 11 × 7 elements reflectarray is designed. A maximum directivity of 18.0 dB and 29° scattering angle and 21.2 dB and 29°scattering angle are obtained at 12GHz and 16GHz, respectively. The proposed reflectarray can be used to eliminate the blind spots of base station antennas in a downtown, high-building district and other applications

Acknowledgement

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