Amplitude Controlled Reflectarray Using Non-uniform FSS Reflection Plane

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***Abstract*—A novel concept using non-uniform frequency selective surface (FSS) backed as a reflection plane for amplitude controlled reflectarray is proposed. First, a modified square-loop FSS element with broad reflection response band (from -22dB to 0dB) is designed. Then, a non-uniform FSS using the modified square-loop element is backed as a reflection plane for reflectarray. By properly controlling each element size of the FSS, the reflection amplitude from the reflectarray element can be sufficiently controlled and amplitude controlled reflectarray can be realized. A reflectarray using Dolph-Tschebyscheff weighting coefficients is implemented and a major-lobe to side-lobe ratios of up to 22 dB is obtained.**

Keywords- Reflectarray, frequency selective surface(FSS), amplitude control, side lobe level (SLL)

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. Also, the reflectarray can achieve very good efficiency since no power divider is needed and thus very little resistive insertion loss is encountered [1]. As we know, the conventional microstrip reflectarray consists of an array of microstrip patches or dipoles printed on a thin metal-grounded dielectric substrate. Thus the incident wave signal is totally reflected by the PEC-liked plane and the reflection amplitude from each reflectarray element is kept the same. As a result, the traditional reflectarray is a phase-only array antenna and most literatures focus on the phase technique in reflectarray design [2-5]. These reflectarray antennas use phase-only control to generate a desired pattern in the far field, while the amplitude distribution along the array is fixed. Phase only beam synthesis in a reflectarray imposes a tight tolerance on the phase control needed at each element [6]. Furthermore, with the increasing requirements of wireless communication system, additional performance is required such as interference suppression. As a result, reflectarray with additional feature such as high side lobe level (SLL) is usually needed to meet the new requirement for high quality communication. Unfortunately, the traditional phase-only reflectarray antenna makes it difficult to tackle such problem.

Together with amplitude control technique, the phase distribution requirement for the reflectarray elements will be relaxed. Furthermore, additional performance such as high SLL, NULL synthesis, desired main-beam width, and broad scattering angle can be realized. However, the amplitude control technique is still a challenge task for reflectarray design. There is little information available in literature about the amplitude controlled reflectarray. Until recently, some work concerning the amplitude controlled reflectarray has been studied and reported by Pochiraju et al [7]. Using impedance tuner, the reflectarray element exhibits good performance with sufficient control of the reflection response. But the impedance tuner attached with each element needs additional DC control lines, strip-line coupler, varactor diode and so on. It will increase the structure complexity and system cost, especially for large aperture reflectarray with hundreds of elements. In addition, the whole reflectarray structure height and weight will also be enlarged for two substrates are used for reflectarray element and impedance tuner, respectively, and connected with coaxial probe.

In this paper, we proposed a novel concept using passive non-uniform FSS backed structure to realize amplitude controlled reflectarray with a high SLL. The reflectarray element and FSS element are simply printed on both sides of a single dielectric substrate. It may be a good candidate from the economic and technological points of view for wireless communication system. Detailed FSS structure design is discussed in Sections II. Section III describes the non-uniform FSS backed reflectarray, which can give sufficient control for major-lobe to side-lobe ratios of up to 22 dB using Dolph-Tschebyscheff amplitude distributions.

II. FREQUENCY SELECTIVE SURFACE DESIGN

A. Square-loop FSS

A Frequency Selective Surface (FSS) is any surface construction designed as a 'filter' for incidence plane waves [8]. A typical band-stop behavior FSS comprises square-loop elements and its equivalent circuit are shown in figure 1. It resonates at:

$$f_r = 1/2\pi\sqrt{LC} \tag{1}$$

where L and C are inductance and capacitance, respectively.

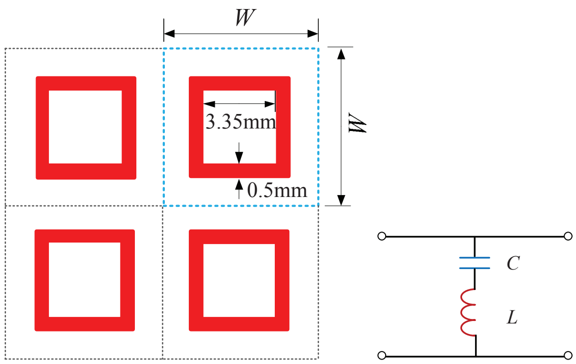

Figure 1. Geometry of the loop FSS and the equivalent circuit.

As can be seen in figure 3, the FSS performs as a reflection plane around the resonating frequency and a transparent plane off resonating, and the reflection response varies with the frequency. This means that, by controlling the element sizes we can obtain a variable reflection response for a fixed frequency. Inspired by the reflection performance of the FSS, we have a concept using an amplitude controlled reflection plane for reflectarray antenna design. However, the traditional square-loop FSS has a narrow reflection response variation in a wide frequency range (10GHz-17.5GHz, $|S_{11}| = -5\text{dB}$). And due to the limitations of the cell size, the variable square-loop size is limited (cannot larger than the cell size). In order to obtain a sufficient reflection response range within a small element size variation, a modified FSS is designed.

B. Modified Square-loop FSS

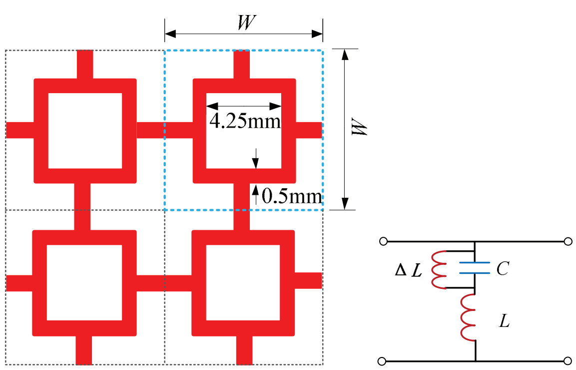

Figure 2. Geometry of the modified FSS and the equivalent circuit.

The modified FSS element geometry is sketched in figure 2. Comparing with the traditional square-loop FSS, to obtain a narrow band-stop performance and sufficient reflection response, the adjacent loop elements are connected by a strip line which is equivalent to shunt an inductor as depicted in figure 2. As can be clearly seen in figure 3, the -5 dB S11 band is reduced to 2 GHz and the reflecting amplitude is decreased to -22 dB at 11.8GHz for modified FSS. Thus a narrow band-stop width can be obtained and broad reflection response can be realized in relative small size variation range. The reflection amplitude is about 0 dB at 16GHz.

The substrate has a thickness *H*=0.8mm and a relative permittivity $\varepsilon_r = 2.5$. The unit cell still keeps the size of *W*×*W*=10mm×10mm. The width of the loop element and the strip line are both 0.5mm. The inner length of the square-loop is tuned to be 4.25mm and the length of the strip line is the distance between the adjacent loop elements, which is optimized as 4.75mm for resonating at 16GHz.

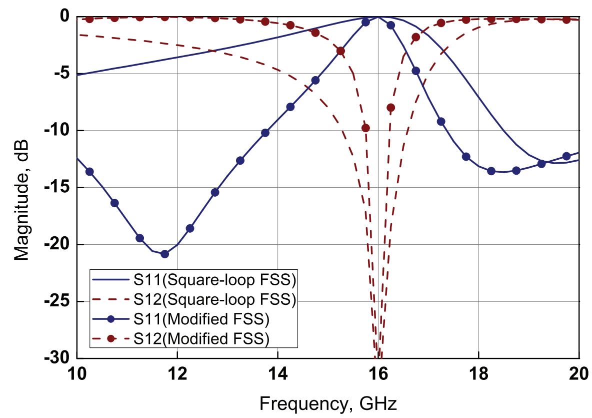

Figure. 3 S-parameter V.S frequency variation for two FSSs @11GHz

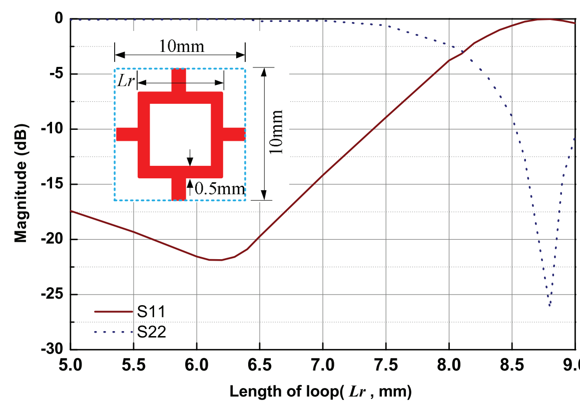

Figure. 4 S-parameter V.S loop length variation @11GHz

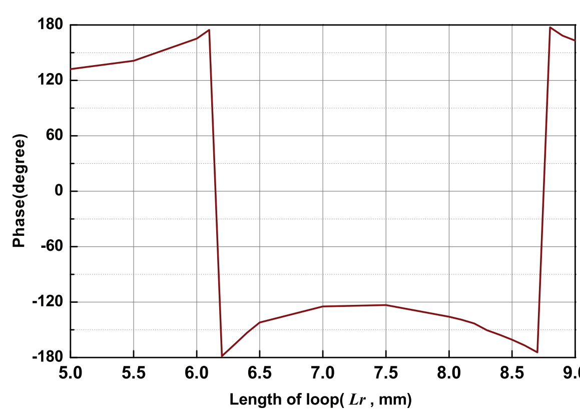

Figure. 5 Reflection phase V.S loop length variation @11GHz

To design an amplitude controlled reflectarray with sufficient reflection response, the modified square-loop FSS element is selected to construct the reflection plane. A simulation model for the modified square-loop FSS element structure, shown in figure 4, is designed in the High Frequency Structure Simulator (HFSS). By controlling the length of the square loop for each FSS element, *Lr*, a broad band reflection response can be obtained. As can be found in figure 4, by controlling the loop length *Lr* from 6.30mm to 8.65mm, a wide reflection response band (-22dB~0dB) can be obtained. And an excellent linear relation between *Lr* and reflection magnitude is realized, which can make the amplitude controlled reflectarray design and fabrication greatly easy and sample. The reflection phase of the modified square-loop FSS element is also calculated as shown in figure 5, which does not change greatly in the loop length variation range from 6.30mm to 8.65mm.

III. REFLECTARRAY WITH AMPLITUDE CONGTROLLING

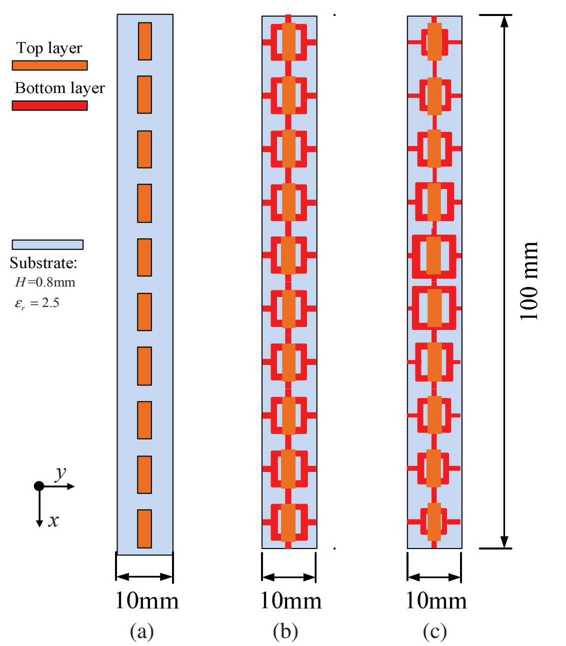

Figure. 6 Geometry of the three reflectarrays with different reflection plane (a) metal (b) uniform FSS (c) tapered FSS

To validate the proposed concept, three cases of reflectarrays are studied. At first, a 10×1 reflectarray using metal ground with identical reflectarray element is simulated. Then a 10×1 reflectarray using uniform FSS element with identical RA element is designed, in which the loop length is select as 8.65mm and the magnitude of the reflection coefficient is 1. At last, a 10×1 reflectarray using non-uniform (tapered) FSS with identical RA element is design and calculated. PBC and normal incidence are used during the reflectarray simulation. The geometries of the three reflectarrays are shown in figure 6 with coordinate system. The size of dipole reflectarray element is select as 9mm×2.4mm and keeps the same in the three reflectarrays. Other dimensions are also shown in figure 6. The substrate has a thickness *H*=0.8mm and a relative permittivity $\varepsilon_r = 2.5$.

The scattering patterns of the reflectarray with metal ground plane and that with uniform FSS can be seen from the figure 7 and figure 8, respectively. For the case of metal ground, the maximum directivity is 9.2dBi at 0 degree and the first sidelobe is -4.2dBi, thus the SLL is 13.4dB. As expected, a similarly performance is obtained for the case of uniform FSS (*Lr*=8.65mm), with the maximum directivity 9.16dBi at 0 degree and the first sidelobe -3.9dBi, and the SLL is 13.06dB.

To improve the SLL, a 10×1 reflectarray using Dolph-Tschebyscheff distribution is designed. The amplitude weighting coefficients, for this 10×1 array are listed in Table Ⅰ [9]. As can be observed in figure 9, the maximum directivity is 8.9dBi for the tapered FSS backed reflectarray, and the first sidelobe is -13.1dBi. Compared with the scattering pattern of metal ground backed reflectarray, almost the same maximum directivity is obtained (only 0.3dBi decrease) while 8.6dB SLL is improved.

The amplitude controlling approach suggested in this paper only uses a simple passive structure, and no active controlling unit is needed. It is low cost and can be easily deployed. In addition if beam steering control was also required, additional phase technique for each element could also be incorporated into a conventional phased array design, such as by varying the reflectarray element size, which is our current research. Further studies on amplitude and phase controlling reflectarray will be summarized in our next study.

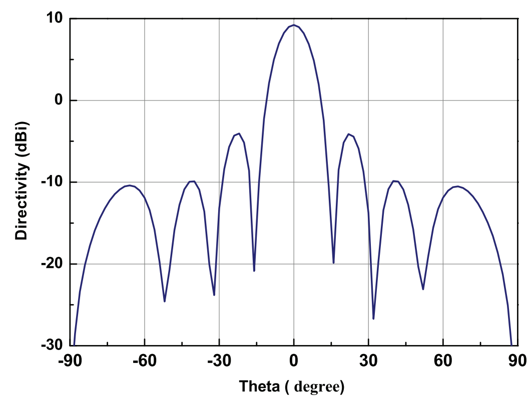

Figure. 7 Scattering pattern with uniform FSS backed plane

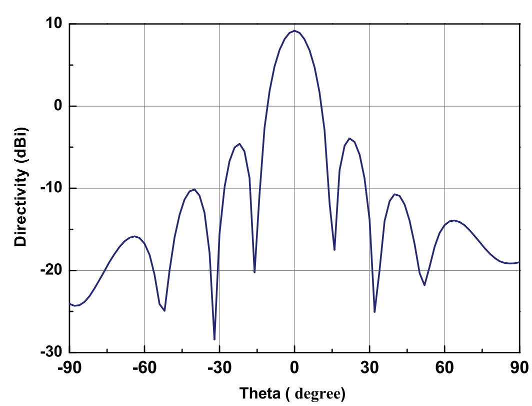

Figure. 8 Scattering pattern with uniform FSS backed plane

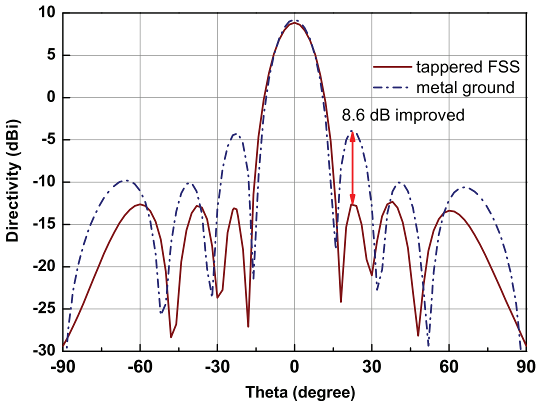

Figure. 9 Scattering patterns with metal and tapered FSS backed plane

TABLE Ⅰ. Normalized Amplitude coefficients for 10×1 Dplph-Tschebyscheff array

Element No.	Amplitude	Loop length(mm)
1	0.17(-15.391dB)	7.00mm
2	0.36(-8.874dB)	7.40mm
3	0.62(-4.150dB)	8.00mm
4	0.86(-1.310dB)	8.40mm
5	1.00(0.000dB)	8.65mm
6	1.00(0.000dB)	8.65mm
7	0.86(-1.310dB)	8.40mm
8	0.62(-4.150dB)	8.00mm
9	0.36(-8.874dB)	7.40mm
10	0.17(-15.391dB)	7.00mm

IV. Conclusion

A novel concept using non-uniform FSS structure as a reflection plane is proposed for amplitude controlled reflectarray in this paper. A modified square-loop FSS is designed to obtained wide reflection responds from -22dB to 0dB, which can support a sufficient amplitude control. By properly design the structure of backed FSS, an amplitude controlling reflectarray is realized. A 10×1-elements reflectarray using Dolph-Tschebyscheff distribution is designed and more than 22dB SLL is obtained. The reflectarray with high SLL can be used for interference suppression in wireless communication system and other similar applications.

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