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Switchable Square Loop Frequency Selective Surface

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Abstract—A switchable square loop frequency selective surface (FSS) design is presented. The FSS is switched between reflective and transparent state by using one gap for each unit cell. Measured and simulated results are compared. PIN diodes are integrated to the FSS for electrical switching. The PIN diodes equivalent circuit capacitance element is varied to investigate its effect on the switchable FSS performance. The switchable FSS power percentages of the reflected and transmitted states are presented in tables and discussed.

1. INTRODUCTION

Many FSS structures have attracted many researchers because of their wide application range [1, 2]. Switchable FSS adds extra functionality over the one state FSS [3, 4] due to its variable influence on the incident electromagnetic wave. The main characteristic of the switchable FSS is that it allows the electromagnetic wave to penetrate in the transparent state and rejects it in the reflective state. This made it favorable in many applications, such as reconfigurable antennas [5], tunable filters and multiband reflector antennas. In this perspective, we propose a new switchable square loop FSS structure for antenna applications. The proposed square loop FSS is very popular and one of the fundamental FSS shapes. However, switching this structure as a function of time did not get much concern as the ring loop structure [1, 2]. In this work a new square loop FSS is designed with only one active element required for switching unlike other references in literature which requires two active elements per unit cell [4]. This reduction reduces the cost and the active element parasitic effect of the FSS to the half.

2. DESIGN AND FABRICATION

Figure 1 shows the proposed FSS unit cell dimensions. It has a square shape with a vertical line between successive unit cells, the square length is **wd**. The continuity of the vertical line **sb**, identifies whether the FSS unit cell has a reflective or transparent surface. If the vertical line is discontinuous as in Fig. 1(a), it will perform as a reflective surface and will not allow the incident electromagnetic wave to penetrate. On the other hand, if the line **sb** is continuous between the successive unit cells, as shown in Fig. 1(b), it will be a transparent surface and allow the electromagnetic wave to propagate through the structure.

Figure 2(a) shows the fabricated FSS in the transparent state. The fabricated FSS array is composed of 16 columns and 10 rows of unit cells. The prototype is fabricated with gaps to measure the reflective state. Afterward, strips are soldered to close the gaps and measure the transparent state as shown in Fig. 2(a). The substrate used for implementation is a flexible R3003 substrate with dielectric constant of 3 and thickness of 0.13 mm. Fig. 2(b) compares the simulated and measured transmission coefficients of the switchable square loop FSS in the transparent and reflective state. The reflective curves are for the passive FSS unit cell shown in Fig. 1(a) when gaps are between the successive unit

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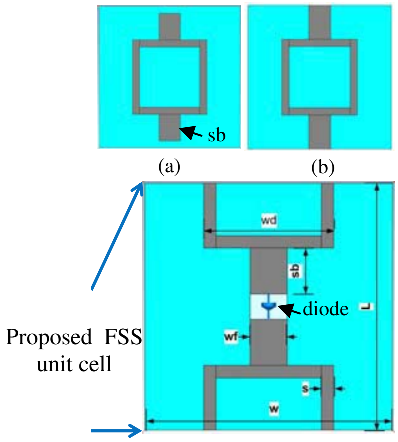
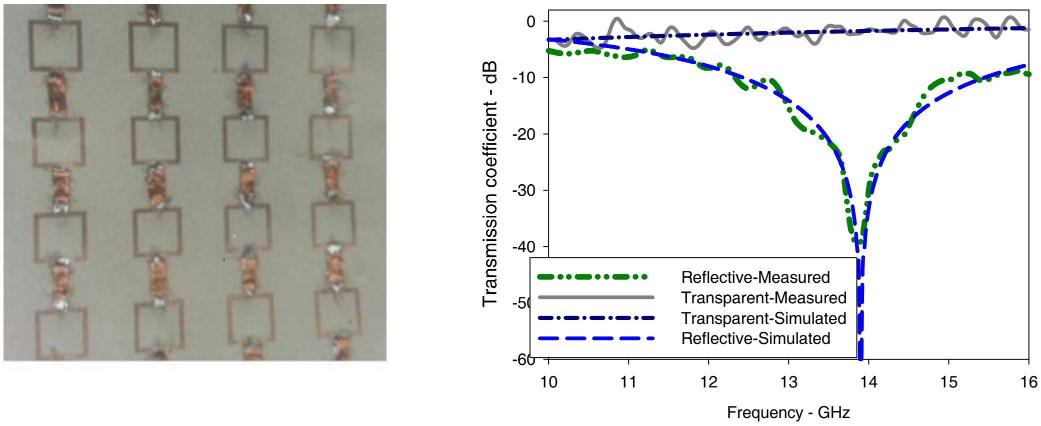


Figure 1. Proposed FSS structure. Dimensions (millimeters): $W = 10$, $L = 10$, $Wd = 5.25$, $Wf = 1.5$, $Sb = 1.85$, $S = 0.5$. (a) FSS with discontinuous lines in reflective state. (b) FSS with continuous lines in transparent state.



(a) (b)

Figure 2. (a) Fabricated FSS in the transparent state. (b) Proposed switchable FSS measured and simulated transmission coefficient for the transparent state shown in Fig. 1(b) and the reflective state shown in Fig. 1(a).

cells. The transparent curves are for the unit cell in Fig. 1(b) when continuous lines exist between the successive unit cells. CST Microwave studio simulator is used for simulation, and simulations are done in the frequency domain. The measurement setup consists of two horn antennas on each side with the fabricated FSS in between. The frequency range of the horn antennas is 1–18 GHz. The reflective state resonant frequency is 13.9 GHz. At this frequency, most of the incident power is reflected. The transmitted power identical to this frequency in the transparent state is 68% of the incident power. Table 1 shows the 90% reflected frequencies and its identical transmitted power percentages for the simulated switchable square loop FSS.

3. ACTIVE ELEMENT INTEGRATION

Integrating active elements such as PIN diodes to the switchable FSS unit cell enables the FSS to be electrically switched as a function of time. Fig. 1 shows the PIN diode location in the centre of the unit cell. In this case, the central gap size should be adapted to the PIN diode size to allow enough space for soldering the diodes. Two DC-feed lines could be added at the top and bottom of the FSS for

Table 1. The Switchable FSS transmitted and reflected power percentages.

Frequency	Power percentage %	
(GHz)	Transmitted	Reflected
12.425	60	90
15.45	73	90

biasing the diodes as shown in Fig. 3. These horizontal lines, shown in blue color, are connected to the beginning and the end of each FSS column.

There are many PIN diode types that could be selected for this design. The main parameters that limit the PIN diode selection are the price and diode characteristics. These parameters will affect the switchable FSS performance as will be shown in a later section. Hence, a suitable PIN diode with sufficient characteristics should be targeted.

PIN diodes are modeled in simulation using their equivalent lumped elements RLC circuit [5]. When the PIN diode is OFF in the reversed bias, it is modeled with a series connection of the equivalent inductance and capacitance elements. When the PIN diode is ON in the forward bias, it is modeled with a resistance value of $R = 1.8\,\text{ohms}$. The inductance value is considered to be $L = 0.5\,\text{nH}$. The capacitance value is the most critical value in the reflective state. Therefore, two values are considered to illustrate its influence on the FSS performance. The capacitance value that gives a performance most identical to the ideal case is $C = 0.001\,\text{pF}$. In addition, a capacitance value of $C = 0.01\,\text{pF}$ is considered to show the influence of the two capacitance values on the switchable FSS reflection coefficient.

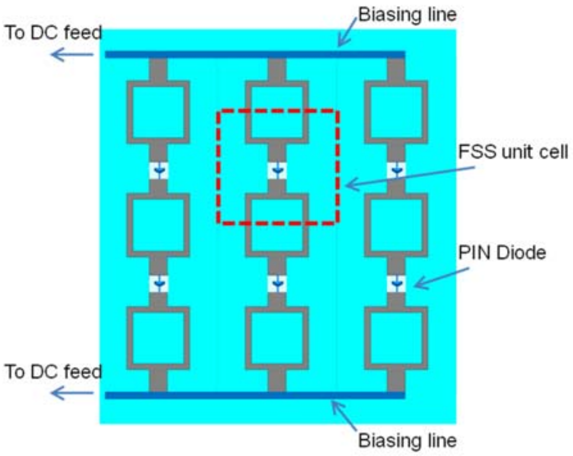


Figure 3. FSS with the biasing lines.

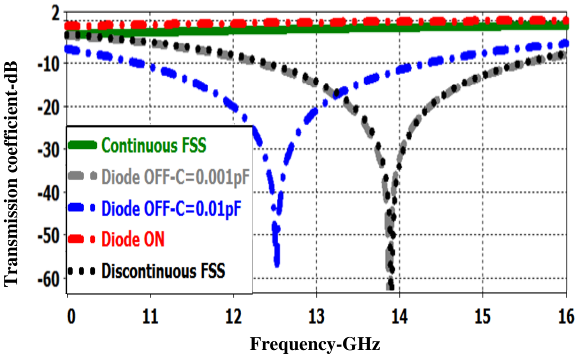


Figure 4. Frequency response of the proposed switchable FSS with PIN diodes.

Figure 4 shows the transmission coefficient of the switchable FSS in the reflective and transparent state. The curves compare between the ideal case, with continuous and discontinuous lines, and the case when PIN diodes are integrated to the circuit. When the capacitance value is $C = 0.001\,\text{pF}$, the maximum reflected power is $-87.5\,\text{dB}$ at 13.88 GHz. On the other hand, when the value is $C = 0.01\,\text{pF}$, the maximum reflected power is $-58\,\text{dB}$ at 12.53 GHz. In addition, the reflective 90% bandwidth in the $C = 0.01\,\text{pF}$ case is more than the $C = 0.001\,\text{pF}$ case by 288 MHz. Table 2 shows the transmitted power percentages for the frequencies with minimum 90% reflected power.

Table 2. Switchable FSS transmitted and reflected power percentages with PIN diodes integrated.

PIN diode Elements	**Frequency**	**Power percentage**	
(pF)	(GHz)	Transmitted	Reflected
$C = 0.01$	10.854	79	90
$C = 0.01$	14.31	95.4	90
$C = 0.001$	12.33	85	90
$C = 0.001$	15.498	98	90

4. CONCLUSION

A square loop switchable FSS has been presented with only one PIN diode required for each unit cell to switch between two reflective and transparent stats. It has been shown that the capacitance element in the diode equivalent circuit is the most important factor in the diode selection. The frequency has been shifted downwards by 1.35 GHz when changing the capacitance values from $C = 0.001\,\text{pF}$ to $C = 0.01\,\text{pF}$. In addition, the transmission coefficient is reduced by 29.5 dB and the 90% reflected power bandwidth increased by 288 MHz. With these features, this unit cell can be used to build reconfigurable FSS structures.

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