The Study on the Effect of Frequency Selective Surface to the Return Loss of Microstrip Array Antenna at 28 GHz Frequency

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***Abstract*— Microstrip Array Antenna has been operated at 28- GHz because of the basic features of the famous microstrip patch. The purpose of this research is to study the effects of Frequency Selective Surface (FSS) on the return loss of microstrip array antenna. In this research, Rogers Duroid RT5880 with a dielectric constant εr is 2.2 and the thickness is 0.254 mm is chosen to be the based substrate. Frequency Selective Surface (FSS) is used with air gap separation, which is 1-wavelength is 10.7143 mm. This research proposed a triangle shape rather than a circle, which is a conventional shape that significantly enlarges the fringe capacitance to compress the overall size of unit cell. The CST Microwave Studio 2016 software has been used. By selecting optimum parameters, the simulated return loss of the proposed antenna with and without FSS is -64.677 dB and -37.621 dB respectively. The results for both simulations fall at 28 GHz. After the fabrication and measurement, the result shifted forward by 1 GHz. At 29 GHz, the result with FSS and without FSS is -43.55 dB and -36.71 dB respectively. Both of result simulation and measurement can be used since the results of both are more than 1 GHz.**

***Index Terms*— 28 GHz; Frequency Selective Surface (FSS) Structure; Microstrip Array.**

I. INTRODUCTION

The frequencies for 5G have started from 10 GHz to 86 GHz [1], and the proposed antenna frequency design has been operated at 28 GHz. The speed of the data, one of the features of 5G, has achieved the standard features of an antenna that needs to have a high directivity and to look like a pencil beamforming radiation pattern [2,3]. There are numerous challenges to fulfill the requirements of the features, as all of the features must meet the technological design issues and commercial criteria, which are low cost, small size, radiation efficiency, antenna gain, broadband performance, and much more.

The Microstrip Array Antenna has been operated at 28-GHz because of the basic features of the famous microstrip patch, which are low cost, easy to manufacture and simple structure. Therefore, the antenna parameters are easy to be designed. Further, the array design permits the antenna to achieve tremendous expansion.

Over the years, the Frequency Selective Surface (FSS) has been used as reflector antennas, random design, polarizers, beam splitter, planar radar absorber and many others. It is a passive spatial filter, in which when exposed to electromagnetic wave, some of the frequencies are transmitted, while others are reflected. FSS has been classified as band-pass and band- stop filters. The band-pass filter is formed when an aperture is used and band-stop filter is formed when patch is used. In the past few decades, FSS had been used to reduce radar cross section (RCS) in military application, but now it is used in daily life. FSS structure has been extravagant with high impedance surface that reflects plane wave in-phase and suppresses surface wave [4]. FSS has many applications as band-pass random for missiles [5]-[6]. It can also be used in radio astronomy [7]-[8]. Its multi-band characteristic can be used for deep space exploration vehicle [9]. There are different methods to analyze FSS, Ben A. Munk proposed the theory of Periodic Moment Method, which is formed by joining an array theory and Method of moment [10] and finite difference time domain (FDTD) method.

As the name suggested, it is called spatial filter because it uses Gaussian pulse for smoothening of the output. Periodic array can be excited in two ways: by an incident plane wave that are called passive array or by individual generators connected to each element that are called active array. In passive arrays, the incident plane wave will be partly transmitted in forward direction and partly reflected in backward direction [13].

Since passive FSS does not need any external power, the question is how it works without any power. In this case, the antenna become the source, the EM wave radiated by the antenna is the source for it. The radiated EM wave excites current on the surface, which decides the frequency response of the superstrate. The design was proposed for polarization independent compact multiband FSS, in which changing the rotation about vertical axis from 0º to 90º does not affect the insertion loss, in which it becomes polarization independent [9].

This antenna was developed from a single patch to 32 - Element patch array antenna and operates at 28 GHz. Material that has been used for this design is Rogers Duroid RT5880, the dielectric constant, which is εr 2.2. The height of the dielectric constant is 0.254 mm.

There are some advantages of the patch which are; low profile design, feed line and matching network that can be fabricated simultaneously, light weight and comfortable, low fabrication loss and countless more.

II. DESIGN OF ANTENNA AND FSS

A. Antenna Design

The antenna was designed from a single patch, which is using a basic equation. According to '*Antenna Theory:*

Analysis and Design' [11,], the calculations of the dimension of a single patch are presented below;

The calculation of the patch width, *Wp*:

$$W_p = \frac{c}{2\,fr\sqrt{\frac{\varepsilon_r + 1}{2}}} \qquad (1)$$

where: $c = 3 \times 10^8$
$fr = 28$ GHz
$\varepsilon_r = 2.2$
$W = 4.42$ mm

The calculation of the actual length of antenna, *L*:

$$L = L_{eff} - 2\Delta L \qquad (2)$$

where: $Leff = 3.73$ mm
$\Delta L = 0.13$ mm
$L = 3.47$ mm

Figure 1 illustrates the front and the back of the single patch antenna. All parameters are calculated manually by using the equations [10].

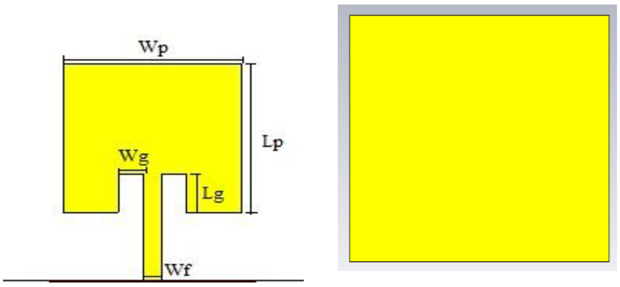

Figure 1: The front view of and back view of single patch antenna

The single section of the quarter-wave transformer has an equal length with the quarter-wave in microstrip and its characteristic of impedance, Z_1, should be given by:

$$z_1 = \sqrt{z_0 z_{in}} \qquad (3)$$

where: Z_0 = Characteristic impedance of the 50 ohm is line
Z_{in} = Input impedance of the rectangular patch

The width *W2* of the quarter-wave transformer can be located by an equation *Wd*, to calculate the value of Z_1, from an equation of the Z_1. The equation is all the same because of the usage of the same feed, but with a different value of the ohm on every feed. The highest the value of ohm, the smallest the size of the feed antenna.

$$\frac{W1}{h} = \left\{ \begin{array}{l} \frac{8C^A}{e^{2A}-2}\ for \frac{W1}{h} < 2 \\ \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_e}{\varepsilon_r}\left\{\ln(B+1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] for \frac{W1}{h} > 2 \end{array} \right\} \qquad (4)$$

$$A = \frac{Z_0}{60}\frac{\sqrt{\varepsilon_r + 1}}{\sqrt{2}} + \frac{\varepsilon_r - 1}{\varepsilon_r + 1}\left(0.23 + \frac{0.11}{\varepsilon_r}\right) \qquad (5)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \qquad (6)$$

Table 1 shows the design of feed antenna from a single patch up to 32-Element, except for the length feed of 100 ohm. This is because the length feed is needed to be measured by using a pick point in CST and separated by a spacing element, therefore, the length feed is designed. Each of the patch antenna is separated by 10.7143 mm.

Table 1
Design of Feed Antenna

Design of Feed	Length of Feed (mm)	Width of Feed (mm)
50 ohm	1.9581	0.7826
70 ohm	1.9873	0.4569
100 ohm	2.0201	0.2276

Figure 2 shows the 32-Element of the microstrip array antenna. The antenna use a feed that is designed by using a formula above.

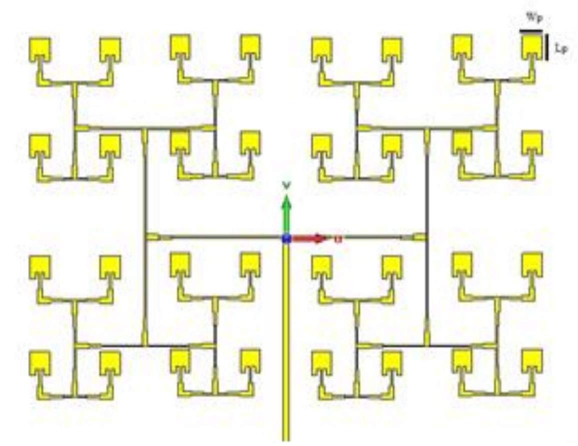

Figure 2: The front view of 8-element patch array design

B. Frequency Selective Surface Design

The Frequency selective surface structure is designed with a different place from the antenna, and it can be either absorber or filter.

The material of designing the FSS is Rogers Duroid RT5880 with the thickness is 0.254mm and the material of the patch is copper with the thickness is 0.0035mm. The design and simulation were completed by computer simulation tools (CST).

The design of antenna started from the circular, and the FSS does not have specific formula for designing the structure. However, it can use the basic formula from the rectangular antenna. In this paper, the FSS was on a triangular shape. Therefore, it uses the basic of circular design formula and have three points to make a triangle shape.

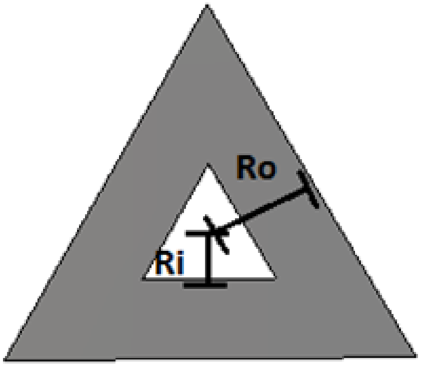

Figure 3: The single FSS

Table 2
Parameters for Single FSS

Parameters	Sizes
Ro	1.88889 mm
Ri	0.611111 mm

Table 2 shows the best parametric studies for the single FSS. The value is the best return loss that has been studied on the parametric studies.

Figure 4 depicts the periodic of FSS, whereas the single FSS are arranged periodically align with the 1-wavelenght, which is 10.7143 mm. Each of the triangle shapes also were separated by 10.7143 mm. Figure 3 shows the parameters of combined FSS.

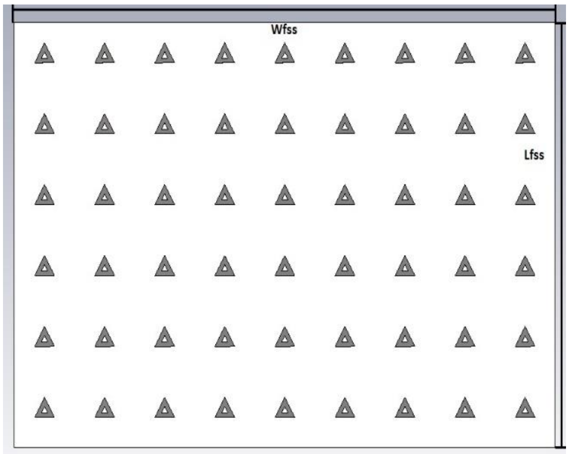

Figure 4: The periodic FSS

Table 3
Parameters for Combined FSS

Parameters	Sizes
Wfss	90 mm
Lfss	60 mm

C. *Integration of Microstrip Array Antenna With 2-Layers of FSS*

The 2-layers of FSS had been chosen due to the best result showed in the single FSS. The microstrip array antenna with Frequency Selective Surface was integrated to study the Return Loss.

The antenna and FSS were separated by 1-wavelength of air gap, which is 10.7143 mm. The first and second layers were separated by the same wavelength.

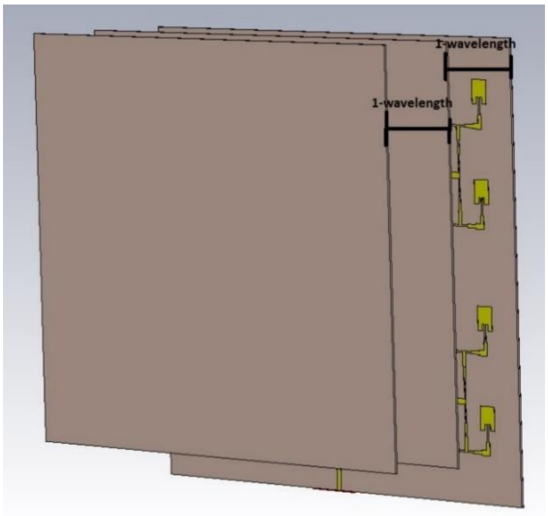

Figure 5: The integrated microstrip array with 2- layers of FSS

III. RESULT AND DISCUSSION

A. *Simulation Result*

Figure 6 shows the Return loss for the antenna with and without the FSS. The results were good when the bandwidth is 1.1 GHz and the return loss is -37.621 dB. Next, when the antenna is integrated with the FSS, the result becomes more efficient, which is the return loss is -64.677 dB and the bandwidth remains the same approximately 1.1 GHz.

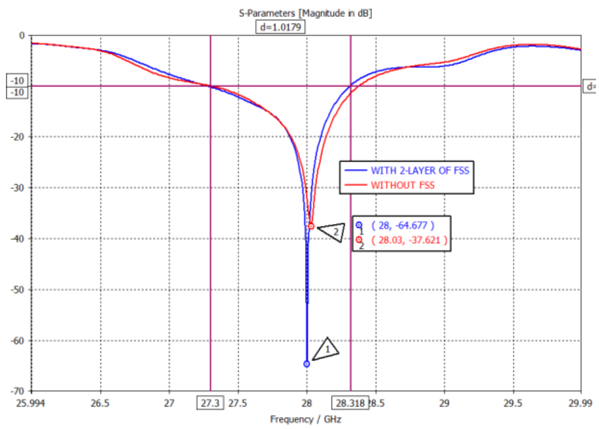

Figure 6: The simulation return loss for integrated antenna with and without EBG

Figure 6 above shows the result for the return loss for the integrated antenna and the FSS. The marked as number 1 is the return loss result for microstrip array antenna with the FSS has more efficient result. It is due to the FSS design and the structure, which is the Triangle design and the periodic arrangement. Therefore, the FSS gives the effect towards the antenna as an absorber.

Below is the simulation results for the Triangle Frequency Selective Surface single element:

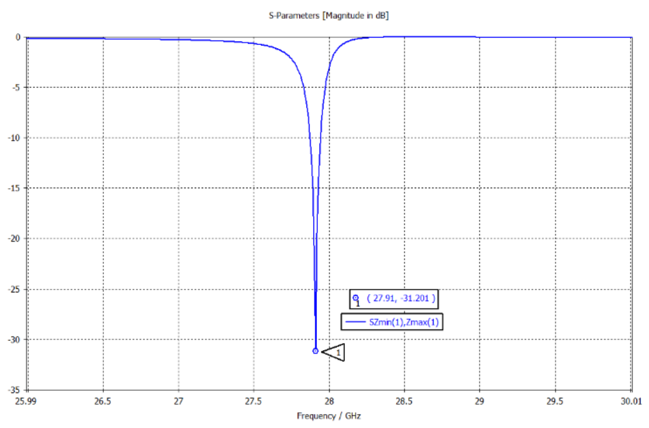

Figure 7: The simulation return loss of Triangle Selective Surface

The antenna integrated with FSS proved that the FSS helps the antenna to have a better return loss, as mentioned before. The triangle FSS design gave the return loss, which is 31.201 dB at 27.91 dB. The bandwidth for the FSS is 420 MHz. Therefore, the FSS gives a very good efficiency, good return loss and Bandwidth.

B. Measurement Result

Figure 8 shows the result for the comparison of measurement result. The measurement result does not fall narrow to the 28 GHz. but it operates on that frequency. But on the 29 GHz, the return loss fall narrow at 29.45 GHz is -36.77 dB is without FSS. The result after 2-layers of FSS is integrated with Antenna shows that the return loss had been narrower, which is -43.55 dB at the same frequency, as summarized in Table 4. The bandwidth for both frequencies are more than 1 GHz. The frequency operates at 29 GHz can still be used because it is still operated under -10 dB and it is the frequency that can be used on 5G sub-millimeter wave.

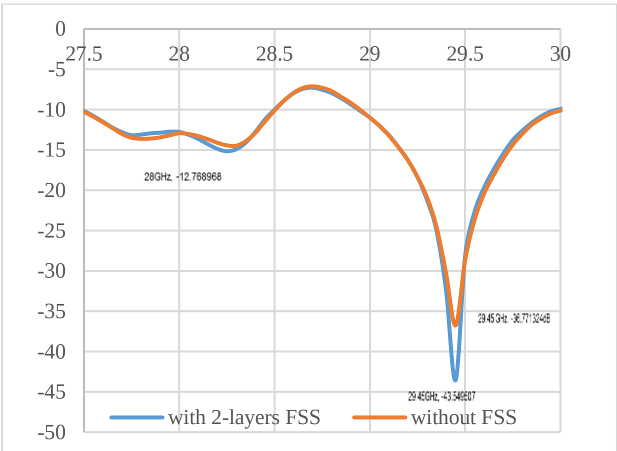

Figure 8: The return loss for with and without FSS

Table 4
Measurement Result for Return Loss for With and Without FSS

Parameters	Return Loss
With FSS	-36.77 dB
Without FSS	-43.55 dB

Next, the figure below depicts the comparison on the simulation and the measurement for Antenna with 2-layers of FSS. The result shows that the simulation is operated at 28 GHz and the measurement is at 29.45 GHz. The antenna with FSS both show a good result, whereas the return loss is -64.98 dB and -43.55 dB repectively. Both are under -10 dB, so it is an effciently working antenna.

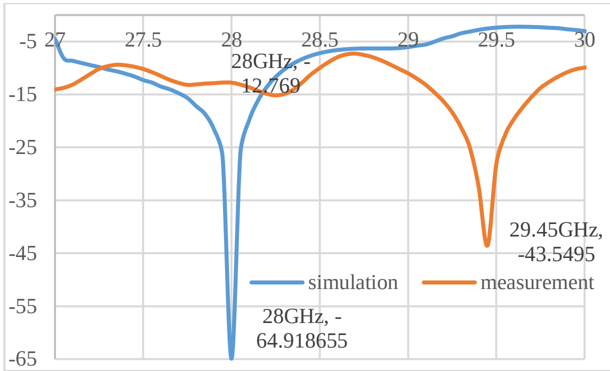

Figure 9: The comparison between simulation and measurement antenna with FSS

The result on Figure 9, shows that the frequency had been shifted by 1.45 GHz. The antennas were designed on 28 GHz. However, after the fabrication, the result was shifted to 29.45 GHz. This is usually happened when the fabrication process was not handle well. Other than that, the antennas was designed on high frequency, so there is consequence when fabrication happened. The high frequency antenna needs to have accurate size on everything, for example on the size of patch, size of antenna, size of feed and size of FSS. Since it is on high frequency, the antenna will be easily interrupted by the surrounding microwave elements.

Table 4
Measurement Result for Return Loss for With and Without FSS

Parameters	Return Loss
Simulation	-64.95 dB
Measurement	-43.55 dB

IV. CONCLUSION

This research investigated the return loss based on the effects of FSS on microstrip array antenna at Sub-Milimeterwave Frequency. In this study, the FSS was attached and unattached to the antenna with air gap separated by 10.7143 mm. The measurement shows that without FSS, the antenna does not have efficient result as with the antenna attached with FSS at 29.45 GHz. The return loss is -36.77 dB and -43.55 dB respectively. The simulation result shows that the antenna works efficient with FSS, in which the return loss is -64.96 dB. It is proved that FSS works efficiently to improve the return loss.

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