M. Hussein *Student member, IEEE*, Y. Huang *Senior Member, IEEE*, B. Al-Juboori and J. Zhou   
Department of Electrical Engineering and Electronics, University of Liverpool, L69 3GJ, UK

M.N.Hussein@liverpool.ac.uk, Yi.Huang@liverpool.ac.uk, Jiafeng.zhou@liverpool.ac.uk (corresponding)

[[1]](#footnote-1)

A Multi-band High Selectivity Frequency Selective Surface for Ka-Band Applications

***Abstract***—**This paper proposes a new method to implement Frequency Selective Surfaces (FSSs) with sharp band edge transitions suitable for millimetres wave applications. A bandpass FSS can be realized by combining two bandstop FSS structures on the same plane. By choosing appropriate dimensions of the structures, the passband and stopbands of the FSS can be controlled to obtain desired characteristics. With this method, multiple passbands and stopbands of an FSS can be achieved simultaneously. A prototype FSS is designed at the Ka band. The FSS is fabricated and tested in free space to verify the proposed design. The structure is polarization independent and exhibit low insertion loss at around 40 GHz.**

Index Terms—*Frequency selective surface (FSS), spatial filter. Millimeters-wave*

# INTRODUCTION

FSSs have been used as frequency diplexers in satellite reflector antenna systems with feeds placed on either side of the FSS [1-3]. Multichannel space-borne sounders were employed for spectroscopic characterization of the Earth’s atmosphere [4]. These devices carry out molecular emission spectroscopy at millimeter and sub millimeter-waves in narrow frequency channels. To meet the satellite restrictive payload on cost, mass and energy consumption, passive remote sensing radiometers traditionally employ a single mechanically scanned reflector antenna to collect radiation over a wide frequency range. Frequency selective surfaces (FSSs) can play an essential role as an enabling technology for these advanced instruments. They can be used in quasi-optical receivers to spectrally separate the signals that are collected by the scanning antenna [4].

The FSS can exhibit very low insertion loss and simultaneously meet the inconsistent requirements for high isolation between adjacent frequency channels. This should be accompanied by minimizing the overall noise performance of the instrument and then achieve high receiver sensitivity which is necessary to detect weak molecular emissions at millimeters waves.

Recently, satellite systems tend to operate in the Circular Polarizations (CP) mode, which is advantageous in communication and sensing systems as it can provide resilience to effects such as Faraday rotation [5], can also remove the requirement for alignment in polarization between the transmitter and receiver.

Recently, the design of polarization independent FSSs has attracted a lot of interests. These surfaces have near identical transmission and reflection coefficient magnitudes for TE and TM polarized waves. Several FSS geometries with such properties have been presented in millimeter- and sub-millimeter waves including crossed dipoles [6], Jerusalem crosses [7], rings [8], two layers of the semi-circle surfaces [9], double square loop arrays and gridded double square loop arrays [10].

In this paper, a new approach is presented to design narrow bandpass FSS with excellent transition edges. In this approach, the stopband and passband frequencies can be easily controlled as will be explained in Section II. The structure is implemented and measured as described in Section III. The FSS can achieve multiple passbands and stopbands. The response has a low insertion loss at the Ka band.

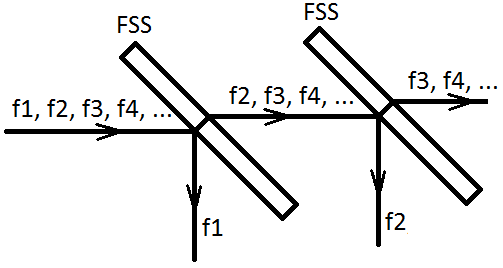


Fig. 1. An FSS is essentially a spatial filter. Signals can be separated by both transmission and reflection.

# Circuit design

An FSS is essentially a spatial filter. Compared to a connectorized filter with fixed ports, an FSS has two distinguitive features. One is that signals can be separated by both transmission and reflection as shown in Fig. 1. If connectorized filters were used, the signals would have to be split by a wideband divider and filtered individually. A three-way power divider has an intrinsic insertion loss of 3 dB, while the maximum measured insertion loss is 0.65 dB for an FSS in the transmission band of 320 GHz in [11]. The other is that two FSSs can co-exist on the same structure without significantly affecting each other. Therefore, a bandstop filter can be realized by combining two bandpass filters. A bandpass filter can be implemented by combing two bandstop filters, and so on.

In this paper, a bandpass FSS is realized by combining two bandstop ones. The proposed FSS can be designed with a simple three-step procedure described in this section. The first step in this approach is to obtain the appropriate bandstop structure based on the desired frequency response. The structure will be the host of a secondary structure. Fig. 2(a) shows the host-structure. More details on the design of this structure can be found in [12]. The second step is to design an appropriate secondary structure with suitable characteristics, such as the frequency response, the array element size and the shape. The four-leg structure shown in Fig. 2(b) is used as the secondary structure in this design. The final step is to combine the host and the secondary structure, as shown in Fig. 3 and tune the performance.



Fig. 2*.* Top view and dimensions of the array element of the proposed FSS. The host-structure is shown on the left-hand side and the secondary structure is shown on the right-hand side.



Fig. 3. 3×3 array elements of the proposed dual-stopband FSS.

For example, to obtain a narrow bandpass FSS with a centre frequency of 40 GHz and a fractional bandwidth of 5%, the dimensions of the structures shown in Fig. 2 can be used. The substrate is a 0.81 mm thick of Rogers RO4003 with a dielectric constant of 3.38. The structures are simulated separately. The shape of the FSS transfer functions can be optimized using simple circuit based simulations. To verify the responses of these structures, the proposed structure was simulated with CST Microwave Studio, using unit cell boundary conditions to provide periodicity along the x and y axes. The structure is excited by an electromagnetic wave with the propagation vector (**K**) towards the z-axis direction, magnetic field vector (**H**) towards the x–axis direction and electric field vector (**E**) towards the y-axis direction as shown in Fig. 3.

Fig. 4 shows the simulated response of the host structure. The resonant frequency is at 43 GHz. The transmission coefficient of the four-leg secondary structure is shown in Fig. 5. The structure exhibits performance with a stopband at 35 GHz. Fig. 6 shows response of the combined structures. It can be observed that a dual-stopband performance is achieved. Put it in another way, a bandpass performance is achieved at 40 GHz. The bandpass FSS has a very sharp selectivity due to the two stopbands introduced by the host and the secondary structures, respectively.



Fig. 4. Simulated transmission response of the host-structure.



Fig. 5. Simulated transmission coefficients of the secondary structure.



Fig. 6. Simulated transmission coefficients of the proposed FSS.

In fact, both the lower and the higher stopband can be shifted downwards or upwards independently by changing of the geometric dimensions of structures. As discussed in Fig. 1, both reflection and transmission of FSSs are useful for signal separation. The proposed is effectively a dual-bandpass filter as well if the reflected signals are received.

# III. Experimental Results

A prototype of the proposed structure has been fabricated and tested to validate the design. The fabricated FSS is shown in Fig. 7. The elements are enlarged and shown in the inset. The size of the FSS prototype is 102.6 mm × 102.6 mm. It consists of 30 × 30 elements. Two horn antennas and a vector network analyzer were used for the measurement. To ensure the accuracy of the experiment, the transmission coefficient between the two horn antennas was measured without the FSS. The transmission coefficient was then measured again with the FSS prototype. Then the measured transmission with the FSS is normalized with respect to the measured data without the FSS. The FSS was measured between 26.5 GHz and 40 GHz due to the bandwidth of the antennas. The measured response after smoothing is shown in Fig. 8. The transmission coefficient *S21* was measured at various angles of incidence. As can be seen in Fig. 8, the response has two stopbands at 35 GHz and 45 GHz and a narrow bandpass at 40 GHz. The insertion loss at the passband is 0.7 dB. The FSS was also tested under various polarization angles. The performance is almost independent from polarization angles due to the symmetrical nature of the proposed element.



Fig. 7.A photograph of the fabricated FSS with the proposed miniaturized array elements.



Fig. 8*.* The simulated and measured transmission coefficients of the proposed FSS structure, the responses are shifted in frequency for easy comparison.

# IV. Conclusion

In this paper, a novel schematic is used to design FSS with desired characteristics. This FSS is built by using a simple configuration of single surfaces layers. The structure exhibit low insertion loss at the millimeters-waves. The frequency response of this test sample was measured both for normal incidence and for oblique angles of incidence. The measurement result for porotype demonstrate that the good agreement with simulation one. The proposed approach with these features is very attractive for a wide range of applications.

References

[1] V. Agrawal, and W. Imbriale, “Design of a dichroic Cassegrain subreflector,” *IEEE Transactions on Antennas and Propagation,* vol. 27, no. 4, pp. 466-473, 1979.

[2] G. Schennum, “Frequency-selective surfaces for multiple-frequency antennas,” *Microwave Journal,* vol. 16, pp. 55-57, 1973.

[3] C.-C. Hunag, and N.-W. Chen, "Frequency selective surface for reflector antenna with multiple feeds." *Antennas and Propagation Society International Symposium (APSURSI)* pp. 1-2, 2012.

[4] R. Martin, and D. Martin, “Quasi-optical antennas for radiometric remote-sensing,” *Electronics & communication engineering journal,* vol. 8, no. 1, pp. 37-48, 1996.

[5] F. E. Nathanson, J. P. Reilly, and M. N. Cohen, “Radar design principles-Signal processing and the Environment,” *NASA STI/Recon Technical Report A,* vol. 91, 1991.

[6] E. A. Parker, A. D. Chuprin, J. C. Batchelor, and S. Savia, “GA optimisation of crossed dipole FSS array geometry,” *Electronics Letters,* vol. 37, no. 16, pp. 996-997, 2001.

[7] A. Kesavan, R. Karimian, and T. A. Denidni, “A Novel Wideband Frequency Selective Surface for Millimeter-Wave Applications,” *IEEE Antennas and Wireless Propagation Letters,* vol. 15, pp. 1711-1714, 2016.

[8] Y. Rahmat-Samii, and A. N. Tulintseff, “Diffraction analysis of frequency selective reflector antennas,” *IEEE transactions on antennas and propagation,* vol. 41, no. 4, pp. 476-487, 1993.

[9] J.-Q. Hou, L.-F. Shi, S. Chen, and Z.-R. Gou, “Compact broadband circular polariser based on two-layer frequency-selective surfaces,” *Electronics Letters,* vol. 51, no. 15, pp. 1134-1136, 2015.

[10] C. Lee, R. J. Langley, and E. A. Parker, "Technical memorandum. Single-layer multiband frequency-selective surfaces." *IEE Proceedings H-Microwaves, Antennas and Propagation* pp. 411-412, 1985.

[11] R. Dickie, R. Cahill, V. Fusco, H. Gamble, P. Huggard, M. Henry, M. Oldfield, P. Howard, Y. Munro, and P. De Maagt, “Micromachined Sub-mm Wave Frequency Selective Surface for Polarimetric Space Science Instruments,” 2009.

[12] M. Hussein, J. Zhou, Y. Huang, A. Sohrab, and M. Kod, "Frequency selective surface with simple configuration stepped-impedance elements." *Antennas and Propagation (EuCAP), 2016 10th European Conference on* pp. 1-4.

1. [↑](#footnote-ref-1)