Switchable Frequency Selective Surface Based on Polydimethyl-siloxane Composite Flexible Substrate for WLAN and 5G Sub-6GHz Applications

Hijab Zahra[(1)], Sujan Shrestha[(1)], Arslan Kiyani[(1)], Syed M. Abbas[(1)], Subhas Mukhopadhyay[(1)], Karu P. Esselle[(2)]

(1) School of Engineering, Faculty of Science and Engineering, Macquarie University, NSW 2109, Australia

(2) School of Electrical & Data Engineering, University of Technology Sydney, Sydney, NSW 2007, Australia

Abstract

A switchable frequency selective surface (FSS) based on Polydimethyl-siloxane (PDMS) composite flexible substrate has been assessed by comparing it with its rigid counterpart is presented in this paper. To realize FSS as switchable, various switching combinations are investigated. The design demonstrates a stop-band and pass-band response. In pass-band it shows single wide band and dual band response. From the bending analysis of the proposed FSS, less variation are observed when the FSS sheet is bend along the H-field direction, whereas minor variations are observed when the FSS sheet is bend along the E-field direction. The flexible substrate design results show a good agreement with the rigid design and the added value of flexibility makes it suitable for 2.4GHz/5.8GHz WLAN and 5G sub-6GHz applications operating in 3.3-4.2 GHz and 4.5-4.9 GHz bands.

1. Introduction

Frequency Selective Surfaces (FSSs) are attracting the attention of researchers due to their attractive features [1] and their usage in broad range of applications in modern communication, such as filters [2-5], polarizers [6], absorbers [7], antennas [8-10], artificial magnetic conductors (AMC) [11, 12], planar metamaterials and radomes [13]. FSSs are arrangement of periodic structures in either one or two dimensions that can act as filters to pass or stop the electromagnetic waves. Being light weight, low profile, easy to fabricate and cost effective solution, make them more encouraging among other periodic structures. The unit cell geometries used for FSS typically include square loops, circular rings, hybrid loops/rings, fractals shapes and dipoles. Jerusalem-cross is a well-known shape investigated in FSSs [6-8, 10-14]. Recently, we have demonstrated a switchable FSS based on modified Jerusalem-cross geometry [14, 15]. By selecting suitable switching combination, the presented FSS offers a single and dual pass-band for 2.45GHz and 5GHz. It also shows a stable resonance frequency at lower band while the resonance frequency of the higher band can be varied. Recently, flexible substrates have gained more attention of researchers and have been explored for wearable applications [16-18], such as for embroidery based antenna applications [19]. In this paper, we investigate a switchable FSS unit cell based on flexible substrate, Polydimethyl-siloxane (PDMS) composite (with $\varepsilon r = 3$, $tan\ \delta = 0.01$) and its performance has been compared to its rigid counterpart designed using Rogers Ro3003 ($\varepsilon r = 3$, $tan\ \delta = 0.001$). Section II gives details the design layout and switching configuration of the proposed FSS. Section III presents the results and bending analysis and Section IV concludes the paper.

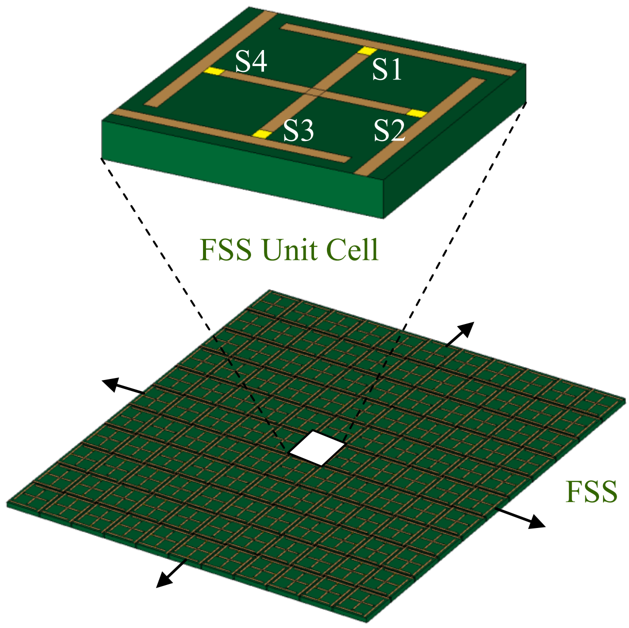

Figure 1. FSS unit cell geometry and switches location.

2. Design and Layout

The geometry of the proposed FSS geometry is shown in Fig. 1. The size of the FSS sheet can be selected depending upon the application requirements. The FSS unit cell has a square geometry with foot print of 11.55mm x 11.55mm. The upper metallic surface uses modified Jerusalem-cross with extended top loading [14]. The metal strip used for tracks are 0.6mm wide, whereas, 8mm long strips are used for the central cross strips and 10mm long strips are used for top loading. Figure 1 also shows the location of the switches used between the central and side metallic strips to realize the switching functionalities.

Table I. Pass and stop bands corresponding to different switch combinations.

Switch Combinations	Band-1 (GHz)	Band-2 (GHz)	Response	Applications
All ON	2.05 – 2.65	5.5 – 6.0	Pass band	2.4/5.8 GHz (WLAN)
All OFF	----------	----------	Stop band	Stop band
S2, S4 ON	3.04 – 4.92	----------	Pass band	3.3-4.9 GHz (5G sub-6GHz)

3. Results

The proposed FSS unit cell simulations are carried out using CST Studio Suite. To investigate the characteristics of the proposed FSS, different switch combinations have been considered. The performance of both, flexible and rigid designs is compared and the corresponding reflection and transmission coefficients response are presented in Fig. 2 and Fig. 3, respectively. The corresponding pass and stop bands results are tabulated in Table I. Results show that a stop-band characteristic is noted when all switches are in OFF state. On the other hand, when all switches are in ON state, a dual pass-band characteristic is observed around a lower resonance frequency of 2.4GHz and a higher resonance frequency of 5.8GHz, which are suitable for WLAN applications. When two switches (i.e. S2 and S4) are in ON state with S1 and S3 in OFF state, a wide pass-band response with -10dB bandwidth of about 1.9GHz is observed. This wide band is suitable for global 5G sub-6GHz applications operating in 3.3-3.6 GHz, 3.4-3.8 GHz, 3.5-3.7 GHz, 3.6-4.1 GHz, 3.45-4.2 GHz and 4.5-4.9 GHz bands [20, 21]. Results are in good agreement and negligible variation is due to variation in dielectric loss tangent.

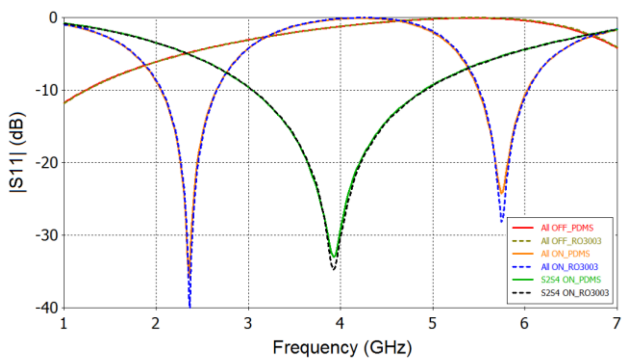

Figure 2. Predicted |S11| response corresponding to different switching combinations.

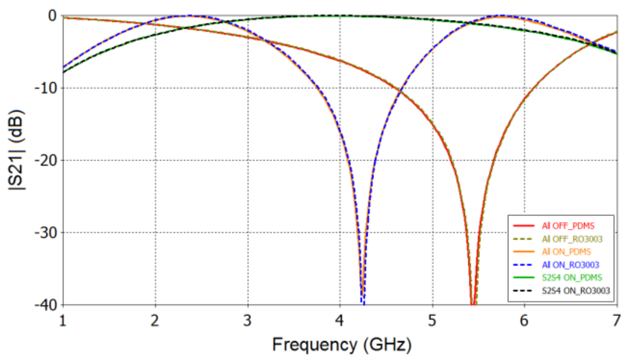

Figure 3. Predicted |S21| response corresponding to various switching combinations.

The proposed FSS has further been analyzed under various bending condition, i.e. bending radius and bending directions (along the E-field direction and along the H-field direction) as shown as in-set of Fig. 4 and Fig. 5. For brevity, selected results are presented here for better graphical understanding. It can be noted from results shown in Fig. 4 and Fig. 5 that when bending is along the E-field direction, sight variation are observed and less variation are observed with the surface is bent along the H-field direction. Thus the proposed surface can offers stable performance under cylindrical bending conditions.

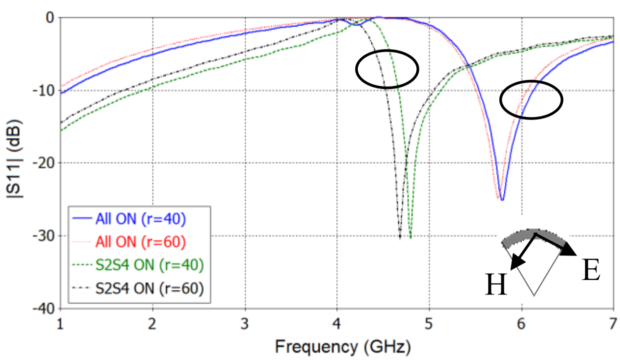

Figure 4. Predicted |S11| response corresponding to various bending radius when bending is along the E-field direction.

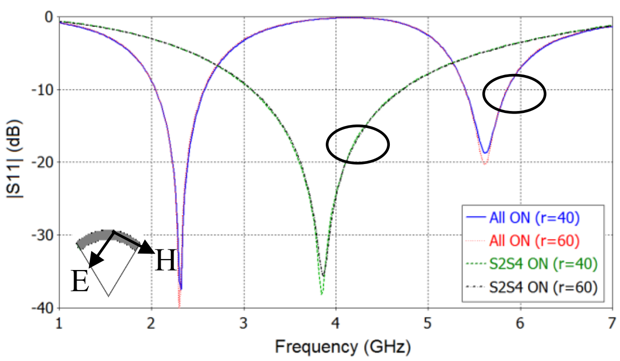

Figure 5. Predicted |S11| response corresponding to various bending radius when bending is along the H-field direction

4. Conclusion

A switchable frequency selective surface based on Polydimethyl-siloxane (PDMS) composite flexible substrate is presented. The performance has been compared with its rigid substrate counterpart. Results show that by selecting appropriate switch combinations, stop band and pass band characteristics can be achieved. Moreover, single wide pass band and two narrower pass bands can be achieved with the pass band operation. The dual band is suitable for WLAN applications, whereas wide band is suitable for 5G sub-6GHz application in the frequency range of 3.3-4.9 GHz, covering global bands for various geographical locations. The proposed FSS offers stable performance under bending condition, is easy to fabricate due to its simple geometry and the use of flexible substrate makes it a bendable reconfigurable solution.

7. References

[1] A. Mackay, B. Sanz-Izquierdo, and E.A. Parker, "Evolution of Frequency Selective Surfaces," *Forum for Electromagnetic Research Methods and Application Technologies (FERMAT),* vol. 2, pp. 1-7, 2014.

[2] I. Sohail, Y. Ranga, K. P. Esselle, and S. G. Hay, "A frequency selective surface with a very wide stop band," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, 2013, pp. 2146-2148.

[3] S. I. Sohail, G. I. Kiani, and K. P. Esselle, "Enhancing RF/microwave efficient transmission through energy saving glass windows using Frequency Selective surface," in *Antennas and Propagation (APSURSI), 2011 IEEE International Symposium on*, 2011, pp. 2262-2263.

[4] I. Sohail, Y. Ranga, K. P. Esselle, L. Matekovits, and S. G. Hay, "Polarization stable ultra-wide-band Frequency Selective Surface for Ku- and K- band applications," in *Electromagnetics in Advanced Applications (ICEAA), 2013 International Conference on*, 2013, pp. 802-805.

[5] I. Sohail, Y. Ranga, K. P. Esselle, L. Matekovits, and S. G. Hay, "Ultra-wide band frequency selective surface filter designed for Ku- and K- band applications," in *Antennas and Propagation Society International Symposium (APSURSI), 2013 IEEE*, 2013, pp. 476-477.

[6] I. Sohail, Y. Ranga, K. P. Esselle, and S. G. Hay, "A linear to circular polarization converter based on Jerusalem-Cross frequency selective surface," in *Antennas and Propagation (EuCAP), 2013 7th European Conference on*, 2013, pp. 2141-2143.

[7] S. Li, Y. Sin Han, I. C. Huang, and C. K. C. Tzuang, "Design and on-chip measurement of CMOS infrared frequency-selective-surface absorbers for thermoelectric energy harvesting," in *Microwave Conference Proceedings (APMC), 2011 Asia-Pacific*, 2011, pp. 461-464.

[8] C. Hsing-Yi, T. Yu, H. Kuo-Lun, and C. Hsi-Tseng, "Bandwidth enhancement using dual-band frequency selective surface with Jerusalem cross elements for 2.4/5.8 GHz WLAN antennas," in *Wireless Information Technology and Systems (ICWITS), 2010 IEEE International Conference on*, 2010, pp. 1-4.

[9] L. Moustafa and B. Jecko, "Broadband high gain compact resonator antennas using combined FSS," in *Antennas and Propagation Society International Symposium, 2008. AP-S 2008. IEEE*, 2008, pp. 1-4.

[10] C. Hsing-Yi and T. Yu, "Performance Improvement of a U-Slot Patch Antenna Using a Dual-Band Frequency Selective Surface With Modified Jerusalem Cross Elements," *Antennas and Propagation, IEEE Transactions on,* vol. 59, pp. 3482-3486, 2011.

[11] M. Hosseini and M. Hakkak, "Characteristics Estimation for Jerusalem Cross-Based Artificial Magnetic Conductors," *Antennas and Wireless Propagation Letters, IEEE,* vol. 7, pp. 58-61, 2008.

[12] M. K. Taher Al-Nuaimi and W. G. Whittow, "Low profile dipole antenna backed by isotropic Artificial Magnetic Conductor reflector," in *Antennas and Propagation (EuCAP), 2010 Proceedings of the Fourth European Conference on*, 2010, pp. 1-5.

[13] F. Costa and A. Monorchio, "A Frequency Selective Radome With Wideband Absorbing Properties," *Antennas and Propagation, IEEE Transactions on,* vol. 60, pp. 2740-2747, 2012.

[14] H. Zahra, S. Rafique, M. Farhan Shafique, and Karu P. Esselle, "A Switchable Frequency Selective Surface based on a Modified Jerusalem-Cross Unit Cell," in *9th European Conference on Antennas and Propagation*, Lisbon, Portugal, 2015.

[15] H. Zahra, S. M. Abbas, M. F. Shafique, and K. P. Esselle, "A switchable FSS based on modified Jerusalem-cross unit cell with extended top loading," in *2015 International Symposium on Antennas and Propagation (ISAP)*, 2015, pp. 1-2.

[16] S. Morris, A. R. Chandran, N. Timmons, and J. Morrison, "Design and performance of a flexible and conformai PDMS Dipole antenna for WBAN applications," in *2016 46th European Microwave Conference (EuMC)*, 2016, pp. 84-87.

[17] S. Hage-Ali, N. Tiercelin, P. Coquet, R. Sauleau, V. Preobrazhensky, and P. Pernod, "Millimeter-wave patch array antenna on ultra flexible micromachined Polydimethylsiloxane (PDMS) substrate," in *Antennas and Propagation Society International Symposium, 2009. APSURSI '09. IEEE*, 2009, pp. 1-4.

[18] W. Zheyu, Z. Lanlin, Y. Bayram, and J. L. Volakis, "Embroidered Conductive Fibers on Polymer Composite for Conformal Antennas," *Antennas and Propagation, IEEE Transactions on,* vol. 60, pp. 4141-4147, 2012.

[19] S. M. Abbas, S. C. Desai, K. P. Esselle, J. L. Volakis, and R. M. Hashmi, "Design and Characterization of a Flexible Wideband Antenna Using Polydimethylsiloxane Composite Substrate," *International Journal of Antennas and Propagation,* 2018.

[20] H. Askari, N. Hussain, D. Choi, M. A. Sufian, M. Abbas, et al., "An AMC-Based Circularly Polarized Antenna for 5G sub-6 GHz Communications," *CMC-Computers, Materials & Continua*, vol. 69, no. 3, pp. 2997–3013, 2021.

[21] M. Farasat, D. N. Thalakotuna, Z. Hu, and Y. Yang, "A Review on 5G Sub-6 GHz Base Station Antenna Design Challenges," *Electronics*, vol. 10, no. 16, pp. 2000, 2021.