The measured and simulated return loss results of proposed antenna are shown in Figure 6. Good agreement is achieved between the simulated and measured results. The measured bandwidths are 257 MHz (from 761 to 1018 MHz) and 681 MHz (from 2201 to 2882 MHz) for the UHF and microwave RFID application.

It is desired to propose a method in controlling the secondary frequency with minimum effect on the primary resonant frequency. The parameter that can be used to control the secondary resonant frequency is L-probe arm length of $y_2$. By adjusting the length of $y_2$, the upper frequency of $f_2$ can be tuned. Figure 7 shows the return loss of the proposed antenna with different length of L-probe. It is found that the first resonant frequency can be easily controlled by selecting the radius of lower band circular patch. Table 2 shows the simulated results of primary frequency, secondary frequency, and their bandwidths by adjusting the arm length of L-probe. It is found that the increasing $y_2$ results in a significant increase of second resonant frequency bandwidth.

### Performance Comparison for the Proposed Antennas with Various Arm Length of Y2

| $y_2$ (mm) | $F_1$ (GHz) | Bandwidth ($f_1$) (MHz) | $F_2$ (GHz) | Bandwidth ($f_2$) (MHz) |
|-----------|-------------|-------------------------|-------------|-------------------------|
| 7         | 1.0536      | 284.8                   | 2.9176      | 825.6                   |
| 9         | 1.0552      | 281.6                   | 2.8792      | 896                     |
| 11        | 1.0568      | 278.4                   | 2.836       | 956.8                   |
| 13        | 1.0584      | 275.2                   | 2.796       | 1024                    |

4. CONCLUSION

In this article, a new wideband L-probe circular dual-patch antenna on an electrically thick substrate has been presented for the dual-frequency RFID application. The proposed antenna achieves wide impedance bandwidth of 28.89 and 26.8% for the lower and upper bands, respectively. The maximum gains are 7.248 dBi in the lower band and 7.914 dBi in upper band. The effects of slot-loading on the circular patches are extensively studied. Finally, it is found that the proposed antenna has exhibited the properties of high gain, broad bandwidth, and good radiation characteristics for dual-frequency RFID operation.

REFERENCES

1. Y. Lo, D. Solomon, and W. Richards, Theory and experiment on microstrip antennas, IEEE Trans Antennas Propag 27 (1979), 137–145.
2. D.M. Pozar, Microstrip antennas, Proc IEEE 80 (1992), 79–91.
3. H.-W. Lai and K.-M. Luk, Dual polarized patch antenna fed by meandering probes, IEEE Trans Antennas Propag 55 (2007), 2625–2627.
4. M.T. Islam, M.N. Shakib, and N. Misran, Design analysis of high gain wideband L-probe fed microstrip patch antenna, Prog Electromagn Res 95 (2009), 397–407.
5. E. Aloni and R. Kastner, Analysis of a dual circularly polarized microstrip antenna fed by crossed slots, IEEE Trans Antennas Propag 42 (1994), 1053–1058.
6. G.P. Gauthier, A. Courtoy, and G.M. Rebeiz, Microstrip antennas on synthesized low dielectric-constant substrates, IEEE Trans Antennas Propag 45 (1997), 1310–1314.
7. T. Chakravarty and A. De, Design of tunable modes and dual-band circular patch antennas using shorting posts, IEEE Proc Microwaves Antennas Propag 146 (1999), 224–228.
8. X.-L. Liang, T.A. Denidni, and L.-N. Zhang, Wideband L-shaped dielectric resonator antenna with a conformal inverted-trapezoidal patch feed, IEEE Trans Antennas Propag 57 (2009), 271–274.
9. A.U. Bhobe, C.L. Holloway, M. Piket-May and R. Hall, Wide-band slot antennas with CPW feed lines: Hybrid and log-periodic designs, IEEE Trans Antennas Propag 52 (2004), 2545–2554.
10. M. T. Islam, M. N. Shakib, and N. Misran, Broadband E–H shaped microstrip patch antenna for wireless systems, Prog Electromagn Res 98 (2009), 163–173.
11. A. Pihadi, H. Bahrami, and J. Nasri, Wideband high directive aperture coupled microstrip antenna design by using a FSS superstrate layer, IEEE Trans Antennas Propag 60 (2012), 2101–2106.
12. E. Chang, S.A. Long, and W.F. Richards, An experimental investigation of electrically thick rectangular microstrip antennas, IEEE Trans Antennas Propag 34 (1986), 767–772.
13. M.T. Islam, M.N. Shakib, and N. Misran, Design analysis of high gain wideband L-probe fed microstrip patch antenna, Prog Electromagn Res 95 (2009), 397–407.
14. Y.X. Guo, C.L. Mak, K.M. Luk, and K.F. Lee, Analysis and design of L-probe proximity fed patch antennas, IEEE Trans Antennas Propag 49 (2001), 145–149.
15. C.L. Mak, K.M. Luk, K.F. Lee, and Y.L. Chow, Experimental study of a microstrip antenna with an L-shaped probe, IEEE Trans Antennas Propag 48 (2000), 777–783.
16. J. Landt, The history of RFID, IEEE Potentials 24 (2005), 8–11.
17. K. Finkenzeller, RFID handbook, 2nd ed., Wiley, Hoboken, NJ, pp. 195–219, 2003.
18. J.A. Ansari, A. Mishra, N.P. Yadav, and P. Singh, Dualband slot loaded circular disk patch antenna for WLAN Application, Int J Microwave Opt Technol 5 (2010), 124–129.
19. L. Jui-Han and K.-L. Wang, Slot-loaded, meandered rectangular microstrip antenna with compact dual frequency operation, Electron Lett 34 (1998), 1048–1050.
20. S. Maci, G. Biffi Gentili, P. Piazzesi, and C. Salvador, Dualband slot-loaded patch antenna, IEEE Proc. Microwaves Antennas Propag 142 (1995), 225–232.
21. R. Garg, P. Bartia, I. Bhal, and A. Ittipiboon, Microstrip antenna design handbook, Artech House, Norwood, MA, 2001.
22. Y.X. Guo, M.Y.W. Chia, Z.N. Chen, and K.-M. Luk, Wide band L-probe fed circular patch antenna for conical pattern radiation, IEEE Trans Antennas Propag 52 (2004), 1115–1116.

© 2014 Wiley Periodicals, Inc.

PASSIVE PIN REFLECTION FREQUENCY SELECTIVE SURFACE FOR INTERFERENCE REDUCTION IN THE BUILT ENVIRONMENT

Christopher J. Davenport and Jonathan M. Rigelsford
Department of Electronic and Electrical Engineering, The University of Sheffield, Mappin Street, Sheffield, S1 3JD, United Kingdom;
Corresponding author: christopher.davenport@sheffield.ac.uk

Received 3 October 2013

ABSTRACT: Proposed is a passive periodic pin reflection frequency selective surface (PR-FSS) suitable for installation in indoor environments to reduce interference caused by multiple cochannel wireless transmitters. The PR-FSS is developed from a comb reflection FSS and provides comparable performance with the use of less material. © 2014 The Authors. Microwave and Optical Technology Letters Published by Wiley Periodicals, Inc. Microwave Opt Technol Lett 56:1424–1427, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28328

Key words: interference reduction; forward scatter reduction; CST; radar cross section; indoor propagation

1. INTRODUCTION

Frequency selective surfaces (FSSs) are increasingly being investigated for their use in modifying radio propagation in buildings, especially through interior walls [1–4]. Despite this, propagation along corridors is rarely considered, even though it
is often the main route of propagation of a transmitted signal [5], especially in buildings with metallized walls [6]. This propagation can cause interference between transmitters in adjacent rooms, and it is, therefore, advantageous to redirect the propagating signal back to the source of transmission to reduce this interference, as seen in Figure 1.

This letter presents a pin reflection frequency selective surface (PR-FSS), which is capable of reducing unwanted propagation down corridors. It is developed from a similar comb-based structure described in [7] but aims to reduce the total material use and cost. This reduction in material is likely to result in an inferior performance, and the relationship between pin separation (reduction in material) and surface performance are presented in this letter, with an optimal solution provided. This letter presents results on the reduction in forward scatter for horizontal and vertical polarizations, and provides a comparison of the comb reflection frequency selective surface (CR-FSS) in [7] and the PR-FSS described here.

Simulation results on the reduction in forward scatter at off-normal angles of incidence ($\theta_r \neq 0^\circ$) like in [8] are presented, despite normal incidence usually being considered in FSS literature [1, 9, 10]. This is due to the fact that only angles of incidence between $30^\circ$ and $70^\circ$ are likely to cause interference issues [7, 11]. Final discussion is on the broad frequency range at which the surface an example surface is active and its frequency dependence on Bragg’s Law [12].

2. DESIGN AND SIMULATION

As described previously in [7], periodic surfaces can be used to reduce the forward scatter of a propagating signal by redirecting it as backscatter. This letter presents a novel pin based FSS for reducing the forward scatter of an incoming signal. The pin period, $a$, and separation $d$ are chosen prior to construction of the surface to provide a frequency selective response. The angle of maximum direct backscatter $\theta_b$ can be appropriately chosen by selecting these parameters, and by using Bragg’s Law [12]. For practicality of comparisons of the presented simulation results with future experimental ones, the surface is designed to operate in the X and Ku frequency bands. For an arbitrary choice of pin period $a = 16$ mm and $f = 10.8$ GHz, the angle of incidence, $\theta_i$, where maximum backscatter will occur is at $\theta_b = \sin^{-1}(c/2zf) = 60^\circ$, where $c$ = speed of light in a vacuum. There is also an operating forward scatter frequency range, which is dependent on angle of this incidence. This letter will address the consequence of converting the previously researched fin structure in [7] into a pin arrangement.

Scattering simulations were performed using the time domain solver in CST microwave synthesizer (MWS) [13], with the PR-FSS in Figure 2 illuminated by a plane wave with an angle of incidence of $60^\circ$. All surface parameters used in the simulation are summarized in Table 1. There were five repetitions of the pins in the $x$-axis and 40 repetitions in the $y$-axis, with the plane wave parallel to the $y$-axis. A field monitor at 12 GHz and $E$-field far-field probes at $\pm 60^\circ$ were used to obtain the simulation results shown in this letter.

3. SIMULATION RESULTS

3.1. Pin Separation

The optimal PR-FSS would have the highest possible pin separation, without negatively effecting the reduction in forward scatter. Figure 3 shows the relationship between the pin separation distance and the reduction in forward scatter. There are clear differences in the performance of the surface when considering the polarization. At $d = 0$ mm, the surface is a CR-FSS and exhibits the best performance, where the forward scatter is reduced by approximately $-13$ dB, independent on polarization. For a vertically polarized signal, the PR-FSS is able to sustain effective reduction for pin separations lower than 20 mm. Higher than this, the PR-FSS becomes less effective, reaching minimal reduction at 26 mm. The surface exhibits some harmonic effects, with a second peak occurring at 36 mm. For a horizontally polarized signal, the performance decreases rapidly, suggesting a PR-FSS is suitable for reducing the forward scatter.

The effects of increasing the pin separation can be summarized by comparison of the normalized radar cross-section (RCS)
plots in Figures 4 and 5, where the flat, perfectly reflecting surface is represented by the dashed line, and the CR-FSS and PR-FSS by the solid line. First, the backscatter angle has shifted to $43^\circ$ because the frequency has increased from 10.8 to 12 GHz. Second, we can compare the reduction of the forward scatter of the CR-FSS with that of a PR-FSS with $d = 16$ mm. Figure 4 compares the differences for a vertically polarized plane wave, where the PR-FSS offers a 9-dB reduction in forward scatter compared to 13 dB for the CR-FSS. Conversely, the PR-FSS offers little reduction when the plane wave is horizontally polarized.

3.2. Frequency Selectivity
The forward scatter frequency range Figure 6(a) is comparable to the CR-FSS in [7], where the range of both is 10–18 GHz. The peak reduction occurs at 10.6 GHz, and this slowly decreases as the frequency is increased. This broadband range

Figure 3  The effect of increasing pin separation on the reduction of forward scatter at $\theta_i = 60^\circ$ and $f = 12$ GHz

Figure 4  RCS plot for a vertically polarized plane wave for (a) a CR-FSS and (b) a PR-FSS with $d = 16$ mm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 5  RCS plot for horizontally polarized plane wave for (a) CR-FSS and (b) PR-FSS with $d = 16$ mm. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]

Figure 6  The vertically polarized frequency ranges for the (a) forward scatter at $60^\circ$ and (b) backscatter at $-60^\circ$. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com]
can be tuned to cut out predefined frequencies by altering the period of the pins. For the angle of incidence of 60° and the pin period of 16 mm, the peak backscatter is at the expected 10.8 GHz, as seen in Figure 6(b). As the angle of incidence changes, the peak of this backscatter will shift according to Bragg's Law.

4. CONCLUSION

This letter presents a PR-FSS from a similar comb-based structure that would be installed on a corridor wall to prevent interference between adjacent wireless transmitters. Compared to the CR-FSS in [7], the PR-FSS is only effective for a vertically polarized plane wave. The PR-FSS can offer a 9-dB reduction in forward scatter compared to the 13-dB reduction offered by the CR-FSS, making the PR-FSS an attractive alternative for reduction vertically polarized signals. The PR-FSS offers no reduction for the horizontal polarization. The PR-FSS has a similar frequency range to the CR-FSS, thus is able to offer an effective alternative, with the use of much less material.

ACKNOWLEDGMENT

This work was funded by the EPSRC E-Futures Doctoral Training Centre and British Gas.

REFERENCES

1. B. Sanz-Izquierdo, E.A. Parker, J.-B. Robertson, and J.C. Batchelor, Tuning technique for active FSS arrays, Electron Lett 45 (2009), 1107–1109.
2. M. Rasopoulos and S. Stavrou, Frequency selective buildings through frequency selective surfaces, IEEE Trans Antennas Propag 59 (2011), 2998–3005.
3. L. Subrt and P. Pechac, Intelligent walls as autonomous parts of smart indoor environments, IET Commun 6 (2012), 1004–1010.
4. L. Subrt and P. Pechac, Controlling propagation environments using Intelligent Walls, In: 6th European Conference on Antennas and Propagation (EUCAP), Prague, CZ, 2012, pp. 1–5.
5. M.J. Neve, A.C. Austin, and G.B. Rowe, Electromagnetic engineering for communications in the built environment, In: 6th European Conference on Antennas and Propagation (EUCAP), Prague, CZ, 2012, pp. 26–30.
6. K. Guo and J. Rigelsford, A wireless sensor network for RF characterisation of buildings, In: 7th European Conference on Antennas and Propagation (EUCAP), Gothenburg, SE, 2013, pp. 3517–3518.
7. C.J. Davenport, J.M. Rigelsford, J. Zhang, and H. Altan, Periodic comb reflection frequency selective surface for interference reduction, In: Loughborough Antennas and Propagation Conference (LAPC), Loughborough, UK, 2013.
8. G.I. Kiani, K.L. Ford, K.P. Esselle, A.R. Weily, and C.J. Panagamuwa, Oblique incidence performance of a novel frequency selective surface absorber, IEEE Trans Antennas Propag 55 (2007), 2921–2924.
9. A.R. Chandran, T. Mathew, C.K. Aanandan, P. Mohanan, and K. Vasudevan, Frequency tunable metallo-dielectric structure for backscattering reduction, Electron Lett 40 (2004), 1245–1246.
10. B. Sanz-Izquierdo, E.A. Parker, J.-B. Robertson, and J.C. Batchelor, Tuning patch-fall FSS, Electron Lett 46 (2010), 329–330.
11. E. Dounamis, G. Goussis, G. Papageorgiou, V. Fusco, R. Cahill, D. Linton, Design of engineered reflectors for radar cross section modification, IEEE Trans Antennas Propag 61 (2013), 232–239.
12. F.W.H. Bragg and W.L. Bragg, The structure of the diamond, Proc Royal Soc London Ser A 89 (1913), 277–291.
13. Computer Simulation Technology AG, 2013, Available at http://www.cst.com.

This is an open access article under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited.

© 2014 The Authors. Microwave and Optical Technology Letters Published by Wiley Periodicals, Inc.

A TRIBAND BANDPASS FILTER WITH LOW LOSS AND HIGH BAND SELECTIVITY USING THE SPLIT-END ASYMMETRIC STEPPED IMPEDANCE RESONATORS

Min-Hang Weng,1 Shou-Jinn Chang,2 Wei-Yu Chen,2 Siang-Wen Lan,2 Cheng-Yuan Hung,1 Yi-Hsin Su,3 and Hon-Kuan3

1Department of Medical devices and Optoelectronics Equipment, Metal Industries Research and Development Center, Taiwan
2Department of Electrical Engineering, Institute of Microelectronics, National Cheng Kung University, Tainan, Taiwan
3Department of Electro-Optical Engineering, Southern Taiwan University, Taiwan; Corresponding author: goliro.goliro@msa.hinet.net

Received 8 October 2013

ABSTRACT: In this article, a triband bandpass filter for the applications of global system for mobile communications at 1.8 GHz, WiMAX at 3.5 GHz, and WLAN at 5.2 GHz with low insertion loss and high selectivity is presented. First, the triband passband responses are designed by tuning the length ratio (u) and impedance ratio (R) of asymmetric stepped impedance resonators (SIRs). Second, the band performances are improved by carefully arranging the coupling structure of the SIR. In this design, the split-end asymmetric SIRs are used to provide desired triband performances. Due to the four transmission zeros near the passband edge, the band selectivity of the proposed filter is much improved. The filter was fabricated and the measured results have a good agreement with the full-wave simulated results. © 2014 Wiley Periodicals, Inc.

Microwave Opt Technol Lett 56:1427–1430, 2014; View this article online at wileyonlinelibrary.com. DOI 10.1002/mop.28342

Key words: triband; stepped impedance resonator; bandpass filter

1. INTRODUCTION

Bandpass filter (BPF) is a key component in the radio frequency (RF) front end to achieve the desired and high-performance signals. In recent years, the development of multiservice wireless communication has attracted much interesting. For example, the combination of global position system (GPS) at 1.575 GHz, or global system for mobile communications (GSM) at 0.9/1.8 GHz, or wireless local area networks (WLANs) at 2.4/5.2 GHz or automotive radar system at 8.2 GHz has created more potential [1–4]. Therefore, the design of the multiband BPFs is becoming more important, especially in many commercial communication products.

In the past, the triple-passband BPFs were reported by combining of two or more single-passband filters. However, this method needs a large circuit size and additional external networks. Recently, a triple-passband BPF designed at 1.8/2.4/3 GHz was proposed using two sets of coupled stub-loaded resonators and half wavelength resonators [5]. However, the design procedure is complex. Another triple-passband filter designed at 2.4/3.5/5.25 GHz was achieved using assembled half-wavelength stepped impedance resonator (SIR) and a common half-wavelength resonator [6]. However, too much design parameters are used and the insertion losses are high for the tri-passbands. Thus, the requirements of the circuit designers to design a tri-band filter are to achieve a low insertion loss in the tri-passbands and a good passband selectivity between each band using a more simple design method.

In this article, we propose a triband BPF located at 1.8/3.5/5.2 GHz for applications of GSM, WiMAX, and WLAN. Only two resonators are used to obtain the desired triband of this