Dual-Band Antenna for High Gain M2M Communication Using PRS

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Abstract **─** A bi-layered, dual-band microstrip antenna for high gain Machine-to-Machine (M2M) communication environment is presented in this paper. This antenna covers WiMAX (3.3-3.7 GHz) and WLAN (4.9-5.1 GHz) bands. The radiating patch is printed on Rogers RT/ Duroid 5880 substrate. A partial ground plane is used to enhance the bandwidth of antenna. A Partial Reflecting Surface (PRS) layer is employed below the antenna layer in order to enhance the gain and bandwidth of the antenna. More importantly, the proposed PRS employed antenna provides gain enhancement of 4.3 dB and 4.4 dB at WiMAX and WLAN bands respectively. Simulated and measured results make this arrangement a potential candidate for high gain Machine-to-Machine (M2M) communication.

Index Terms **─** Antenna, M2M, metasurface, Partial Reflecting Surface (PRS), WiMAX, WLAN

I. INTRODUCTION

A rapid growth in the wireless industry has raised the demand of new technologies such as Internet-of-Things (IoT) and Machine-to-Machine (M2M) communication. However, these communication technologies require a platform that allows range of devices to communicate with each other efficiently [1]. In order to achieve a reliable communication link, these machines or devices require antenna systems that can easily provide multiband access using different wireless services such as Wi-Fi, ZigBee, WiMAX and Wireless LAN (WLAN) [2]. Lately IoT/M2M communication has attracted a lot of interest from researchers and is now playing a pivotal role in providing various applications in the areas of e-health, smart homes and intelligent transport systems [3-4]. Typically, a wireless device, to communicate in IoT communication environment, requires compact high gain and multi-band antennas. Microstrip patch antennas are classified as suitable candidates for multiband operation, primarily due to their small size and easy integration characteristics with other electronic circuitry. Traditionally microstrip antennas are fabricated using single layer structures and these patch antennas have certain inherent drawbacks like low gain and narrow bandwidth [5-6]. In order to overcome these limitations, a commonly adopted technique is to employ a multi-layered structure [7-8]. In [7], authors have presented a design of a dual-layered antenna for multiband communication environment. The proposed design however only results in a 2 dB increase in the antenna gain.

For wideband or ultra wideband antennas which adopt the technique of partial ground radiate in the backward direction resulting in the energy loss in the undesired direction. To overcome this loss, a reflector can be added at the backside of antenna, physically placed with a certain separation beneath the partial ground plane. Metamaterials that are typically designed by arranging a set of small apertures in a regular array are employed to improve the performance of antennas in a similar fashion [9-10]. Specialized meta-surfaces known as Partial Reflecting Surfaces (PRS) are reported widely in the existing literature to enhance the gain of antennas [9-12]. A PRS is commonly placed at a distance of $\lambda_0/2$ from the radiating layer. In [9], the reported antenna aims to create a Fabry-Perot (FP) cavity which comprises of a parallel-plates configuration. In [10-11], the distance between PRS and ground plane is reduced up to $\lambda_0/4$ by replacing ground planes by Artificial Magnetic Conductors (AMCs). However, the AMCs do not help significantly in achieving a compact design. A

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PRS is placed below the antenna in [9] but a gain enhancement of only 3 dB is achieved. The antennas reported in [9-11] operate only on single band. Overall, simultaneously achieving enhanced gain, compactness and a multiband functionality is not trivial in multi-layered structures.

This paper presents an antenna design to cater for IoT/M2M applications that require enhanced gain and multiband capabilities. The proposed design arrangement utilizes a PRS layer below the antenna layer to achieve the desired functionalities. The simulated and measured results show good impedance match and enhanced gain on both WiMAX and WLAN bands.

The rest of this paper is structured as follows: in Section II design configuration is presented, whereas simulated results are presented in Section III. An analysis of PRS is presented in Section IV. Finally, Section V concludes the paper.

II. GEOMETRIC CONFIGURATION

The design of the proposed antenna consists of two layers. First layer comprises of the antenna along with ground plane placed on the rear side. This layer is fabricated on Rogers RT/Duroid 5880 substrate ($\varepsilon_r = 2.2, \tan\delta = 0.0009$) of thickness 1.6 mm. The second layer consists of PRS. This layer is also fabricated on Rogers RT/Duroid 5880 substrate. The distance between two layers is kept at $\lambda_0/8$. Layout of the antenna is shown in Fig. 1. A 50-Ω microstrip feed line is employed to excite the antenna. The dimensions of radiating element are $W_P \times L_P$. A triangular taper with a circular slot is employed as an impedance transformer connected to the feedline, to enhance the overall impedance match. As the proposed design is multi-resonant so three slots having dimensions $L_1 \times 2$ mm (slot 1), $L_2 \times 1.5$ mm (slot 2) and $L_3 \times 1.2$ mm (slot 3), respectively, are introduced in the main radiating element as shown in Fig. 2 (a). Distance between slot 1 and slot 2 is W_2, while the distance between slot 2 and slot 3 is W_3. A partial ground plane having dimensions $O_G \times P_G$ is placed on the flip side of antenna.

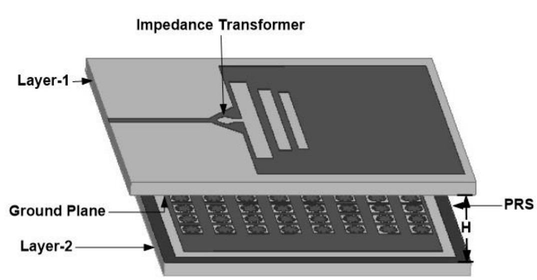
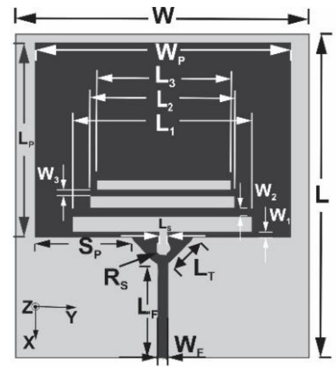
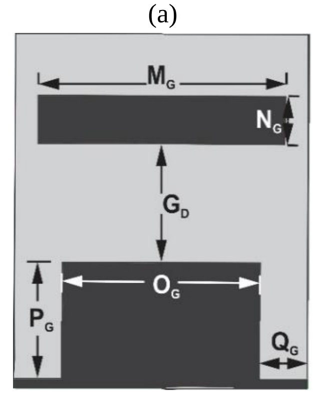


Fig. 1. Layout of the proposed antenna.

In order to enhance the impedance match over the two desired bands, a rectangular parasitic strip with dimensions $M_G \times N_G$ is employed on the flip side of antenna along the partial ground plane. Back view of the antenna layer is shown in the Fig. 2. The optimized antenna design parameters are listed in Table 1.



(a)



(b)

Fig. 2. Geometric configuration of antenna layer: (a) front view and (b) back view.

III. SIMULATED RESULTS

Partially reflecting surfaces (PRSs) are etched on layer 2 of the proposed antenna. The analysis and optimization of these computationally intensive structures is performed using a full-wave Finite Element Method (FEM) based electromagnetic solver (Ansys HFSS™). The whole structure is enclosed in an air box with radiation boundary condition and the antenna is fed through a wave port excitation. In order to get realistic results of simulation, whole structure is simulated at once and no symmetric boundary has been adopted for PRS. This section presents the design architecture and the simulated results.

A. Patch antenna

The technique of etching slots in the patch is employed for size reduction and attaining multi-resonant functionality in the antenna. For this, appropriate selection of position and dimensions of slots is important. The current flow reverses around sides of horizontal slots, which in turn, provides the desired resonances [10]. Effects of three slots on the return loss are shown in Fig. 3.

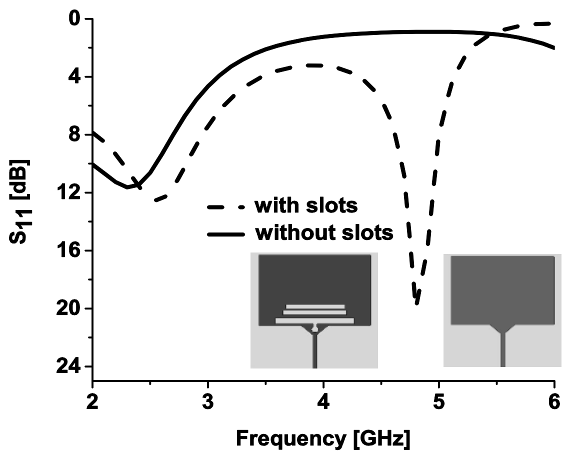


Fig. 3. Simulated return loss of antenna, with and without resonant slots.

Table 1: Parametric values of proposed antenna

Parameter	(mm)	Parameter	(mm)
H	9.66	S_P	11.7
W	35.5	L	1
L	40	L_F	11.8
L_P	24	M_G	30
W_P	30.9	N_G	5.5
L_3	16.3	O_G	24
L_1	21.8	X	0.5
Q_G	5.75	L_2	17.5
W_{PRS}	35.5	T	30
U	29	W_U	2.4
L_{PRS}	35.5	L_U	2.4
P_G	13.2	Y	2
W_F	1.1	R_S	1
W_1	0.6	W_2	1
W_3	0.8	G_D	13.3
L_T	3.1	-	-

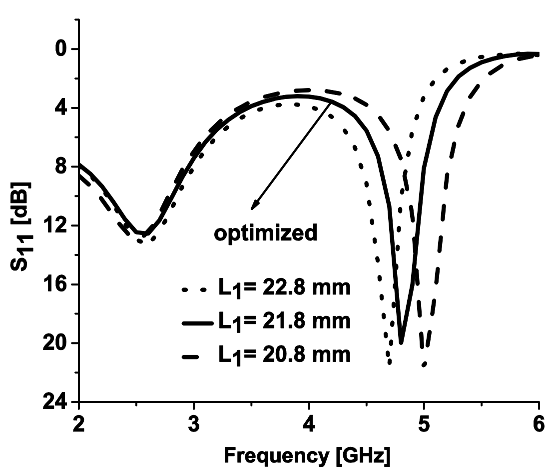


Fig. 4. Effect of slot 1 length variation on WLAN band.

Resonance is created mainly by slot 1 having length L_1 while the following two slots enhance its effect. Lengths of all the three horizontal slots effect the position of resonance at WLAN band. However, this effect can be observed more prominently by varying the length of slot 1 (L_1).

Effects of length variation of slot L_1 on resonance at WLAN is shown in Fig. 4. A triangular region with a circular slot employed as impedance transformer is introduced in the transition region between feed line and main radiating element. This structure is used to enhance the overall impedance match [13].

B. Ground plane

Dimensions of the ground plane effect the excitation mode and the resonance of the antenna. Partial ground plane is used in the proposed antenna as partial ground plane helps to increase the bandwidth of a patch antenna [14]. Figure 5 shows the effects of ground plane dimensions on resonance at WLAN band. It may be observed that the resonance becomes weaker as the width O_G and P_G of the ground plane increases.

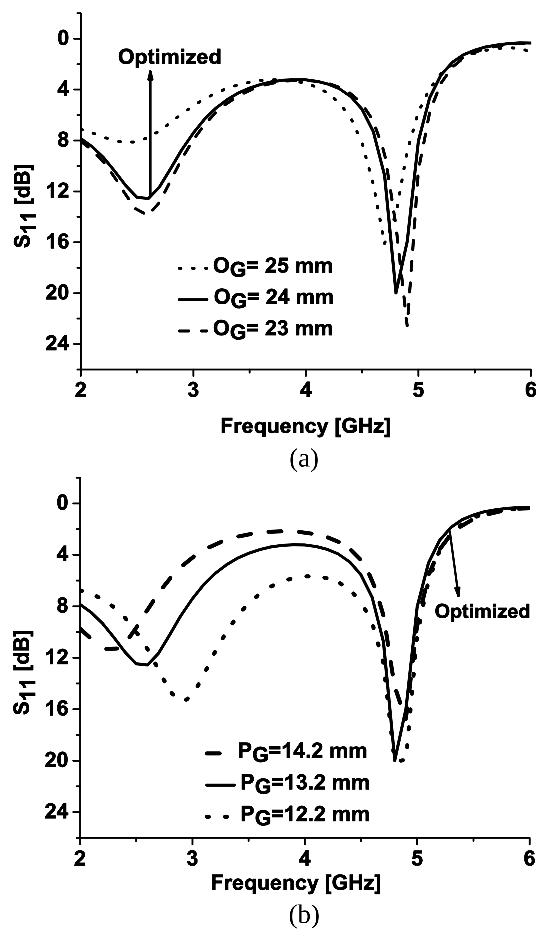


Fig. 5. Effects of ground plane dimensions on resonance at WLAN: (a) effect of width and (b) effect of length.

IV. PARTIAL REFLECTING SURFACE

The proposed PRS consists of an array of eight-point star-shaped patches arranged in a rectangular grid as shown in Fig. 6. The size of rectangular grid is T × U. The overall array size of the PRS is 7 × 8 cells. The overall dimensions of PRS are $L_{PRS} \times S_{PRS}$. Figure 6 illustrates the dimensions of the proposed PRS. To enhance gain at higher frequency, i.e., WLAN, the size of these patches should be small. However, in order to achieve high gain at low frequency, i.e., WiMAX, the size of these patches should be kept larger. Therefore, dimension of the unit cell is optimized to achieve high gain at both resonant frequencies. Optimized dimensions of the PRS unit cell are listed in Table 1.

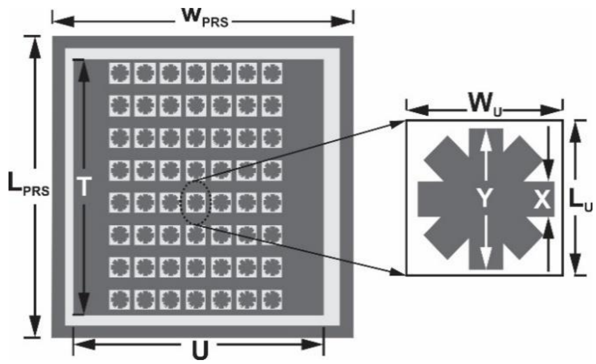


Fig. 6. PRS configuration (PRS and unit cell).

A. Effects of PRS on S-parameter

The PRS-based structure improves the impedance matching at both frequencies, more importantly, at the lower band as shown in the Fig. 7.

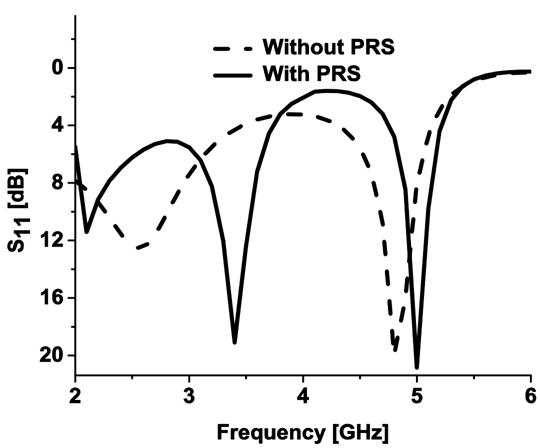


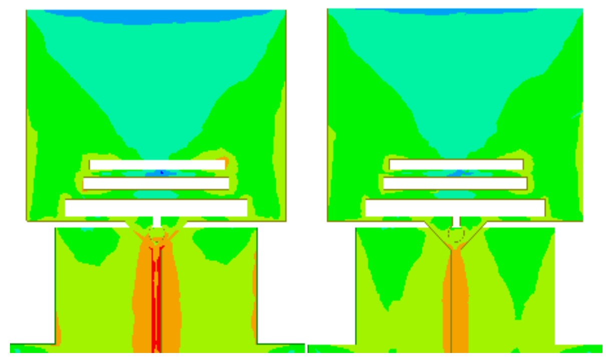
Fig. 7. Simulated effect of PRS on resonances.

B. Effects of PRS on gain

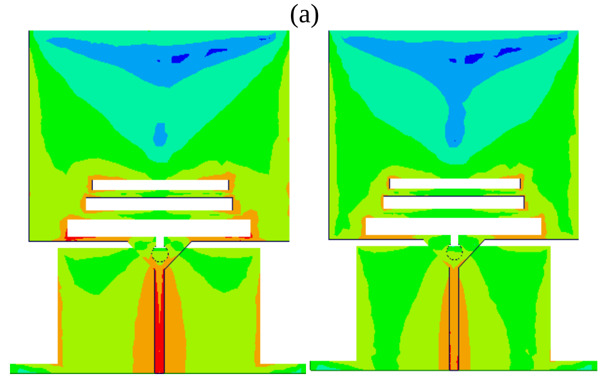
The gain enhancement, results from the electromagnetic coupling or cavity effect initiated between the PRS structure and radiating patch. The PRS significantly enhances the gain at both the desired bands owing to the Fabry-Perot effect as shown in Fig. 8. The gain at 3.5 GHz improves from 2.7 dB to 7 dB and the gain at 5 GHz increase from 3.6 dB to 8 dB.

C. Surface current density

Simulated surface current distributions at resonant frequencies 3.5 and 5 GHz of the proposed antenna, with and without PRS are shown in Fig. 8. It is clear from the figure that at 3.5 GHz current distribution is strong at feedline and ground plane. Current distribution on rectangular patch shows that slot 1 having length L_1 supports the resonating mode at 5 GHz and other two slots help in enhancing its effect.



(a)

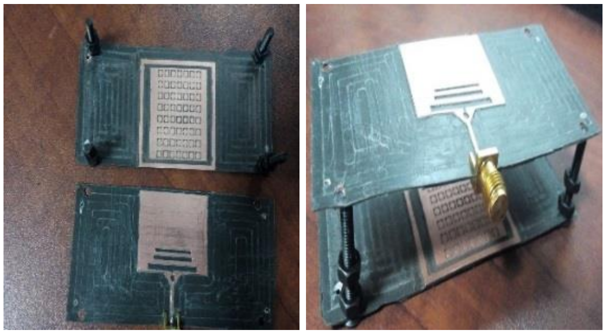


(b)

Fig. 8. Simulated surface current distribution at 3.5 GHz (left) and 5 GHz (right): (a) without PRS and (b) with PRS.

V. MEASURED RESULT ANALYSIS

This section presents an analysis of the measured results of the fabricated antenna. A prototype with optimized dimensions as given in Table 1 is fabricated and tested on Rogers RT/Duroid 5880 substrate, as shown in Fig. 9. The measurements were taken on Agilent N5242A PNA-X network analyzer and radiation patterns were measured using Diamond Engineering pattern measurement setup.



(a) (b)

Fig. 9. Fabricated prototype: (a) Microstrip Patch Antenna (MPA) with PRS and (b) PRS-backed MPA.

A. S-parameter

Measured and simulated return loss of antenna system is shown in Fig. 10. It may be observed that antenna is matched over WiMAX and WLAN bands. There is good agreement between measured and simulated results.

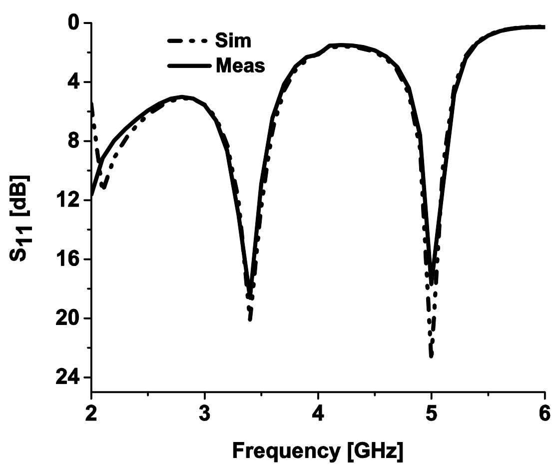


Fig. 10. Simulated and measured return loss of the proposed design.

B. Gain

Measured and simulated gains of the proposed design are shown Fig. 11. It may be observed that the gains at 3.5 and 5 GHz are 5 and 6 dB respectively. A 2-dB difference from the simulated results is due to fabrication and measurement imperfections.

C. Radiation patterns

Measured radiation patterns of the proposed design at 3.5 and 5 GHz with and without PRS are shown in Fig. 12. The antenna has partial ground plane as standard technique to achieve ultra wideband response and consequently the radiation pattern has radiation in both upper and lower direction. The PRS is not backed by a solid ground plane, unlike Artificial Magnetic Conductor (AMC). Thus, it also allows certain radiation to pass through it. It is clear from the figure that proposed PRS-employed antenna exhibits good broadside radiation with a considerable gain.

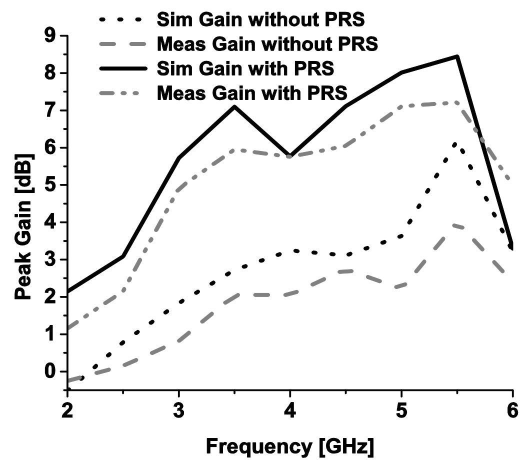
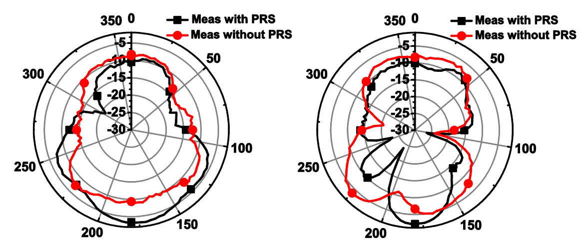
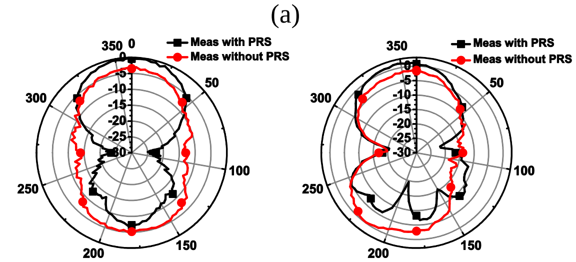


Fig. 11. Simulated and measured gains of antenna with and without PRS.



(a)



(b)

Fig. 12. Measured radiation pattern in E-plane (left) and H-Plane (right) at: (a) 3.5 GHz and (b) 5 GHz.

VI. CONCLUSION

A compact PRS-employed bi-layered, dual-band antenna is presented in this paper which provides high gain at WiMAX and WLAN bands. Slots are introduced in the patch to achieve multiband operation. The PRS layer is placed below the antenna layer to achieve an enhanced gain. The antenna has gains of 7 dB and 8 dB at WiMAX and WLAN bands respectively. Simulated and measured results are in good agreement, suggesting that the antenna is suitable for dual-band high gain applications, for M2M communication and for a wide range of services in e-health, smart cities and intelligent transport systems.

REFERENCES

[1] L. D. Xu, W. He, and S. Li, "Internet of things in industries: A survey," *IEEE Transactions on Indust-rial Informatics*, vol. 10, no. 4, pp. 2233-2243, Nov. 2014.

[2] K. Y. Yazdandoost and R. Miura, "Compact printed multiband antenna for M2M applications," *8th European Conference on Antennas and Propag-ation (EuCAP)*, pp. 2521-2524, 2014.

[3] S. M. R. Islam, D. Kwak, M. H. Kabir, M. Hossain, and K. S. Kwak, "The internet of things for health care: A comprehensive survey," *IEEE Access*, vol. 3, pp. 678-708, 2015.

[4] J. Cheng, M. Zhou, F. Liu, S. Gao, and C. Liu, "Routing in internet of vehicles: A review," *IEEE Transactions on Intelligent Transportation Systems*, vol. 16, no. 5, pp. 2339-2352, 2015.

[5] M. T. Wu and M. L. Chuang, "Multibroadband slotted bow-tie monopole antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 887-890, 2015.

[6] M. Moosazadeh and S. Kharkovsky, "Compact and small planar monopole antenna with symmetrical L- and U-shaped slots for WLAN/WiMAX applica-tions," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 388-391, 2014.

[7] P. S. Bakariya, S. Dwari, M. Sarkar, and M. K. Mandal, "Proximity-coupled microstrip antenna for bluetooth, WiMAX, and WLAN applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 755-758, 2015.

[8] B. Feng, W. An, S. Yin, L. Deng, and S. Li, "Dual-wideband complementary antenna with a dual-layer cross-ME-dipole structure for 2G/3G/LTE/WLAN applications," *IEEE Antennas and Wireless Propag-ation Letters*, vol. 14, pp. 626-629, 2015.

[9] D. Germain, D. Seetharamdoo, S. N. Burokur, and A. de Lustrac, "Phase-compensated metasurface for a conformal microwave antenna," *Applied Physics Letters*, vol. 103, no. 12, pp. 124102, Sep. 2013.

[10] A. P. Feresidis, G. Goussetis, S Wang, and J. C. Vardaxoglou, "Artificial magnetic conductor surfaces and their application to low-profile high-gain planar antennas," *IEEE Transactions on Antennas and Propagation*, vol. 53, no. 1, pp. 209-215, Jan. 2005.

[11] A. Hosseini, F. Capolino, and F. De Flaviis, "Gain enhancement of a V-band antenna using a Fabry-Pérot cavity with a self-sustained all-metal cap with FSS," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 909-921, Mar. 2015.

[12] R. V. S. R. Krishna and R. Kumar, "Slotted ground microstrip antenna with FSS reflector for high-gain horizontal polarization," *Electronics Letters*, vol. 51, no. 8, pp. 599-600, Apr. 2015.

[13] M. Bilal, R. Saleem, M. F. Shafique, and H. A. Khan, "MIMO application UWB antenna doublet incorporating a sinusoidal decoupling structure," *Microw. Opt. Technol. Letters*, vol. 56, no. 7, pp. 1547-1553, Apr. 2014.

[14] R. Saleem, M. Bilal, K. B. Bajwa, and M. F. Shafique, "Eight-element UWB-MIMO array with three distinct isolation mechanisms," *IET Electronics Letters*, vol. 51, no. 4, pp. 311-313, 2015.

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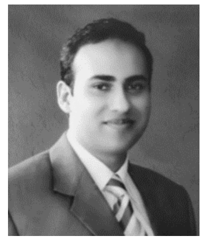

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