www.czasopisma.pan.pl PAN www.journals.pan.pl

jet INTL JOURNAL OF ELECTRONICS AND TELECOMMUNICATIONS, 2019, VOL. 65, NO.2 , PP. 167-174
Manuscript received October 23, 2018; revised April, 2019. DOI: 10.24425/ijet.2019.126297

A Hepta-band Antenna Loaded with E-shaped Slot for S/C/X-band Applications

Imran Khan, Geetha D Devanagavi, Sudhindra K R, Tanweer Ali, Rashmitha R K, Raksha Gunjal

***Abstract*—A compact planar multiband antenna operating at 3.1 (S-band) /4.7/6.4/7.6 (C-band) /8.9/10.4/11.8 GHz (X-band) is presented. The proposed Microstrip Patch Antenna (MSPA) consists of a rectangular radiator in which an E-shaped slot is etched out and a microstrip feed line. The E-shaped slot modifies the total current path thereby making the antenna to operate at seven useful bands. No external impedance matching circuit is used and the impedance matching at these bands are solely achieved by using a rectangular microstrip feed line of length 10mm (L6) and width 2mm (W10). The antenna has a compact dimension of $32 \times 32 \times 1.6\ mm^3$ and exhibits S_{11}<-10dB bandwidth of about 6.45% (3.2-3.0GHz), 8.5% (4.9-4.5GHz), 7.6% (6.7-6.2GHz), 3.9% (7.8-7.5GHz), 5.7% (9.1-8.6GHz), 1.2% (10.44-10.35GHz) and 2.2% (11.87-11.62GHz). The simulation analysis of the antenna is carried out by using HFSS v.13.0.**

***Keywords*—S-band, C-band, X-band, E-shaped slot, current distribution**

I. INTRODUCTION

BEFORE we get into the Microstrip Patch Antenna (MSPA) there are some basic principles of antenna which we should mention. The embracing definition of antenna is that it changes energy from one form to another. There are various types of MSPA presented in the literature; this paper provides a detailed design and simulation of E-shaped slotted MSPA. The study of MSP antenna had a great advancement in the recent times. These are usually manufactured on printed circuit board. These antennas are mostly used in the devices which require the small antenna, leading to the frequencies in the Giga hertz. There are four parts in microstrip antennas; ground, patch, substrate, and feeding part. The advantage of the MSP antenna is low volume, light-weight, low profile, smaller in dimension, easy to fabricate, and planar configuration compatibility with many of the MMIC design, compliance with all most all non – planar structure. Many researches are relatively influenced by the additional features of these MSPA. These may be used in C – band for mobile communication except the aeronautical mobile and in the X -band for satellite application, aviation and space research purpose and also used in the field of WiMAX, medical imaging and radiolocation applications [1-2]. To design a MSPA needs essentials shape, measurements, sustaining and working frequency.

Be that as it may, the most basic essential is assurance of substrate in perspective of the cost, viability and size. Substrates used for MSPA lie between$2.2 \leq \varepsilon_r \leq 12$. Lower the ε_r of dielectric material, greater size of antenna yet achieves better profitability and greater transmission limit as compared to the smaller ones. Antennas outline an imperative bit of advantageous devices like telephones, tablets, workstations and gaming underpins [3]. MSPA contains a dielectric substrate with some relative permeability and permittivity sandwiched between the two conductors (i.e. radiator and ground plane). The notion about the MSPA was originated in 1953, before the practical antennas [4]. MSPA apparatus can be activated by assortment of strategies. These strategies can be characterized into two classifications non-contacting and contacting [5]. MSPA are designed by various feeding techniques such as: -coaxial probe, microstrip line, aperture coupling and proximity coupling. The frequently used feeding technique is the microstrip line because of ease of fabrication and integration. The most important part of MSPA is the ground plane. Due to the fringing effect between the ground and patch the radiation is emerged in MSPA [6]. By utilizing numerous substrate, distinctive thickness of substrate, distinctive states of patch, numerous sizes of patch, completely different feeding procedure, distinctive position of feed a feed line is employed to empower the reception equipment for creating radiation by prompt and deviant contact. [7].

Lately, with the approach of new measures and smaller gadgets, there emerged a requirement for compact multiband antenna, which is being accomplished by different strategy. Out of available data transfer capacity enlargement procedures, cutting slots and indents of various sizes and shapes in the ground plane or in the front patch is for the most part utilized without disquieting the volume of the structure [8]. To improve the Transfer speed (TS) of the MSPA one conceivable technique is the alteration of the width of patch and thickness of the substrate. All things considered, legitimate enhancements should be improved the situation keeping up the coveted focus or full recurrence. As of late, upgrade of the TS has been exhibited by the specialists with the utilization of different outlines including modification of shape and patch [9]. The MSPA apparatuses has request in communication and radar frameworks because of minimal effort, simple to plan, and backings both roundabout and direct polarizations, utilized in extensive Ultra-wideband (UWB) applications [10]. To enhance the gain and operational transfer speed, a successive stage feed

Imran Khan and Geetha D Devanagavi are with School of Electronics and Communication Engineering, REVA university, Bangalore, India (e-mail: imrangce@gmail.com, dgeetha@revainstitution.org)

Sudhindra K R is with Department of Electronics & Communication Engineering, BMSCE, Bangalore, India (e-mail: sudhin77@gmail.com)

Tanweer Ali is with Department of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India (e-mail: tanweer.ali@manipal.edu).

Rashmitha R K and Raksha Gunjal are with Department of Electronics & Communication Engineering, Government Engineering College, Ramanagara, India (e-mail: rashu01996@gmail.com, rakshagunjal97@gmail.com)

*Correspomdance- tanweer.ali@manipal.edu

has been widely utilized for the antenna [11]. Hypothetically, it was demonstrated in many spearheading literary works that the directivity of a customary rectangular patch antenna apparatus is just a component of its electrical width and length. Under the proportionality of a two-opening exhibit, growing the electrical size of patch is by all accounts the main viable approach to upgrade its directivity [12-15].

A. Contributions

The main contributions of this paper are as follows:-

- A compact slotted patch multiband antenna that can be utilized for various applications, such as, S-band (3.1 GHz), C-band (4.7/6.4/7.6 GHz) and X band (8.9/10.4/11.8 GHz), thus satisfying the need of optimum smart antenna technology is proposed.
- The antenna configuration consists of a rectangular radiator with $\frac{\lambda}{4}$ E-shaped slot etched out. The advantage of this slot is that it helps in achieving compactness as well seven operating bands by modifying the surface current path of the radiating patch.
- The microstrip feed line is placed in such a manner that good impedance performances are obtained at the aforementioned seven operating bands.
- The obtained gain from the proposed compact antenna is greater as compared to the antennas presented in [1-21].
- The main advantage of the proposed design is its compact size, planar structure, seven different operating bands, high gain and simple design which make it very efficient to be integrated with various portable wireless handheld devices.

II. Design of Multiband Antenna

The proposed antenna structure is modeled on FR4 substrate (*height =1.6 mm*, $\varepsilon_r = 4.4$ *and* $\delta = 0.02$) with compact size of 32×32 mm^2, as detailed in Fig. 1. The proposed design consists of the ground plane and radiating patch loaded with $\frac{\lambda}{4}$E-shaped slot which are jointly used as a single antenna as shown in Fig. 1. The E-shaped slot is engraved on the front patch (basically a radiator) of the antenna. The E-shaped structure is the elementary structure. The outline procedure of the proposed E-shaped structure is very simple for implementation in different handheld gadgets. The detailed E-shaped slot antenna dimensions are illustrated in Table I. The presentation of this E-shaped slot adjusts the electrical current length path because of which antenna works in multiband mode with the frequencies of 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz. The designed patch antenna is excited by microstrip feed line to achieve good impedance match at the operating bands.

A. Antenna Design Equations

The width and the length of the proposed antenna can be calculated by the following design equations

$$W = \frac{\lambda_o}{f_o\sqrt{(\varepsilon_r+1)/2}} \quad (1)$$

$$\varepsilon_{reff} = \frac{(\varepsilon_r+1)}{2} + \frac{(\varepsilon_r-1)}{2}[1+12\frac{h}{w}]^{-1/2} \quad (2)$$

$$L = \frac{\lambda_o}{f_o\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \quad (4)$$

B. Design Methodology

The proposed antenna design and its detailed dimensional layouts are illustrated in Fig. 1 and Table I respectively. The antenna consists of a rectangular patch($L1 \times W1$) in which an $\frac{\lambda}{4}$ E-shaped slot ($L3 \times W3 \times W7 \times L5$) is etched out. The overall impedance match is provided by microstrip feed line ($L6 \times W10$) using lumped port excitation. The design and the structure of the proposed antenna are intended to be used for S-band (3.1 GHz), C-band (4.7/6.4/7.6 GHz) and X-band (8.9/10.4/11.8 GHz) applications.

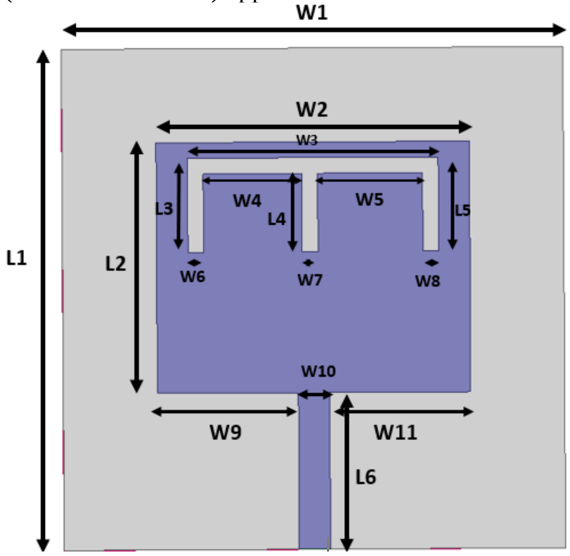

Fig. 1. Physical layout of the proposed antenna

TABLE I
DIMENSIONAL DETAILS OF THE PROPOSED DESIGN

PARAMETERS	DIMENSIONS (mm)
L1	32
W1	32
L2	16
W2	20
L3	6
W3	16
L4	5
W4	6.3
L5	6
W5	6.7
L6	10
W6	1
W7	1
W8	1
W9	9
W10	2
W11	9

C. Analysis of the proposed Antenna

The analysis of different slot structures are carried out before finalizing the proposed $\frac{\lambda}{4}$E-shaped as presented in Fig. 2.Correspondingly, the S_{11} values of these analyses are presented in Fig. 3. First a simple rectangular slot is etched out in the radiating patch which makes the “Design 1” (Fig. 2) to operate at 3.8/6.6/9.0 GHz (Fig. 3). Further modification of this slot in to L-shaped slot (i.e. "Design 2", Fig. 2) makes the antenna to operate at 3/6.4/7.3/8.5 GHz (Fig. 3). Modification of L-shaped slot in to F-shaped slot ("Design 3", Fig. 2) disturbs the current path of the radiator as a result of which antenna in "Design 3" operates at 3.6/6.5 GHz (Fig. 3). Finally, to obtain more no multiple bands we lastly optimize the F-shaped slot to E-shaped slot (i.e. proposed "Design 4", Fig. 2). This modification further affects the surface electrical current path and thus making the antenna to finally operate at 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz, as depicted in Fig. 3.

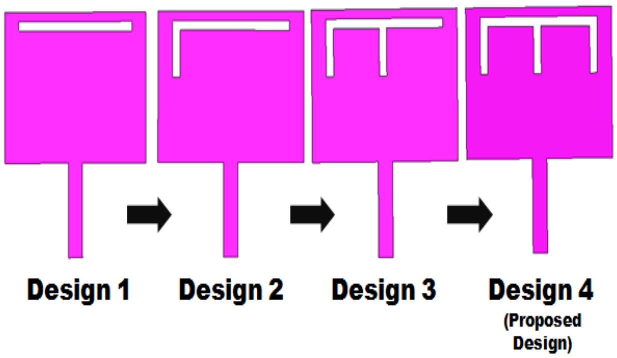

Fig. 2. Evolution steps of the proposed antenna structure.

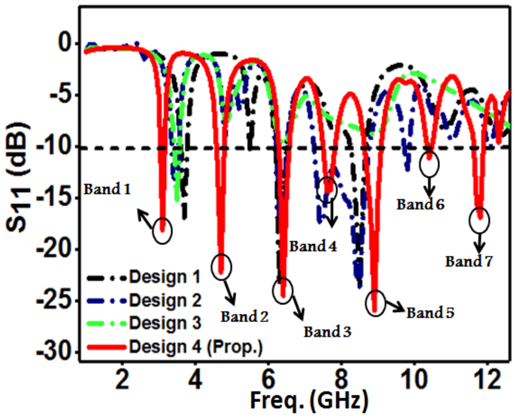

Fig. 3. Evolution design variation of S_{11} results

D.Parametric Analysis

So as to investigate the operational execution of the proposed Hepta (seven) band antenna with the changes in the optimized measurements, its parametric examinations are completed as outlined in Fig. 4. These parametric examinations are analyzed in three conditions, they are: - (1) changes in length L3, (2) changes in length L5 and (3) changes in length L4 of the E-shaped slot. The investigations of the slots present in the radiating patch are done in detail to demonstrate its impact on the impedance coordinating of the multiband MSPA. All the investigations are accomplished by changing L3, L4 and L5, while keeping other measurements unchanged. For the conditions, (1) and (2) length L3 and L5 is shifted from 5 to 7mm at a stage of 1 mm, as represented in Fig. 4(a) and (b). It very well may be seen that when L3 and L5=5 and 7 mm, the band at 10.4 GHz is lost. In this way for best impedance coordinating at all the frequencies the length of L3 and L5=6mm is picked as the optimized dimensions. Fig. 4(c) indicates the parametric variation of L4 in which the length of L4=5mm provides better impedance matching when compared to L4=4 and 6mm, hence L4=5mm is taken as optimized dimension.

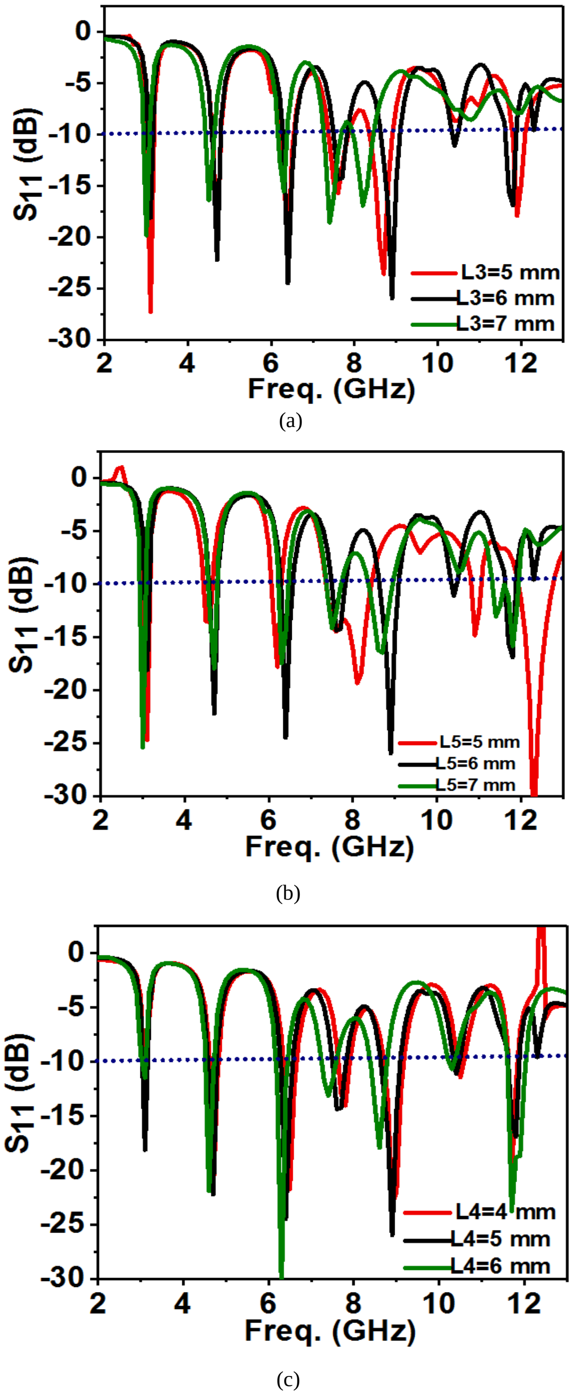

Fig. 4. Parametric study of (a) L3, (b) L5 and (c) L4

III. Results

The simulation of the antenna design structure outlined in Fig. 1 is carried out by using HFSS v.13.0 on widely and available low cost FR4 substrate with ε_r of 4.4 and height of 1.6mm. The estimated S_{11} (reflection coefficient) of the proposed design is illustrated in Fig.5. It is clearly observed that antenna shows multiband operation in which the 1st resonance is observed at 3.1GHz and 7th resonance is observed at 11.8GHz. The simulated-10dB impedance bandwidth of the antenna at 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz are 200/400/500/300/450/ 100/250 MHz respectively. The accomplished bandwidth is adequate to meet the necessity of S-band (3.1 GHz), C-band (4.7/6.4/7.6 GHz) and X-band (8.9/10.4/11.8 GHz) applications.

A. VSWR and Input Impedance

The VSWR (voltage standing wave ratio) of the proposed antenna design structure is presented in Fig. 6. It is clearly noticed that the antenna has required VSWR values of 1.28/1.16/1.12/1.47/1.10/1.76/1.33 for all the resonating frequencies 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz, respectively.

The input impedance of the antenna is presented in Fig. 7. The antenna has an input impedance of (64+1.7j),(55+6.3j),(53+5.2j),(69-12.2j),(48-4.8j),(30-10.4j) and(58+12.8j) at the operating frequencies of 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz, respectively.

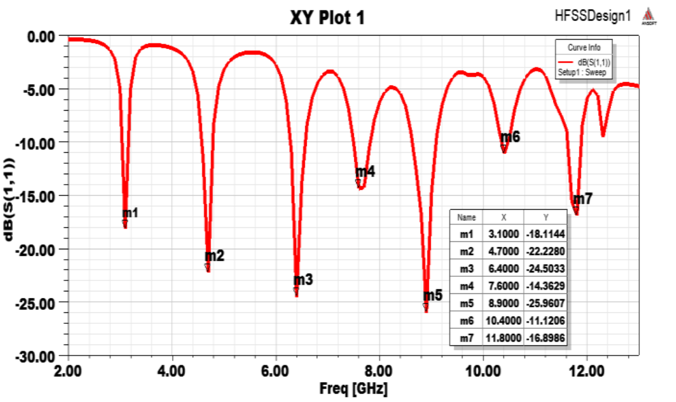

Fig. 5. Simulated S_{11} (reflection coefficient) of the proposed design

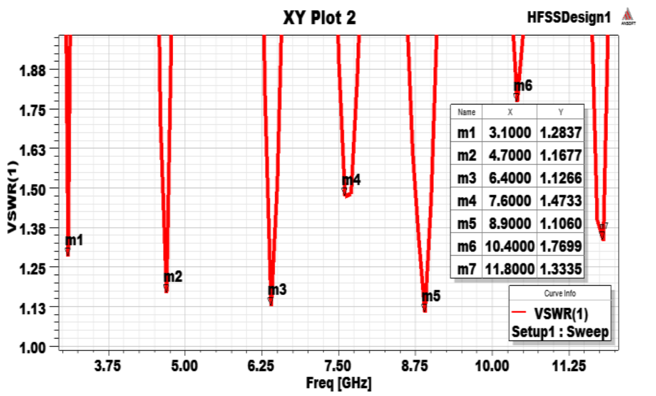

Fig. 6. VSWR plot of the proposed antenna

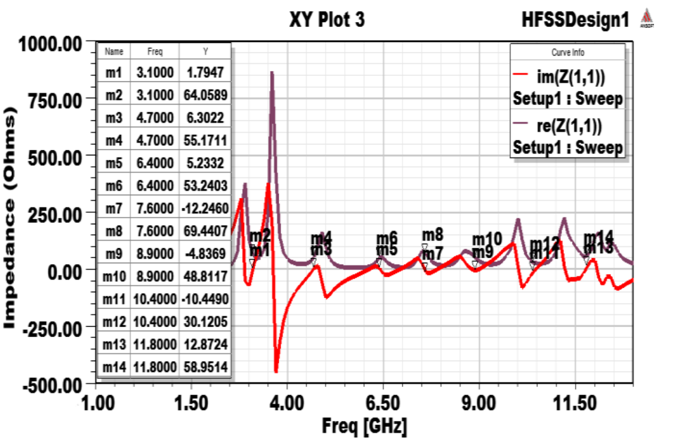

Fig. 7. Simulated input impedance

B. Current Distributions

The current distributions at the surface of the antenna at the different operating frequencies are illustrated in Fig. 8. For band 1 (3.1 GHz) maximum current distribution is observed at the edges of the E-shape slot. Similarly, for the remaining bands the different part of the antenna structure and E-shaped slots have a corresponding resonant path length.

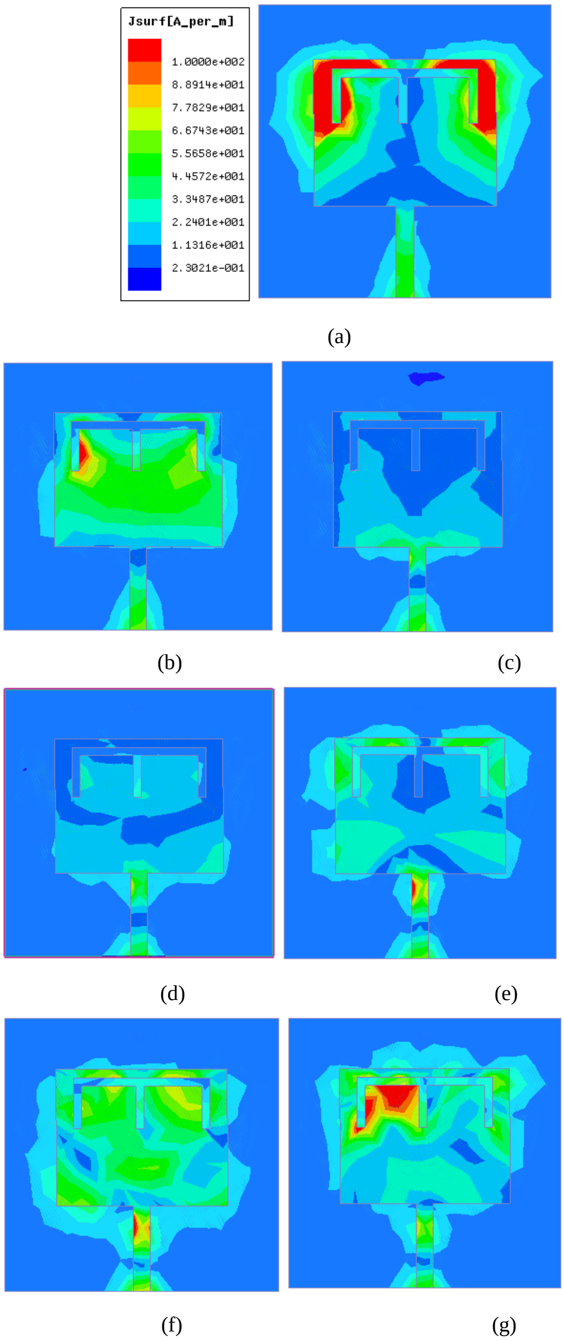

Fig. 8. Distribution of surface Current at (a) 3.1, (b) 4.7, (c) 6.4, (d) 7.6, (e) 8.9, (f) 10.4 and (g) 11.8 GHz

C. Gain

The 3D gain plots of the proposed design are illustrated in Fig. 9. It can be noticed that the antenna has an excellent gain at all the resonant bands even though it has a compact size. At 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz a gain of about 4.54/5.97/3.46/2.41/6.51/4.14/ 6.51 dB are obtained respectively.

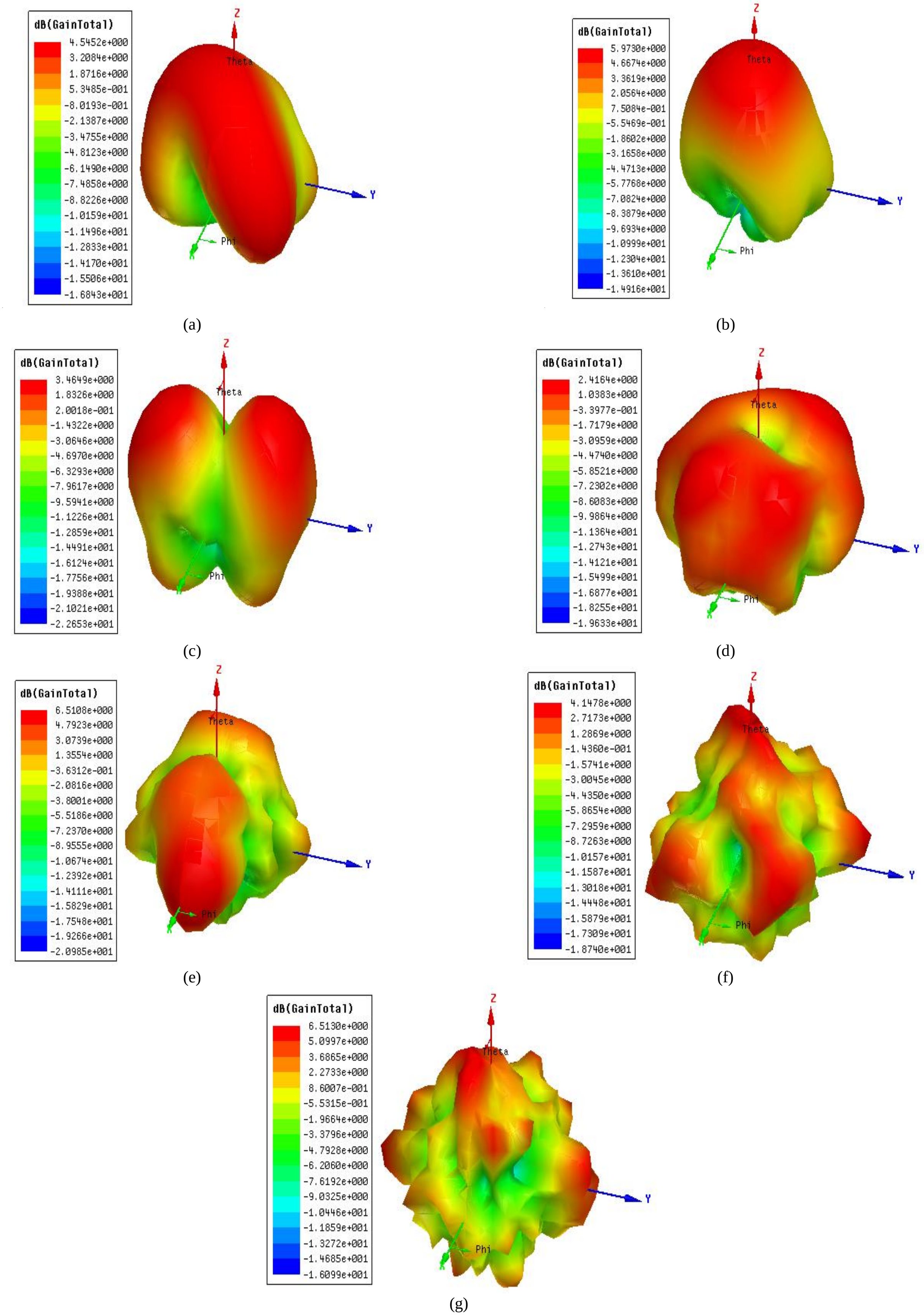

Fig. 9. Simulated at (a) 3.1, (b) 4.7, (c) 6.4, (d) 7.6, (e) 8.9,(f) 10.4 and (g) 11.8 GHz

D. Radiation Pattern

The radiation pattern for the proposed antenna for condition Phi=0^0 and 90^0 for all the resonating frequency bands are presented in Fig.10. It can be analyzed that for Ø=90^0 antenna shows omnidirectional pattern and for Ø=0^0 it shows almost bidirectional pattern.

To show the advantage of the proposed antenna with those similar types available in the literature a comparison is made and is presented in Table II. From the table it can be clearly studied that the proposed design has greater advantage in terms of size, number of operating bands, and bandwidth over its counterparts.

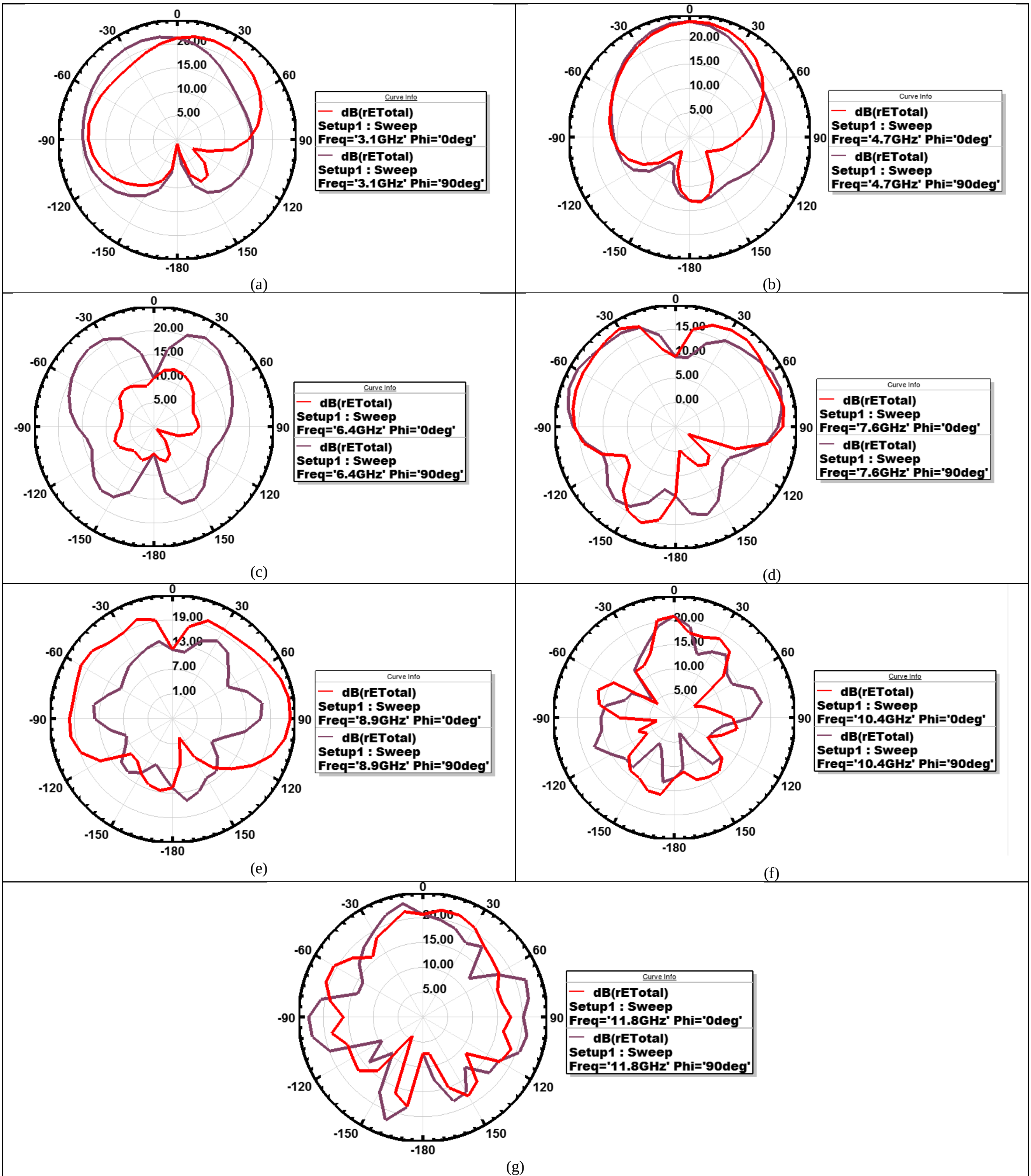

Fig. 10. Simulated radiation pattern at (a) 3.1, (b) 4.7, (c) 6.4, (d) 7.6, (e) 8.9, (f) 10.4 and (g) 11.8 GHz

TABLE II
COMPARATIVE ANALYSIS OF THE PROPOSED CONFIGURATION

Ref.	Size (mm^2)	No. of Bands	Freq. of Operation (GHz)	% BW	Appl.
[14]	20 × 20	2	2.4/5.45	18.2/2.8	Lower/Upper Wi-Fi
[16]	9 × 8	2	2.95/5.23	--	WLAN
[17]	29 × 32	3	2.4/3.5/5.8	13.7/10.09/5.09	WiMAX/ WLAN
[18]	9 × 12	3	2.5/3.4/5.7	6.45/3.03/5.9	WiMAX/ WLAN
[19]	28 × 30	4	1.6/2.5/5.8/9.8	11.1/10.5/5.2/9.3	GNSS/WLAN/Wi-MAX/X-band
[20]	27 × 29	4	1.5/2.4/3.5/5.2	6.06/8.33/5.5/5.94	GPS/ WiMAX/ WLAN
[21]	40 × 35	5	2.4/2.7/4.7/5.6/8.8	4.1/5.7/10.25/6.2/2.3	WLAN/Wi-MAX/C-band/X-band
Prop	32 × 32	7	3.1/4.7/6.4/7.6/8.9/10.4/11.8	6.5/8.5/7.6/3.9/5.7/1.2/2.2	WiMAX/ WLAN/ C-band / X-band

IV. CONCLUSION

This research presents a compact slotted MSPA loaded with E-shaped slot with seven frequency bands (i.e. 3.1/4.7/6.4/7.6/8.9/10.4/11.8 GHz). It utilizes an $\frac{\lambda}{4}$ E-shaped slot that makes the antenna to radiate in seven bands. Parametric investigation demonstrates that the slight change in the dimension of E-shaped slot influences the surface current dispersion of the patch which thus influences the operating frequencies of the MSPA. The antenna has a tuning range of 6.45% (3.2-3.0GHz), 8.5% (4.9-4.5GHz), 7.6% (6.7-6.2GHz), 3.9% (7.8-7.5GHz), 5.7% (9.1-8.6GHz), 1.2% (10.44-10.35GHz) and 2.2% (11.87-11.62GHz) with the gain of 4.38/5.98/3.48/2.41/6.51/4.14/6.51 dB at the operating frequencies 3.1/4.7/6.4/7.6/8.9/10.4 and 11.8 GHz, respectively under simulation. The proposed configuration produces better outcomes as far as gain, radiation pattern, VSWR is in the scope of 1– 2, great reflection coefficient and impedance coordinating for all the frequency bands. Also, it is easy to plan and fabricate. Future work includes the integration of the proposed MSPA with metamaterial (especially split ring resonator) keeping in mind the end goal to make the antenna more compact. Good impedance matching, acceptable radiation performances and good gain makes the proposed configuration an attractive candidate for S-band, C-band and X-band applications.

V. REFERENCES

[1] Kaushal, D., Shanmuganantham, T., & Sajith, K. (2017, July). Dua1 band characteristics in a microstrip rectangular patch antenna using Novel slotting technique. In Intelligent Computing, Instrumentation and Control Technologies (ICICICT), 2017 International Conference on (pp. 957-960). IEEE.

[2] Jose, J. V., &Rekh, A. S. (2017, February). Emerging trends in high gain antennas for wireless communication. In Innovations in Electrical, Electronics, Instrumentation and Media Technology (ICEEIMT), 2017 International Conference on (pp. 334-336). IEEE.

[3] Ali, T., & Biradar, R. C. (2017). A miniaturized Volkswagen logo UWB antenna with slotted ground structure and metamaterial for GPS, WiMAX and WLAN applications. *Progress In Electromagnetics Research*, *72*, 29-41.

[4] Ansari, N. F., & Mishra, R. (2017, September). 1× 1 Rectangular patch antenna. In *2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI)* (pp. 2656-2558). IEEE.

[5] Constantine A. Balanis; Antenna Theory, Analysis and Design, John Wiley & Sons Inc. 2nd edition. 1997.

[6] Rahman, S. U., Cao, Q., Hussain, I., Khalil, H., Zeeshan, M., & Nazar, W. (2017, May). Design of rectangular patch antenna array for 5G wireless communication. In *Progress In Electromagnetics Research Symposium-Spring (PIERS), 2017*(pp. 1558-1562). IEEE.

[7] Abdullah-Al-Mamun, M., Datto, S., & Rahman, M. S. (2017, December). Performance Analysis of Rectangular, Circular and Elliptical Shape Microstrip Patch Antenna using Coaxial Probe Feed. In *2017 2nd International Conference on Electrical & Electronic Engineering (ICEEE)* (pp. 1-4). IEEE..

[8] Singh, G., Kumar, M., Saxena, R., & Ansari, J. A. (2017, August). Bandwidth analysis of boomerang slot rectangular microstrip patch antenna. In *Telecommunication and Networks (TEL-NET), 2017 2nd International Conference on* (pp. 1-5). IEEE.

[9] Nayna, T. F. A., Ahmed, F., & Haque, E. (2017, March). Bandwidth enhancement of a rectangular patch antenna in X band by introducing diamond shaped slot and ring in patch and defected ground structure. In *Wireless Communications, Signal Processing and Networking (WiSPNET), 2017 International Conference on* (pp. 2512-2516). IEEE.

[10] Sri, P. A. V., Yasasvini, N., Anjum, M., Manikanta, A. V., Harsha, D. N. S. S., Dattatreya, G., & Naik, K. K. (2017, April). Analysis of wideband circular ring with rectangular patch antenna for airborne radar application. In *Electronics, Communication and Aerospace Technology (ICECA), 2017 International conference of* (Vol. 1, pp. 459-461). IEEE.

[11] Ta, Son Xuat, and Ikmo Park. "Compact wideband circularly polarized patch antenna array using metasurface." IEEE Antennas Wireless Propag. Lett. 16 (2017): 1932-1935.

[12] Zhang, Xiao, and Lei Zhu. "Gain-enhanced patch antenna without enlarged size via loading of slot and shorting pins." IEEE Transactions on Antennas and Propagation 65.11 (2017): 5702-5709.

[13] Jin, Jun Ye, Shaowei Liao, and Quan Xue. "Design of Filtering-Radiating Patch Antennas With Tunable Radiation Nulls for High Selectivity." IEEE Transactions on Antennas and Propagation 66.4 (2018): 2125-2130.

[14] Imran Khan, Geetha D, Sudhindra K R, Tanweer Ali and R C Biradar. "A Frequency Reconfigurable Antenna loaded with H-shaped Radiators for WLAN/WiMAX Applications".International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 10 (2018) pp. 8583-8587 © Research India Publications.

[15] Song, Lingnan, and Yahya Rahmat-Samii. "A Systematic Investigation of Rectangular Patch Antenna Bending Effects for Wearable Applications." IEEE Transactions on Antennas and Propagation 66.5 (2018): 2219-2228.

[16] Ali, T., Mohammad, S. A., & Biradar, R. C. (2017, May). A novel metamaterial rectangular CSRR with pass band characteristics at 2.95 and 5.23 GHz. In Recent Trends in Electronics, Information & Communication Technology (RTEICT), 2017 2nd IEEE International Conference on (pp. 256-260). IEEE

[17] Ali, T., & Biradar, R. (2017). A compact multiband antenna using λ/4 rectangular stub loaded with metamaterial for IEEE 802.11 N and IEEE 802.16 E. Microwave and Optical Technology Letters, 59(5), 1000-1006.

[18] Ali, T., & Biradar, R. C. (2018). A triple-band highly miniaturized antenna for WiMAX/WLAN applications. Microwave and Optical Technology Letters, 60(2), 466-471.

[19] Ali, T., Khaleeq, M. M., & Biradar, R. C. (2018). A multiband reconfigurable slot antenna for wireless applications. AEU-International Journal of Electronics and Communications, 84, 273-280.

[20] Ali, T., Khaleeq, M. M., Pathan, S., & Biradar, R. C. (2018). A multiband antenna loaded with metamaterial and slots for GPS/WLAN/WiMAX applications. Microwave and Optical Technology Letters, 60(1), 79-85.

[21] Ali, T., Saadh, A. M., Biradar, R. C., Anguera, J., & Andújar, A. (2017). A miniaturized metamaterial slot antenna for wireless applications. AEU-International Journal of Electronics and Communications, 82, 368-382.