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Research paper

Design and fabrication of a dual band 1.8/2.5 GHZ antenna for RF energy harvester

Jahariah Sampe [1] *, Noor Hidayah Mohd Yunus [1, 2], Jumril Yunas [1], Alipah Pawi [2], Zeti Akma Rhazali [3]

[1] *Institute of Micro engineering and Nano electronics, University Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia*
[2] *Communication Technology Section, University Kuala Lumpur British Malaysian Institute, Batu 8 Sungai Pusu, 53100 Gombak, Selanguor, Malaysia*
[3] *Department of Electronics and Communication Engineering, University Tenaga Nasional, Jalan UNITEN-IKRAM, 43900 Kajang, Selangor, Malaysia*
**Corresponding author E-mail: jahariah@ukm.edu.my*

Abstract

This paper proposes a patch antenna that integrated with the RF energy harvester system. The research goal is to propose a slotted and shorted pin patch antenna, which offers a promising solution for efficient dual band RF receiver. A high gain and directivity parameter is desired to reach the goal as it defines the strength of an antenna in capturing more energy and to maximize the transferred power towards the harvesting system. The fabricated antenna on RT/Duroid 5880 is measured to evaluate the simulated results by CST-MWS. The measure-ment is carried in an anechoic chamber. The measured dual antenna gain is 2.29 dBi and 5.51 dBi at 1.8 GHz and 2.5 GHz band, respective-ly. The gain obtained by the proposed antenna is higher compared to the previous patch antenna designs in the frequency range of 1 to 3 GHz, with reasonable matching parameter. The antenna meets the acceptable specifications in the bandwidth range of 0.1 to 2.45 GHz, ex-hibit top omnidirectional pattern, the VSWR < 2 and the directivity > 7 dBi across the dual band. Thus, the proposed antenna is good enough to be adopted with the RF energy harvester.

Keywords: *RF Energy Harvesting; Dual Band; High Antenna Gain; Rectangular Patch Antenna; Far Field*.

1. Introduction

Vast amount of radio frequency (RF) energy is spread over numerous frequency bands based on their application. It is possible to receive RF energy in combined form and transferred into electrical energy [1]. RF energy harvesting is the technique developed to derive energy from external RF energy sources and convert into useful electrical power [1-5]. Since an ultra-low amount of energy resources from as much as 1 μW/cm2 in energy harvesting, the energy harvested is restricted can be exploited only for battery-less electronic devices such as remote control, wearable devices, structural health monitoring, Internet of Things (IoT), wireless applications, etc. [1-11]. RF energy sources are received from various frequency bands such as from global system mobile-communication (GSM - 850, 900, 1800, 1900 MHz) [1, 2, 11], WiMAX internet service providers (2.3, 2.5, 2.6, 3.5, 5.5 GHz) [12], wireless local area network (WLAN) at 2.4, 5.2, 5.8 GHz [12], technology devices wireless LAN (WiFi) in IEEE 802.11 standard (2.45, 5 GHz) [2, 13] etc.

The RF energy harvesting system includes antenna, impedance matching circuit and power rectifying circuit. The general structure of the RF energy harvester is shown in Fig. 1. This paper focuses on the antenna device. An antenna is a key important device in the front end of the RF energy harvester system since its affect the quantity of energy harvested [13]. An antenna is also the main component used to receive the incoming RF energy of various frequencies. Several features of the conventional antennas are outsized and protrude from a surface [14]. Salient features, including low profile, ease of integration and compact application of antenna are important for RF energy harvester adopted in mobile wireless applications. In response to the need, the microstrip patch antenna (MPA) is developed.

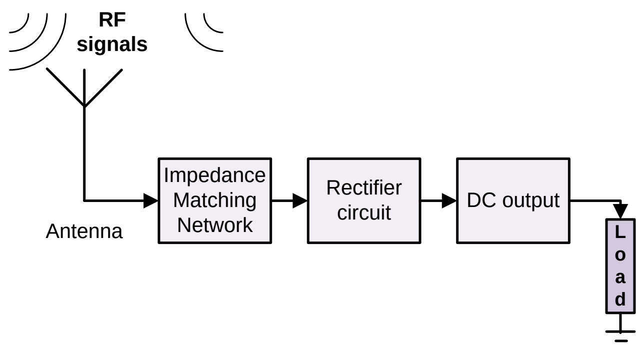

Fig. 1: RF Energy Harvesting System.

A MPA is mechanically rugged, can be fabricated on a plane surface, can be designed and shaped to adapt the curving casing of a vehicle which often mounted on the aircraft body and can be incorporated into electronic devices. Any MPA shapes such as circular, elliptical, triangle, oval, rectangular, etc are possible to be created. Among these shapes, the rectangular shape of MPA is broadly used and it is have been proposed here. MPA radiates a linearly polarized travelling wave and quite efficiently operate over a narrow bandwidth operation [15].

However, the performance specifications cannot be met by only the basic MPA structure. Substrate materials, thickness and features such as slots in patch, parasitic patches or shorting pins have to be considered [4], [6-15]. There are lots of research in MPA apertures, including rectangular patch [4, 5, 7, 8], circular microstrip patch [6], dual-band operation [9], slotted ring [10], multiport pixel [11] and triple-band operation [12] to achieve variation applications and goals. Its planar profile and rugged of the MPA can be created using printed circuit technology and integrated with circuit components has been found as an attractive feature in various applications.

The idea of energy harvesting concept has taken consideration in an approach for designing an efficient MPA to capture a maximum level of low power RF input from the surroundings. Effective dimensions of MPA are proposed to incorporate the ultra-low power input source, accordingly high antenna gain parameter is produced. Here the RF energy harvesting for targeted transferring power applications, a high antenna gain and a high directivity parameters are desired for the MPA to radiate more energy in all angles and to optimize power transfer as well as to decrease any signal from unwanted angles, respectively.

In literature, the operating frequencies used are mostly based on high frequency ranges in order to achieve maximum gain [7], [12-13], [16-19]. Here, this paper proposed a MPA of RF energy harvester operating at 1.8 GHz from global radio application and 2.5 GHz from WiMAX application. It is considered operating at (less than 3 GHz) low microwave frequencies than the previous literature, besides to take the challenge in producing high antenna gain, high directivity and moderate physical size. To establish the performance parameter, U slot on the radiator patch and defected ground plane is designed to increase the current distributions that correspond to the desired dual operating frequencies. The physical size reduction of the proposed MPA is performed by shorted patch in which locating a single shorting pin to the feed point. The proposed MPA is desired also in the structure flexibility for extra receptive of the RF input sources.

In order to characterize the MPA, the transmission line model is used to estimate the geometric dimension of the MPA at the desired dual band operation which is presented in the following section. The radiation pattern of the fabricated MPA is measured to evaluate the parameter performance. Finally, concluding remarks of the RT/Duroid-based MPA is presented.

2. Antenna design

The fundamental purpose of this research is to develop a receiving MPA for RF energy harvesting of mobile wireless applications. The proposed design is simulated and optimized by Computer Simulation Technology-Microwave Studio (CST-MWS). Simulation conducted based on a 50 Ω port impedance of a transmission line feed on the lossy material. In order to evaluate the results, the fabricated antenna is measured. The copper patch is fabricated on standard RT/Duroid 5880 substrate with important specifications of dielectric constant Ɛr = 2.20, dissipation factor tan δ = 0.0009, substrate thickness = 1.57 mm and copper thickness = 17.5 µm. A low dissipation factor of the RT/Duroid 5880 substrate has contributed to a low dielectric loss value of the fabricated antenna.

The detail specifications (dimension in mm unit) of the proposed MPA is shown in Table 1. The dimensions of the proposed MPA are calculated based on the given formula guide as in Equation (1-5) [4], [16], [20]. The substrate material and thickness that have been selected determines the length L and width W dimension of the MPA.

In this paper, the design formula from the transmission line model is utilized for designing a single band frequency. Here, the single frequency band operating at 1.8 GHz is calculated from the model. The model offers good physical insight, but less precise as the approximate of the antenna dimension calculation formula used. Then a U-slot is etched inside the patch to obtain another frequency operating at 2.5 GHz with reasonable return loss and gain parameter values. Some of the specification dimension values are varied and optimized in order to obtain the desired dual operating frequencies. Optimization of the MPA by frequency operation properties in return loss parameter grid is performed by adjusting the dimension values using parametric sweep in CST- MWS.

Table 1: Design Specifications of the Proposed MPA

Specifications	Unit (mm)
Length of the rectangular patch (ℓ)	39.2
Width of the rectangular patch (w)	40.1
Patch thickness (hp)	0.0175
Substrate thickness (hs)	1.57
Ground thickness (hg)	0.0175
Length of the horizontal slot cut (Lh)	4.18
Length of the vertical slot cut (Lv)	6.2
Width of the slot cut (ws)	1.3
Length of the notch (ℓn)	18.1
Width of the notch (wn)	6.3
Length of the strip line (ℓsl)	30.2
Width of the strip line (wsl)	2.1
Gap of the patch feed (Gpf)	2.1
Feed point (x0, y0)	(0, -1.665)

$$W = \frac{c}{2f\sqrt{\frac{\varepsilon_r + 1}{2}}} \tag{1}$$

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{2}(\varepsilon_r - 1)\left[\frac{1}{\sqrt{1 + 12\left(\frac{h}{W}\right)}}\right] \tag{2}$$

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right) \tag{3}$$

$$\Delta L = 0.412h\left(\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)}\right) \tag{4}$$

$$L = \frac{c}{2f\sqrt{\varepsilon_{eff}}} - 2\Delta L \tag{5}$$

Preliminary design specification of a rectangular MPA is resonating in a single band frequency. Dual-band, triple-band and multi-band rectangular MPA can be obtained by choosing the slot dimensions inside the patch appropriately [19]. Thus, this section is introduced on the U-slot MPA; yield in a dual-band resonances. The geometry of the proposed rectangular MPA with U-slot and the fabricated prototype are shown in Fig. 2. The proposed MPA consists of rectangular microstrip line feed, notches and loaded with U-slot. The U-slot consists of one vertical rectangular slot and two parallel horizontal rectangular slots.

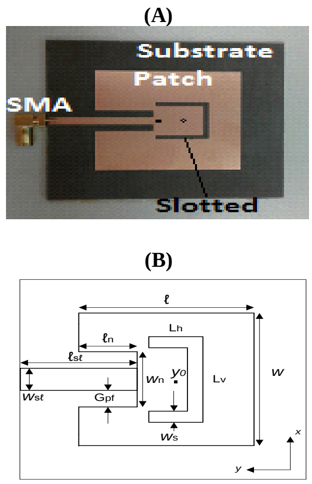

Fig. 2: The A) Fabricated and B) Geometry Layout of the Proposed Design.

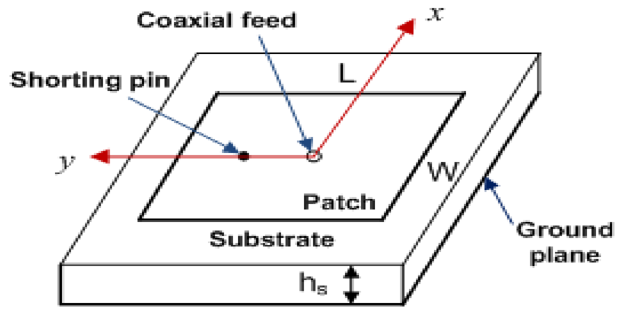

Fig. 3: Shorting Pin Loaded Configuration.

Here by introducing a shorting pin in the patch, the physical size reduction of the MPA has been achieved. A good impedance matching for the dual band frequencies are also achievable. The overall physical size, 63.4 x 60.5 mm2 of the MPA meets the requirement of the RF energy harvester system. The proposed MPA with a single shorting pin is as shown in Fig. 3. The configuration consists of a radiator patch, a shorting pin and a coaxial feed connector that analyzed by transmission line model [15].
Details analysis results are provided in the following section.

3. Result and discussion

Measurement of the radiation characteristics is initially obtained by Agilent network analyzer. Then the final measurements of the MPA parameters are conducted on an indoor far field ranges in the anechoic chamber. The return loss plots of the simulated and measured MPA are shown in Fig. 4.
The measured and simulated results are in a good agreement of the first operating band at 1.8 GHz. The return loss of less than -10 dB has described perfect impedance matching properties of the proposed MPA. It can be observed that the return loss value is lesser than -12 dB at 1.8 GHz and 2.5 GHz bands. The -10 dB bandwidth is calculated based on the parameter guide of less than -10 dB values of the return loss S11 parameter and less than 2 of the voltage standing wave ratio (VSWR) parameter. The -10 dB bandwidth formula is calculated based on Equation (6),

$$-10dB\ bandwidth\ (\%) = \frac{F_H - F_L}{F_c}\ X\ 100\% \qquad (6)$$

Where, FH, FL and FC are the highest, the lowest and the centered frequency or the desired operating frequency of the -10 dB of the return loss plot.
The -10 dB bandwidth operating at 1.8 GHz is 3.33% (60 MHz, from 1.76 GHz to 1.82 GHz) for the simulated result whereas the bandwidth is 6.67% (120 MHz, from 1.76 GHz to 1.88 GHz) for the measured result. The shifting in the second operating frequency is observed in which shifted from 2.5 GHz for the simulated result to 2.48 GHz band for the measured result with 20 MHz deviation. The deviation of the second operating frequency possibly due to the improper etched of the U-slot dimension in fabrication. The -10 dB bandwidth operating at 2.5 GHz is 2% (50 MHz, from 2.47 GHz to 2.52 GHz) for the simulated result whereas no bandwidth parameter valuation is observed for the measured result due to the frequency shifting from the desired 2.5 GHz to 2.48 GHz band.
VSWR parameter is used for match-tune value guideline of the antenna. The VSWR value lies between 1 and 2 for practical applications and shows good antenna performance. The VSWR ratio versus (vs) frequency of the proposed antenna is shown in Fig. 5. From the simulation output, the VSWR is 1.6768 and 1.4871 for 1.8 GHz and 2.5 GHz frequency bands, respectively. Based on the measurement by the network analyzer, the VSWR value is 1.4761 and 1.6612 at 1.8 GHz and 2.48 GHz, respectively.
The proposed MPA provides good directivity parameter of 7.074 dB and 7.492 dB at 1.8 GHz and 2.5 GHz operating frequencies, respectively. The 2D radiation patterns in E-plane (y-z plane) and H-plane (x-z plane) of the proposed MPA at the dual band are illustrated in Fig. 6.
The proposed MPA with 3 dB beam-width of 83.20 and 78.40 is sufficiently wide-ranging beam for the intended applications. Accordingly, it results in a good top omnidirectional radiation pattern at the dual band frequencies for both planes.
Current distribution directed by arrow sign is illustrated in Fig. 7. It is observed that the maximum current flow is nearby outer of two parallel horizontal rectangular slots at 1.8 GHz band. While at 2.5 GHz band, the current density is on its maximum nearby inner of U-slot and around the notch of the strip line. The proposed U-slotted dimension is beneficial in improving the RF input dual-banding of the MPA.

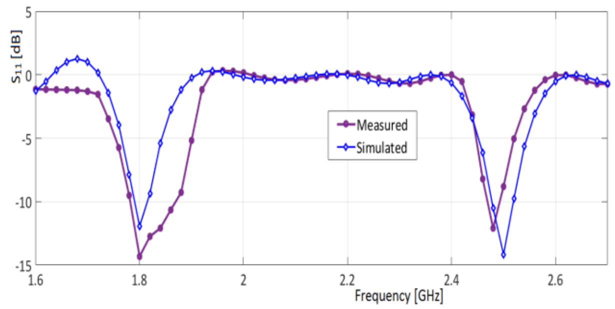

Fig. 4: Return Loss Plots.

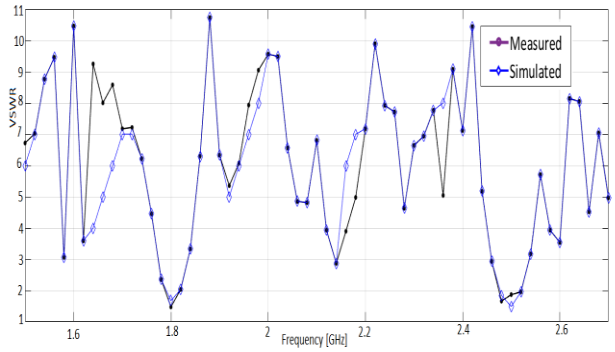

Fig. 5: VSWR Plots.

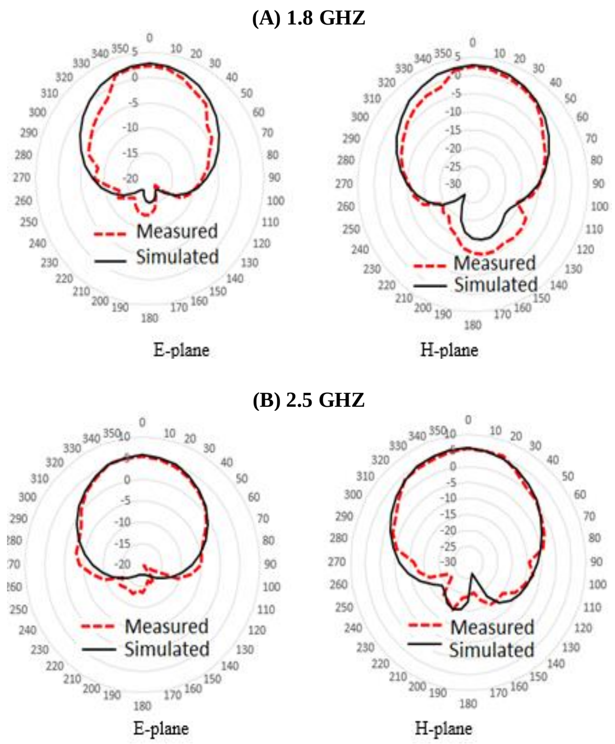

Fig. 6: Radiation Patterns of Realized Gain at (A) 1.8 GHZ and (B) 2.5 GHZ.

(A)

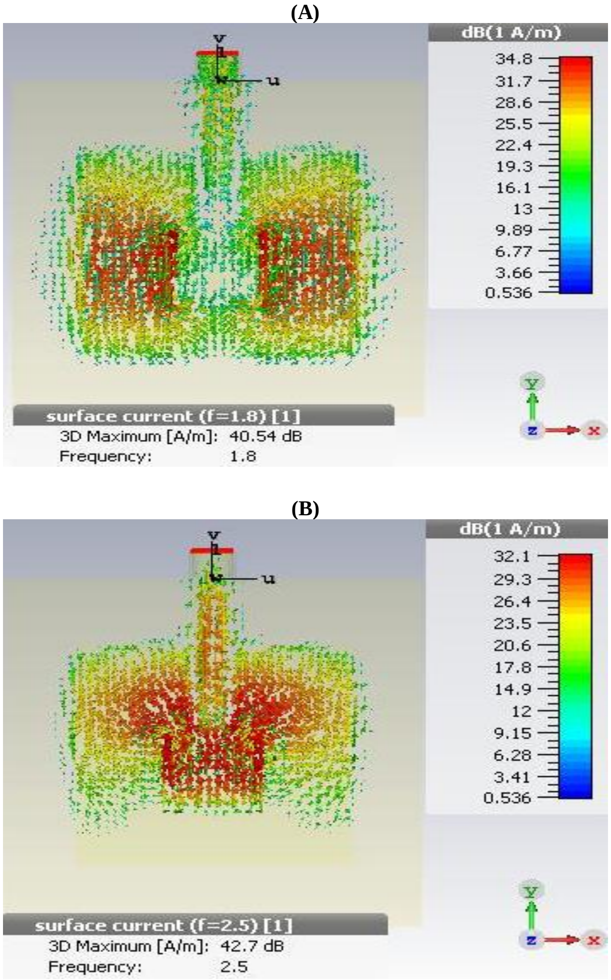

Fig. 7: Simulated Current Distribution at A) 1.8 GHz and B) 2.5 GHZ.

Table 2: Comparison Performance of the Proposed Antenna with Other MPAS

Ref. No	Substrate	Frequency (GHz)	S11 (dB)	Gain (dBi)	Directivity (dB)
[6]	RT/Duroid 5880 (εr = 2.2)	6.11	-10.9	5.04	n/a
[7]	RT/Duroid 5880 (εr = 2.2)	3.34 4.23 6.7	-21.9306 -14.8824 -12.0012	1.7666 4.0753 4.1688	n/a
[8]	RT/Duroid 5880 (εr = 2.2)	59	-42.4383	2.0675	n/a
[9]	RT/Duroid 5880 (εr = 2.2)	2.45 5.4	-22 -15	2 3.3	n/a
[10]	Polyethylene terephthalate, PET (εr = 2.5)	2.45	-26.4	2.7	n/a
[11]	Rogers 4003 (εr = 3.38)	1.84	<-10	1.87	n/a
Proposed	RT/Duroid 5880 (εr = 2.2)	1.8 2.5	-14.321 -12.105	2.29 5.51	7.074 7.492

The proposed MPA is compared with numerous other reported antennas. The comparisons are as summarized in Table 2. As compared, the frequency bands show effective antenna gain results in lower operating frequencies than the reported results. It is considered a high gain parameter of more than 5 dBi for the 2.5 GHz band. The simulated gain parameter is 2.73 dBi and 5.74 dBi with 16.1% and 4% difference over the measured result at 1.8 GHz and 2.5 GHz, respectively. The magnitude of the radiation pattern describes the antenna gain parameter. The directivity of the reported antennas is not presented owing to their application in which not focusing on receiving RF signals from a fixed angle and perhaps the directivity parameter is not considered as the main priority. Here, the directivi-ty parameter is considered important in such a way to maximize the transferred power to the RF energy harvesting system. The pro-posed MPA is considered with a high directivity parameter perfor-mance of more than 5 dB.

4. Conclusion

A dual band MPA of the RF energy harvester that can be adopted in mobile wireless applications is proposed. The proposed MPA with slotted and shorted pin patch is simulated, fabricated and measured to evaluate the parameters performances. The average simulated and measured results are 92% matched. The 8% differences are because of losing soldering at the SMA connector contacts, the precision of the cutting dimension and the slot cut of the material layers. The overall physical size of the MPA is reduced by utilizing the concept of a single shorting pin. The dual band opera-tion is achieved by etching the U-slot on the radiator patch. The results obtained clearly indicates that the proposed MPA is capable providing a good return loss S11, peak gain, VSWR, directivity, current surface distribution and radiation pattern parameters perfor-mances. Its moderate physical size and a good performance made it acceptable for the integrated wireless devices by the RF energy harvester.

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References

[1] Agrawal, P. (2016). Effect of matching network on ambient RF energy harvesting circuit for wireless sensor networks. *Futuristic Trends in Engineering, Science, Humanities, and Technology FTESHT-16*, 11.

[2] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A. (2017). MEMS based RF energy harvester for battery-less remote control: A review. *American Journal of Applied Sciences*, 14(2), 316-324. https://doi.org/10.3844/ajassp.2017.316.324.

[3] Sampe, J., Semsudin, N. A. A., Zulkifli, F. F., & Majlis, B. Y. (2017). Micro Hybrid Energy Harvester Circuit for Biomedical Application", Jurnal Kejuruteraan, 29(1), 41-48. https://doi.org/10.17576/jkukm-2017-29(1)-06.

[4] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A. (2017, August). Parameter design of microstrip patch antenna operating at dual microwave-band for RF energy harvester application, In 2017 IEEE Regional Symposium on Micro and Nanoelectronics, RSM 2017, 92-95.

[5] Sampe, J., Yunus, N. H. M., Yunas, J., & Pawi, A. (2017). Ultra-low power RF energy harvesting of 1.9 GHz & 2.45 GHz narrow-band rectenna for battery-less remote control. *International Journal of Information and Electronics Engineering*, *7*(3), 118-122. https://doi.org/10.18178/IJIEE.2017.7.3.673.

[6] Raval, F., Kosta, Y. P., & Joshi, H. (2015). Reduced size patch antenna using complementary split ring resonator as defected ground plane. *AEU-International Journal of Electronics and Communications*, *69*(8), 1126-1133. https://doi.org/10.1016/j.aeue.2015.04.013.

[7] Sidhu, S. K., & Sivia, J. S. (2016). Analysis and design Rectangular patch with half Rectangular Fractal Techniques. *Procedia Comput-*

er Science, *85*, 386-392. https://doi.org/10.1016/j.procs.2016.05.247.

[8] R.Siri Chandana, P.Sai Deepthi, D.SriramTeja, N.Veera JayaKrishna, M.Sujatha. (2018). Design of a Single Band Microstrip Patch Antenna for 5G Applications. International Journal of Engineering & Technology, 7 (2.7), 532-535. https://doi.org/10.14419/ijet.v7i2.7.10877.

[9] Yen, J. H., Liu, N. C., Chen, K. H., & Tarng, J. H. (2017, March). A compact planar dual-band filtering antenna. In *2017 IEEE International Conference on Computational Electromagnetics (ICCEM)*, 367-369. https://doi.org/10.1109/COMPEM.2017.7912768.

[10] Dong, H., Hou, X., Zhang, Q., & Wang, F. (2018, March). Flexible slot-ring antenna for RF wireless energy harvesting. In *2018 International Workshop on Antenna Technology (iWAT)*, 1-4.

[11] Shen, S., Chiu, C. Y., & Murch, R. D. (2018). Multiport Pixel Rectenna for Ambient RF Energy Harvesting. *IEEE Transactions on Antennas and Propagation*, *66*(2), 644-656. https://doi.org/10.1109/TAP.2017.2786320.

[12] Kunwar, A., Gautam, A. K., & Rambabu, K. (2017). Design of a compact U-shaped slot triple band antenna for WLAN/WiMAX applications. *AEU-International Journal of Electronics and Communications*, *71*, 82-88. https://doi.org/10.1016/j.aeue.2016.10.013.

[13] Yunus, N. H. M., Sampe, J., Yunas, J., & Pawi, A. (15-17 August 2018). Comparative Study of Si Based Micromachined Patch Antenna Operating at 5 GHz for RF Energy Harvester. Proceedings of 2018 IEEE International Conference on Semiconductor Electronics, ICSE2018, Kuala Lumpur.

[14] K. F. L. and K. M. Luk. (2011). Microstrip Patch Antennas. Imperial College Press: London.

[15] Waterhouse, R. (2013). Microstrip patch antennas: a designer’s guide. Springer Science & Business Media. https://doi.org/10.2528/PIERB13111105.

[16] Aneesh, M., Ansari, J. A., Singh, A., & Sayeed, S. S. (2014). Analysis of microstrip line feed slot loaded patch antenna using artificial neural network. *Progress in Electromagnetics Research*, *58*, 35-46.

[17] Jetti, C. R., & Nandanavanam, V. R. (2018). Trident-shape strip loaded dual band-notched UWB MIMO antenna for portable device applications. *AEU-International Journal of Electronics and Communications*, *83*, 11-21. https://doi.org/10.1016/j.aeue.2017.08.021.

[18] Chatterjee, A., Mondal, T., Patanvariya, D. G., & Jagannath, R. P. K. (2018). Fractal-based design and fabrication of low-sidelobe antenna array. *AEU-International Journal of Electronics and Communications*, *83*, 549-557. https://doi.org/10.1016/j.aeue.2017.11.010.

[19] Lee, K. F., Yang, S. L. S., Kishk, A. A., & Luk, K. M. (2010). The versatile U-slot patch antenna. *IEEE Antennas and Propagation Magazine*, *52*(1), 71-88. https://doi.org/10.1109/MAP.2010.5466402.

[20] Garg, R., Bhartia, P., Bahl, I., Ittipiboon, A. (2001). Microstrip Antenna Design Handbook, Artech House.