CERAMIC MATERIAL BASED MULTIBAND PATCH ANTENNA FOR SATELLITE APPLICATIONS

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Materials have a vital effect on satellite communications. Using PTFE (Polytetrafluoroethylene) composite ceramic material, a fractal triangular shape multiband satellite application antenna has presented in this paper. Different kinds of material substrate are used for analysis in the proposed antenna design and depicted their antenna characteristics. The proposed material antenna has attained a bandwidth of 50 MHz, 140 MHz, 145 MHz and 245 MHz at center frequency 5.67 GHz, 6.52 GHz, 7.66 GHz and 8.88 GHz respectively. The design of the proposed antenna is tested in the experimentation. The overall antenna dimension is 0.66λ × 0.75λ × 0.02λ at 5.67 GHz center frequency. In addition, a detailed analysis has been carried out to study the effects of different geometrical parameters on the performance of the antenna by using Finite Element Method based high frequency structural simulator (HFSS).

1. INTRODUCTION

Now the whole world is interconnected by satellite communication network. A satellite is usually linked to an earth station by a microwave signal, which is transmitted and received through antennas. Mechanical design of microstrip antennas for satellite communication has to take into account the some mechanical conditions such as dimensions, weight, vibration, acoustic, thermal, strength stiffness and deployment shock, and choose the suitable materials to accommodate these conditions. So the fundamental materials must be selected carefully to full fill these requirements. The purpose of the substrate material of a microstrip antenna is primarily to provide mechanical support for radiating patch elements. However it plays an important role in the microstrip antenna design, production and finished product performance. Especially in satellite application, the parameters of the

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substrate material are a key factor for the performance of the antennas. Besides the dielectric constant and dissipation factor, normally the microwave substrate material has other properties such as volume resistivity, surface resistivity, tensile modulus, compressive modulus, water absorption, specific gravity, heat distortion temperature, thermal conductivity, thermal expansion and so on. The selection of correct material for microstrip antenna should be based on cost, insertion loss, thermal stability, dielectric constant and similar considerations [1]. The wireless communication system requires antennas that have large bandwidth and fewer dimensions than existed before. Various types of multiband antenna can be made depending on the idea of fractal geometry because of proving itself the Sierpinski as an attractive and excellent multiband antenna. An antenna has multiband and ultra-band characteristics on account of being self-similarity of fractal geometry [2]. Fractal hexagonal shape has been evaluated and found appropriate for multiband usage [3, 4]. The microstrip triangular patch searches various applications with many useful MIC (Microstrip) components such as circulators, resonators and filters. The triangular patches have been reading practically and theoretically [5–10]. They have got to deliver radiation properties [11, 12] similar to those of rectangular patches with a small size. In this paper, an effort is performed to design a triangular fractal antenna of effective radiation, intact size and multiband properties. It can be seen that greater demand is created by means of quick growth of wireless communications and electronics for wireless devices that can obey different rules at different standards. The process for decreasing the size of microstrip patch antenna are reported vastly and include capacitive loading [13], LC resonator [14], and reactive loading [15]. However, this process deals with antenna bandwidth or antenna efficiency to achieve the decrease in antenna size. Different processes for constructing multiband microstrip patch antennas have been disclosed such as including parasitic elements [16] to make an additional resonant frequency or including more radiating elements shared with similar feed and ground [17–19]. This process compulsory extends the physical size to make the multiband properties. There is dealing between number of using bands and antenna size. This paper represents a concept of reconfigurable antenna for operating the resonant frequency to avoid the difficulties created in frequency steering by using rectangular defected ground structure [20]. Multiband resonance frequency is constructed and operated by balancing the number of turns of the spiral AMC (Artificial Magnetic Conductor) ground plane [21].

In this paper, the authors target is to analysis the different substrate material for the satellite application and tries to achieve multiband characteristic antenna. After different substrate material analysis, authors have proposed a new microstrip two triangular slotted with two triangular radiating patches that achieves multiband characteristics antenna compared to others and medium operating frequency for spacecraft, aircraft and satellite based communication system.

2. ANTENNA DESIGN ARCHITECTURE

The geometry and configuration of the proposed antenna are depicted in Fig. 1: a) top view, b) bottom view and c) side view. The antenna consists of two triangular slot with two triangular patches which are connected with a microstrip line. On the other hand, ground plane consists of pentagon shape where a small pentagon shape slot etched out from that big one. The slot and tuning stub are printed on the opposite side of a PTFE composite material Rogers/RT Duroid 5870 substrates of thickness 1.575 mm with low dielectric constant 2.33 and less tangent loss. The characteristic impedance of the microstrip line is taken as 50 Ω. By properly selecting the slot and tuning stub, a good impedance bandwidth with multiband characteristics is achieved. The optimized antenna parameters are arranged in Table 1.

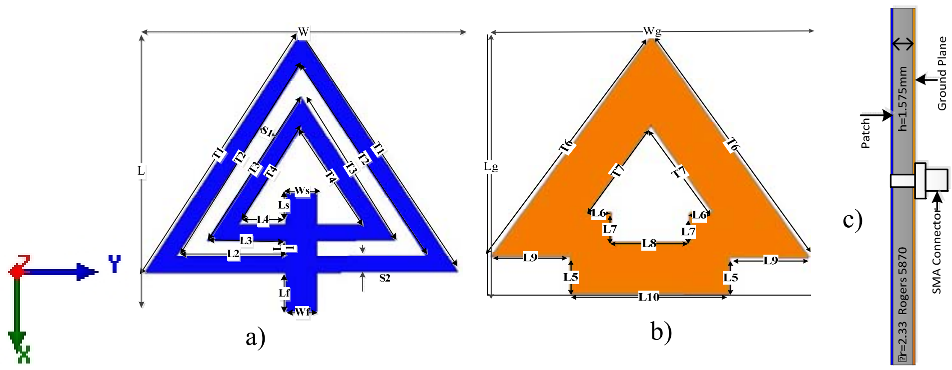


Fig. 1 − Proposed antenna geometry: a) top view; b) bottom view; c) side view.

Table 1

Parameters of the proposed antenna

Parameter	Value (mm)	Description	Parameter	Value (mm)	Description
L	30	Length of the Patch	S1	2	Slot width
W	40	Width of the Patch	S2	2	Single patch width
Ws	4	Width of the inner I slit	Parameters of Ground Plane		
Ls	4	Length of the inner slit	T6	36.05	First Triangular arm length
Wf	4	Width of the feed	T7	14.42	Slot arm length
Lf	5	Length of the feed	L5	5	Different arm length
T1	36.05	First equatorial triangular patch arm length	L6	3	
T2	28.84	Second equatorial triangular slot arm length	L7	4	
T3	21.63	Third equatorial triangular patch arm length	L8	10	
T4	14.42	Fourth equatorial triangular slot arm length	L9	10	
L1	2	Length of two equatorial triangular patch connecting slit	L10	20	

Table 1 (continued)

L2	18		WGnd	40	Width of Ground plane
L3	14		LGnd	35	Length of ground plane
L4	10		L5	6	Arm length

3. **RESULTS AND DISCUSSION**

3.1. SIMULATED ANTENNA PERFORMANCE

Based on the above optimized design parameters, six substrate material were studied numerically in order to investigate the influence of the parameter on antenna performance. In this analysis only substrate material is changed with dielectric constant. Figures 2 and 3 depict the six substrate material reflection coefficients and average peak gain where Rogers PTFE material reflection coefficients and average peak gain is better than all other material. Tables 2 and 3 showed the different parameter values of the proposed shape antenna.

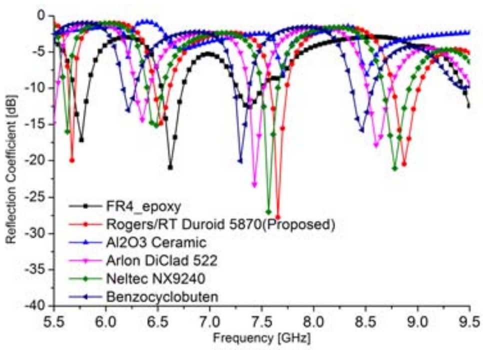


Fig. 2 – Various substrate material reflexion coefficients of the proposed design .

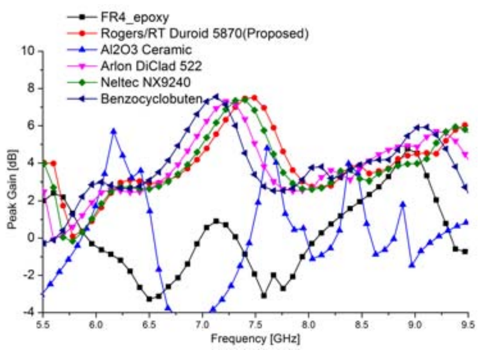


Fig. 3 − Peak gain of various substrate material of the proposed design.

Table 2

Different antenna parameters from different material through proposed design

Substrate Material	Dielectric Constant(εr)	Resonance Frequency (GHz) & Maximum Return Loss(dB)				AveragePeak Gain(dB)				Bandwidth (MHz)			
		*fc1	fc2	fc3	fc4	fc1	fc2	fc3	fc4	*Bw1	Bw2	Bw3	Bw4
FR4 _epoxy	4.6	5.75 & -17.43	5.63 & -21.2	7.37 & -12.63	9.61& -15.61	1.56	-2.88	-0.39	-0.39	135	200	235	380
Rogers RT/ duroid	2.33	5.67 & -26.52	6.52 & -14.8	7.66 & -30.85	8.88 & -20.4	2.20	2.91	5.96	4.30	50	140	145	245

Table 2 (continued)

Al2O3 ceramic	9.8	-	-	-	9.99 -20.99	-	-	-	7.53	-	-	-	25
ArlonDiclad	2.5	5.51 - 27.93	6.34 - 14.38	7.45 - 28.59	8.63 -17.81	2.34	2.46	5.56	4.40	50	130	140	215
Neltec NY	2.4	5.61 - 26.71	6.45 - 15.50	7.57 - 35.84	8.79 -20.63	2.63	2.17	5.75	3.75	50	140	150	245
Benzocyclobuten	2.6	5.41 - 16.67	6.22 - 13.05	7.30 - 21.35	8.46 -21.35	2.06	2.68	6	3.84	40	110	135	200

* fc1=First Resoance Frequency ,fc2=Second Resoannce Frequency---
* Bw1=Bandwidth 1,Bw2=Bandwidth 2

Table 3

Different antenna parameters with different substrate material

Material	Resonance Frequency	Max U(radiation (directivity) *(W/sr)	Peak Directivity	Peak Gain	Peak Realized Gain	Radiation Efficiency	Front to Back Ratio
FR4 eproxy	5.67	0.00103	3.931	1.703	1.530	0.433	236.126
	6.52	0.00027	1.261	0.467	0.407	0.370	9.484
	7.66	0.00036	1.063	0.617	0.534	0.580	49.480
	8.88	0.00116	4.055	2.734	1.721	0.674	100.122
Rogers/RT Duroid 5870	5.67	0.00115	1.980	1.721	1.698	0.869	7.260
	6.52	0.00123	2.019	1.959	1.822	0.971	37.659
	7.66	0.00268	4.089	4.009	3.961	0.980	814.598
	8.88	0.00178	2.786	2.695	2.634	0.967	17.958
Al2O3 Ceramic	5.67	0.00018	0.685	0.676	0.267	0.987	74.667
	6.52	0.00027	1.199	1.208	0.395	1.007	3.314
	7.66	0.00190	3.415	3.457	2.828	1.012	64.310
	8.88	0.00068	1.535	1.793	1.019	1.168	7.885
ArlonDiClad 522	5.67	0.00025	1.020	0.900	0.378	0.882	57.575
	6.52	0.00098	1.923	1.858	1.459	0.967	39.307
	7.66	0.00092	2.127	2.048	1.369	0.962	506.158
	8.88	0.00148	2.782	2.653	2.200	0.954	13.780
Neltec NX9240	5.67	0.00061	1.351	1.165	0.911	0.863	6.032
	6.52	0.00115	1.909	1.846	1.713	0.967	39.379
	7.66	0.00177	2.987	2.892	2.640	0.968	3485.500
	8.88	0.00158	2.598	2.454	2.360	0.944	14.981
Benzocyclobuten	5.67	0.00019	1.096	1.065	0.279	0.971	34.873
	6.52	0.00061	1.351	1.165	0.911	0.863	6.032
	7.66	0.00057	1.805	1.821	0.853	1.009	110.038
	8.88	0.00147	3.201	3.177	2.195	0.992	30.009

*watts per steradian (W/sr)

By cutting different kinds of slots, the final proposed shaped are getting which is responsible for multi resonances. Figure 4 displays the reflection coefficients of the different patch shape.

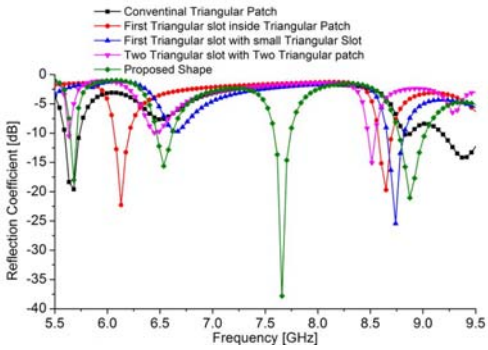


Fig. 4 − Simulated reflection coefficient against frequency for different patch shapes.

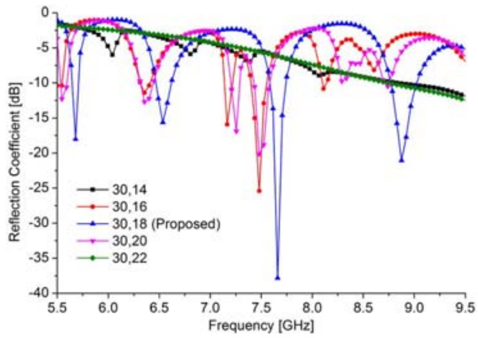


Fig. 5 − Simulated reflection coefficient for different feed position.

The different probe feed position is shown in Fig. 5 where 30, 18 (*x* axes position,*y* axes position in Fig. 1 is the optimized position for better antenna performance. Figures 6 and 7 depicts the transmission response of the different values of slit width W_s and slit length L_s. Actually this slit is responsible for achieving good impedance response. It could be noted that when slit width W_s=4 mm and length Ls= 4 mm with others parameter values (Table 1) unchanged, the return loss of the proposed antenna is better value than others. Figure 8 represents the return loss effect of the changing the values of feed width W_f. Optimized feed width is 4 mm where all other parameter's value depicted in Table 1 is fixed. The peak gain of the proposed antenna is illustrated in Fig. 9. An average peak gain of 2.20 dB, 2.91dB, 5.96 dB and 4.30 dB are obtained in a different frequency band. As for the radiation properties in Fig. 10 give an overview of the antenna behavior.

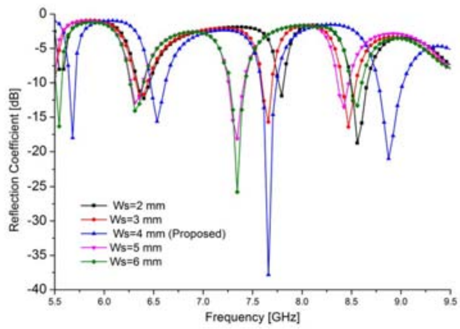


Fig. 6 −Simulated reflection coefficient against frequency for different values of W_s.

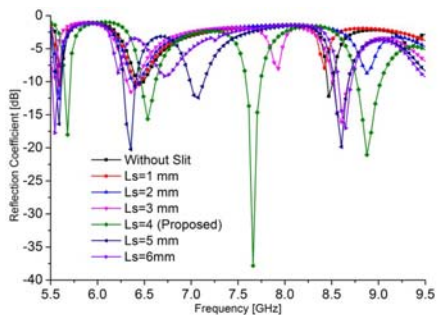


Fig. 7 −Simulated reflection coefficient against frequency for different values of L_s.

More specifically in Fig. 10, the left side displays *E* plane and right side *H* plane and the dotted line represents the cross polarization and straight line express Co polarization. Cross polarization is low compared to Co polarization. The gain pattern of *E* plane is nearly omnidirectional and *H* plane is donut shape.

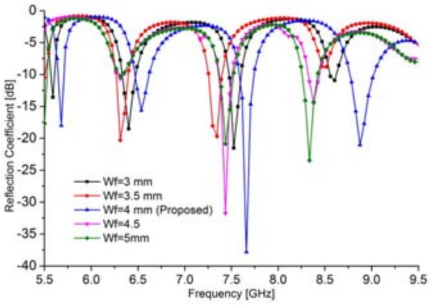


Fig. 8 − Simulated return loss for different feed width values of W_f.

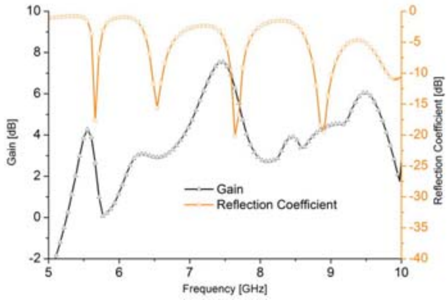
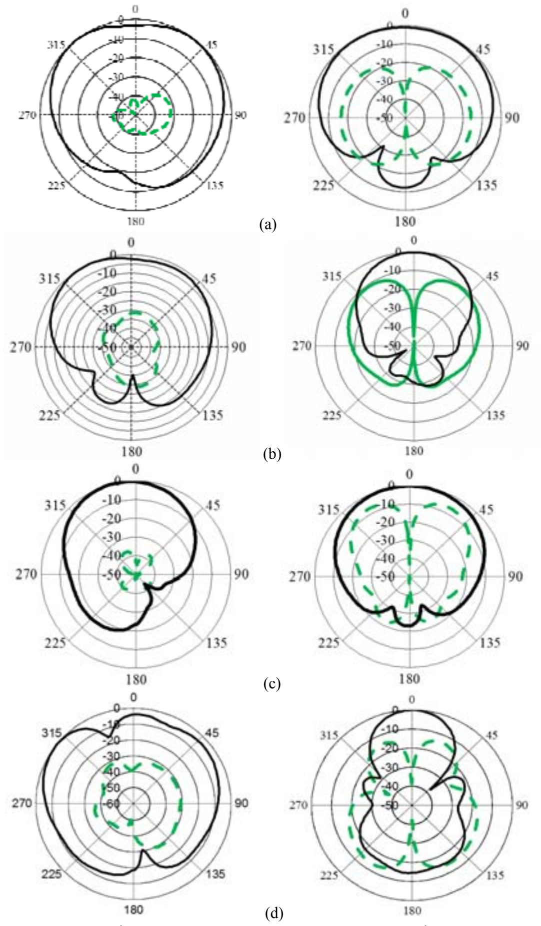


Fig. 9 − Simulated peak gain with frequency.



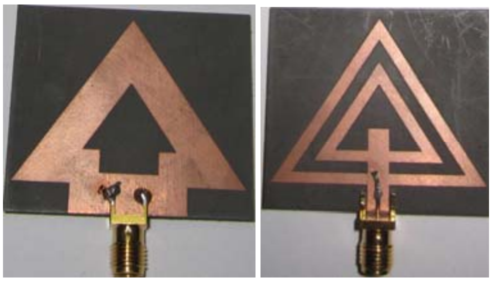
E Plane H Plane

Co-polarization Cross polarization

Fig. 10 − Radiation pattern of the proposed shape antenna at: a) 5.67 GHz; b) 6.52 GHz; c) 7.66 GHz; d) 8.88 GHz.

3.2. EXPERIMENTAL RESULTS

A prototype of the optimized antenna was fabricated and tested. Figure 11 shows the photograph of the fabricated antenna. The prototype is made of a 1.575 mm thick Rogers RT/Duroid 5870 (PTFE composite ceramic material) substrate with relative permittivity $\varepsilon_r = 2.33$. The measured and simulated S parameters are shown in Fig. 12. From these curves it can be observed that there is a good agreement between measured and simulated results due to the SMA (Subminiature version A) connector not included in the simulation. From these measured results a bandwidth of 45MHz, 110 MHz, 150 MHz and 230 MHz (for reflection coefficient $S_{11} \leq -10$ dB) around centre frequency at 5.69 GHz, 6.53 GHz, 7.68 GHz and 8.89 GHz, respectively.



a) b)

Fig. 11 − Prototype of the proposed shape: a) top view; b) bottom view.

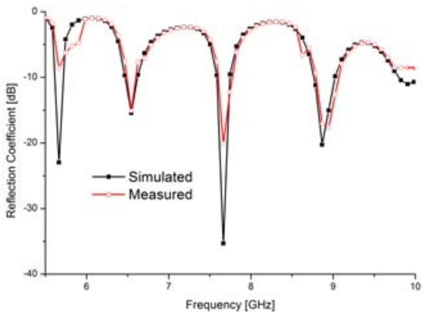


Fig. 12 − Measured and simulated reflection coefficient with frequency.

4. **CONCLUSION**

Designed, fabricated and performance analysis of the proposed multiband triangular shape patch antenna based on different substrate material are investigated and their performance characteristics are tabulated in Table 2 and Table 3. From this analysis, it could be easily stated that PTFE composite ceramic material substrate (Rogers RT/Duroid) performance is better than other materials, especially reflection coefficients (− 26.52 dB, −14.8, −30.85 dB, −30.85 dB, and −20.4 dB), average gain (2.20 dB, 2.91 dB, 5.96 dB and 4.30 dB), radiation efficiency (85.78 %, 97.30 %, 98.80 % and 95.66 %), peak realized gain, radiated power and accepted power at resonance frequency 5.67 GHz , 6.52 GHz , 7.66 GHz and 8.88 GHz respectively. So, with the advancement of materials, RT/Duroid has conquered the specification for the requirements of space application.

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REFERENCES

1. J. Xia, Tan, S., and Arichandran, K., *Application of Microstrip Antennas in Small Satellites. Cooperation in Space*, Euro-Asian Space Week: where East and West finally meet, Singapore, 23–27 November 1998. Paris, European Space Agency (ESA), SP **430**, 1999, p. 459, 1999.
2. M. Naghshvarian Jahromi, Falahati, A., and Edwards, R.M., *Bandwidth and Impedance-Matching Enhancement of Fractal Monopole Antennas Using Compact Grounded Coplanar Waveguide*, Antennas and Propagation, (IEEE) Transactions on, **59**,*7*, pp. 2480–2487, 2011.
3. P.W. Tang and Wahid, P., *Hexagonal fractal multiband antenna*, Antennas and Wireless Propagation Letters; IEEE, **3**,*1*, p. 111–112, 2004.
4. N.A. Saidatul, Azremi, A.A.H., and Soh, P.J, *A hexagonal fractal antenna for multiband application*, Intelligent and Advanced Systems (ICIAS 2007), International Conference on, 2007.
5. M. Polivka, Drahovzal, M., Rohan, J., and Hazdra, P, *Multiband patch antenna with perturbation elements generated by genetic algorithm*, Antennas and Propagation (EuCAP). First European Conference on, 2006.
6. M. Biswas and Dam, M., *Fast and accurate model of equilateral triangular patch antennas with and without suspended substrates*, Microwave and Optical Technology Letters, **54**, *11*, pp. 2663–2668, 2012.
7. R. Garg and Long, S.A., *An improved formula for the resonant frequencies of the triangular microstrip patch antenna*, Antennas and Propagation, IEEE Transactions on, **36**, *4*, pp. 570, 1988.
8. D. Fazal, Khan, Q.U., and Ihsan, M.B., *Use of partial koch boundaries for improved return loss, gain and sidelobe levels of triangular patch antenna*, Electronics Letters, **48**, *15*, pp. 902–903, 2012.
9. M. Habib Ullah and Islam, M.T., *Design of a modified W-shaped patch antenna on Al_2O_3 ceramic material substrate for Ku-Band*, Chalcogenide Letters, **9**, *2*, pp. 61–66, 2012.
10. R. Azim, Islam, M.T., Misran, N., Cheung, S.W., and Yamada, Y., *Planar UWB antenna with multi-slotted ground plane*, Microwave and Optical Technology Letters, **53**, *5*, pp. 966–968, 2011.
11. S. Alexandru, Gheorghe, G., Alina, B., Ionut, D., and Alexandru, B., *Feedback electromagnetic field of a ship metal wall*, Rev. Roum. Sci. Techn.–Electrotechn. et Energ., **58**, *1*, pp. 3–13, 2013.
12. S.Z. Stanojcic, Stefanovic, M.C., Panic, S.R., Mekic, S., and Popovic, G., *Second order statistics of the mimo κ-μ keyhole fading channels*, Rev. Roum. Sci. Techn.–Electrotechn. et Energ., **57**, *2*, pp. 183–191, 2012.
13. W. Sung-Jung, Chi-Hung, C., and Jenn-Hwan, T., *A capacitively-loaded PIFA based reader antenna for portable RFID application*, Antennas and Propagation (EuCAP) 2010, Proceedings of the Fourth European Conference on, 2010.
14. D. Yuandan, Toyao, H., and Itoh, T., *Design and Characterization of Miniaturized Patch Antennas Loaded With Complementary Split-Ring Resonators*, Antennas and Propagation, IEEE Transactions on, **60**, *2*, pp. 772–785, 2012.
15. M. Deshpande and Bailey, M., *Analysis of stub loaded microstrip patch antennas*, Antennas and Propagation Society International Symposium (IEEE), 1997.
16. Y.J. Cho, Hwang, S.H., and Park, S.-O., *A dual-band internal antenna with a parasitic patch for mobile handsets and the consideration of the handset case and battery*, Antennas and Wireless Propagation Letters (IEEE), **4**, pp. 429–432, 2005.
17. P. Ciais, Staraj, R., Kossiavas, G., and Luxey, C., *Compact internal multiband antenna for mobile phone and WLAN standards*, Electronics Letters, **40**, *15*, pp. 920–921, 2004.
18. C. Rowell, Mak, A., and Mak, C.L. *Isolation between multiband antennas*, Proc. IEEE APS/URSI/AMEREM Int. Symp., 2006.
19. M. Samsuzzaman, Islam, M.T., Yatim, B., and Ali, M.M., *Dual Frequency Triangular Slotted Microstrip Patch Antenna for Ku Band Applications*, Przegląd Elektrotechniczny, **89**, *1*, pp. 275–279, 2013.
20. L.H. Weng, Guo, Y.-C., Shi, X.-W., and Chen, X.-Q., *An overview on defected ground structure*, Progress In Electromagnetics Research B, **7,** pp. 173–189, 2008.
21. D. Nashaat, Elsadek, H.A., Abdallah, E., Elhenawy, H., and Iskander, M.F, *Electromagnetic analyses and an equivalent circuit model of microstrip patch antenna with rectangular defected ground plane*, Antennas and Propagation Society International Symposium, APSURSI'09, IEEE, 2009.