

# A compact monopole antenna with improved bandwidth for Ku band applications

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A compact monopole antenna has been presented with improved bandwidth for Ku-band applications. The proposed Ku-band antenna is made of rectangular slots and circular slots on the ground and the patch, respectively, by a microstrip line of 50  $\Omega$ . It is designed on a printed circuit board of 15 mm  $\times$  15 mm  $\times$  1.6 mm using FR4 as a substrate material. High Frequency Structural Simulator (HFSS) is commercially available, which has been considered in this study depending on the concept of the Finite Element Method (FEM). 2.70 GHz (14.10 GHz to 16.80 GHz) is the achieved bandwidth of the proposed Ku-band antenna. The average gain is 3.66 dBi where 3.94 dBi is the maximum gain. The proposed Ku-band patch antenna exhibits smooth current distribution and durable nearly Omni-directional radiation patterns.

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*Keywords:* Finite element method, Ku-band, Microstrip antenna, Microstrip line

## 1. Introduction

Developments in wireless communication systems are created remarkable needs in the antenna technology. It is used to make the easiest way for broad application of cellular mobile phones in update society resulting in climbing up attentions enclosing its detrimental radiation [1-3]. Remarkable needs are gradually created in the antenna technology with the developments in wireless communication systems. The demand of size reduction and improved bandwidth of the radiating patch are necessary to face the condition for practical applications with the advent of communication engineering. Microstrip antennas have been extensively utilized in satellite communications, missile guidance, electronic countermeasure, marine, airborne intercept and radar etc. due to their low-weight, low-cost, low-profile, mechanically robust, easy fabrication [4-6]. But, unfortunately microstrip patch antennas have been suffering from some demerits and limitations such as narrow bandwidth, higher cross polarization, limited tolerance and power capacity [7]. Researchers have been narrated and proposed many processes and techniques to face these limitations such as coupling resonator patch, stacked patch configuration, using impedance matching techniques, and several feeding techniques [8-10].

In [11], a Ku-band patch antenna has been proposed with notches and slit where dimension is 7.6 mm  $\times$  10 mm, substrate thickness is 0.8 mm Teflon is used as dielectric substrate material and has been obtained maximum 600 MHz bandwidth. A dual polarized microstrip patch antenna has been proposed for Ku-band applications where dimension is 15 mm  $\times$  15 mm [12]. Moreover, this paper has been achieved 950 MHz bandwidth with maximum gain 7.6 dB. In [13], a dual

frequency triangular slotted microstrip patch antenna has been proposed for Ku-band applications where patch dimension is 8.5 mm  $\times$  7.96 mm  $\times$  1.905 mm. substrate thickness is 1.905 mm, Rogers RT/Duroid 6010 is used as dielectric substrate material and has been achieved maximum 576 MHz bandwidth. In this reported antenna design, narrow bandwidth has been achieved for Ku-band applications. A dual band compact microstrip antenna also has been proposed for Ku-band applications with using three pairs of thin slits from the sides of a rectangular patch where dimension is 9.5 mm  $\times$  10 mm [14]. The reported antenna design printed on Rogers RT/Duroid 5880 substrate material, which thickness was 0.254 mm, and was obtained maximum 90 MHz bandwidth.

A compact patch antenna with circular slots that attains Ku band profile physically belonging to nearly Omni-directional radiation characteristics, gain and reasonable current distribution is presented in this paper. The mentioned Ku-band antenna is made of circular slotted radiating patch and a defected ground plane containing rectangular slots generating a wide bandwidth ranging from 14.10 to 16.80 GHz. The antenna formation is smooth with simple design and comfortable fabrication. Circular Slots are inserted inside the rectangular patch to generate a wide frequency band for Ku-band applications. By virtue of significant selection of rectangular patch with circular slots and rectangular ground with rectangular slots, it is observed that the reported antenna can obtain wide band for Ku-band applications.

## 2. Antenna geometry and parametric study

The geometry of the proposed Ku-band antenna is demonstrated in Fig. 1. The antenna comprises of conducting rectangular patch with circular slots and

rectangular ground with rectangular slots. Thirteen circular slots are on the radiating patch and four rectangular slots on the ground of the proposed patch antenna. The four rectangular slots on ground plane are of equal lengths  $L_s$  and widths  $W_s$ .  $R_1$ ,  $R_2$ ,  $R_3$ , and  $R_4$  are the radius of the circular slots respectively. The design procedure begins with the radiating patch with substrate, ground plane and a feed line. It is printed on a 1.6 mm thick FR4 substrate that contains relative permeability 1, dielectric loss tangent 0.02, and relative permittivity 4.6. Thirteen circular slots are cut from the rectangular copper patch. Four rectangular slots are also cut from the ground plane. Thus, the proposed patch antenna is attained finally. Resonance at 15.27 GHz has been obtained adjusting the length and width of the slots of the proposed antenna endlessly. Here, microstrip transmission line is utilized to provide feeding to the proposed patch antenna. An SMA 50 $\Omega$  connector is conducted at the antenna feed line. The input impedance of the proposed Ku-band antenna is shown in Fig. 2.

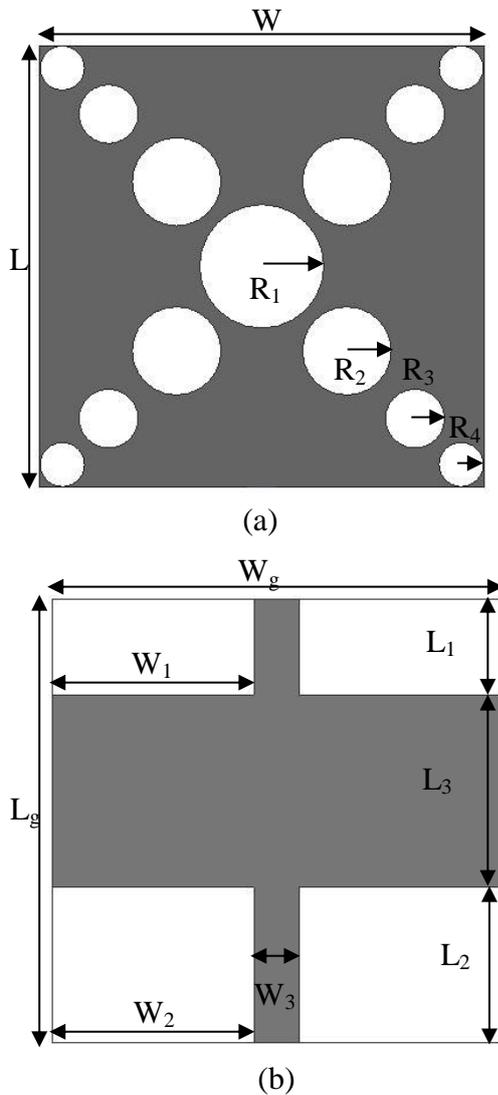


Fig. 1. The proposed Ku-band antenna a) top view b) bottom view.

HFSS is used for the simulations of the proposed Ku-band patch antenna design and dimensions depending on the FEM, and ultimately the optimized dimensions are ascertained as follows:  $L=15$  mm,  $W=15$  mm,  $R_1=2.1$  mm,  $R_2=1.5$  mm,  $R_3=1$  mm,  $R_4=.75$  mm,  $L_g=15$  mm,  $W_g=15$  mm,  $L_1=3.25$  mm,  $L_2=5.25$  mm,  $L_3=6.5$  mm,  $W_1=6.75$  mm,  $W_2=6.75$  mm,  $W_3=1.5$  mm.

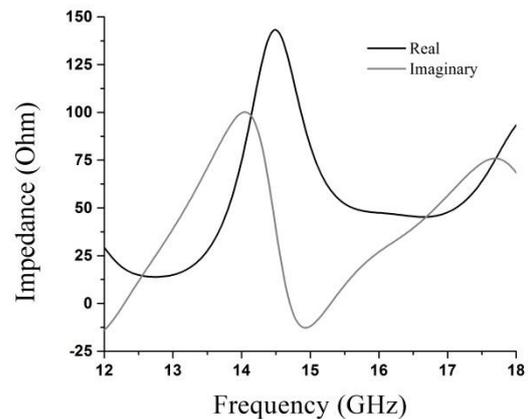


Fig. 2. Impedance of the proposed Ku-band antenna.

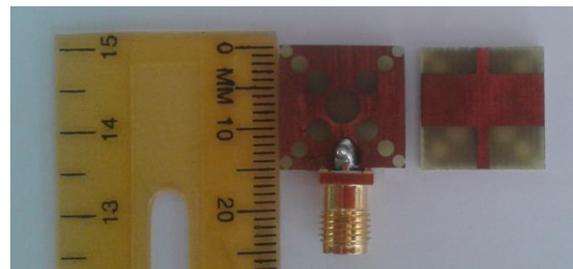


Fig. 3. Prototype of the proposed antenna.

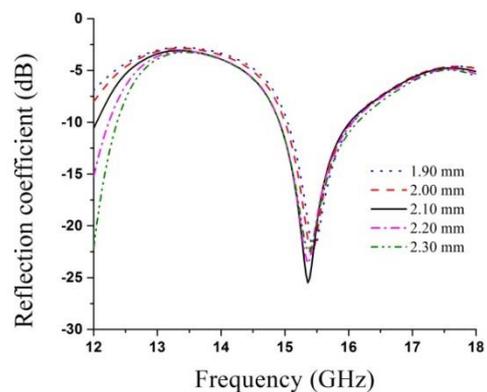


Fig. 4. Reflection coefficient with different values of  $R_1$ .

A parametric study is performed to realize the effects of the proposed Ku-band antenna parameters. Mainly, the effects of the different parameters on the reflection coefficient are observed.

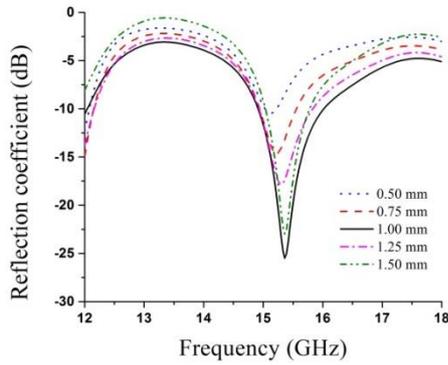


Fig. 5. Reflection coefficient with different values of  $R_3$ .

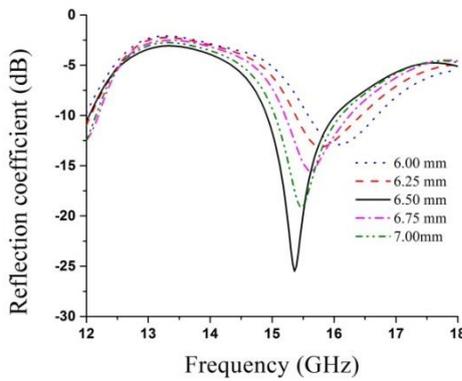


Fig. 6. Reflection coefficient with different values of  $L_3$ .

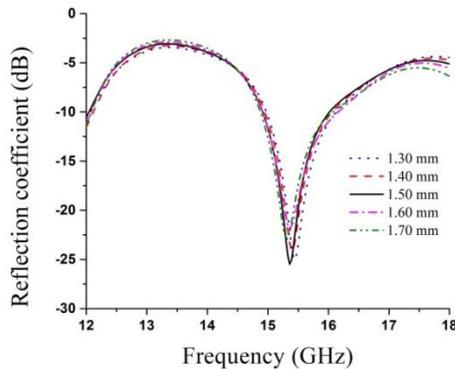


Fig. 7. Reflection coefficient with different values of  $W_3$ .

Fig. 4 indicates the reflection coefficient for different values of  $R_1$ . It includes  $L = 15$  mm,  $W = 15$  mm,  $R_2 = 1.5$  mm,  $R_3 = 1$  mm,  $R_4 = .75$  mm,  $L_g = 15$  mm,  $W_g = 15$  mm,  $L_1 = 3.25$  mm,  $L_2 = 5.25$  mm,  $L_3 = 6.5$  mm,  $W_1 = 6.75$  mm,  $W_2 = 6.75$  mm,  $W_3 = 1.5$  mm with  $R_1$ . It was shown that there are little effects on resonances. The optimized value of  $R_1$  is 2.1 mm.

Fig. 5 illustrates the reflection coefficient for different values of  $R_3$ . It includes  $L = 15$  mm,  $W = 15$  mm,  $R_1 = 2.1$  mm,  $R_2 = 1.5$  mm,  $R_4 = .75$  mm,  $L_g = 15$  mm,  $W_g = 15$  mm,  $L_1 = 3.25$  mm,  $L_2 = 5.25$  mm,  $L_3 = 6.5$  mm,  $W_1 = 6.75$  mm,  $W_2 = 6.75$  mm,  $W_3 = 1.5$  mm with  $R_3$ . It was observed from the graph clearly that better coupling has been acquired at

the operating band using the value of  $R_3$  as 1 mm. That is why; the optimized value is 1 mm.

The reflection coefficient for different values of  $L_3$  is as shown in Fig. 6. It includes  $L = 15$  mm,  $W = 15$  mm,  $R_1 = 2.1$  mm,  $R_2 = 1.5$  mm,  $R_3 = 1$  mm,  $R_4 = .75$  mm,  $L_g = 15$  mm,  $W_g = 15$  mm,  $L_1 = 3.25$  mm,  $L_2 = 5.25$  mm,  $W_1 = 6.75$  mm,  $W_2 = 6.75$  mm,  $W_3 = 1.5$  mm with  $L_3$ . It was observed that impedance is well matched using  $L_3 = 6.50$  mm at the operating frequency bands. 6.50 mm is the optimized value of  $L_3$ .

The reflection coefficient for different values of  $W_3$  is as shown in Fig. 7. It includes  $L = 15$  mm,  $W = 15$  mm,  $R_1 = 2.1$  mm,  $R_2 = 1.5$  mm,  $R_3 = 1$  mm,  $R_4 = .75$  mm,  $L_g = 15$  mm,  $W_g = 15$  mm,  $L_1 = 3.25$  mm,  $L_2 = 5.25$  mm,  $L_3 = 6.5$  mm,  $W_1 = 6.75$  mm,  $W_2 = 6.75$  mm with  $W_3$ . It was observed that there were little effects on reflection coefficient. 1.50 mm is the optimized value of  $W_3$ .

### 3. Results and discussion

The total calculation is performed using commercially available simulation software HFSS to carry out the resonance requirements of the proposed Ku-band patch antenna. A VNA (Agilent E8362C) is used for the measurements with a range of up to 20 GHz in a standard far-field testing environment.

Fig. 8 illustrates the simulated and measured reflection coefficient of the proposed Ku-band patch antenna. Input impedance has been matched properly as well as Feed line has been well-positioned also. As a result, reflection coefficient of -24.42 dB has been obtained at resonant frequency 15.24 GHz. Meanwhile, to examine the effects of the embedded circular slots of the patch to the antenna's matching condition, the measured results of reflection coefficient for the proposed antenna without part of the embedded slots were also studied. A large value of frequency ratio is obtained due to the presence of slots in simulated antenna resonant frequency operation. We have achieved bandwidth 2.70 GHz (14.10 GHz to 16.80 GHz) at the desired resonant frequency. This bandwidth covers Ku-band frequency that has already been mentioned before.

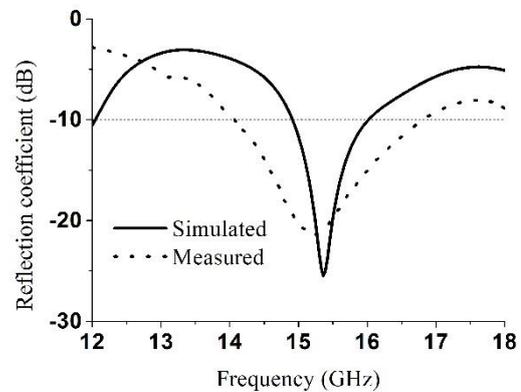


Fig. 8. Simulated and Measured reflection coefficient.

The measured gain of the proposed Ku-band antenna is plotted in Fig. 9. The obtained average gain is 3.66 dBi

where 3.94 dBi is the maximum achieved gain. The radiation and total efficiency of the proposed antenna have been shown in Fig. 10. The average radiation efficiency is 86.65% where the maximum and the minimum radiation efficiency are 91.32% and 75.45% over the operating band. On the other hand, the average total antenna efficiency is 74.56% where the maximum and the minimum total antenna efficiency are 80.29% and 61.20% over the operating band, which are suitable for Ku-band applications.

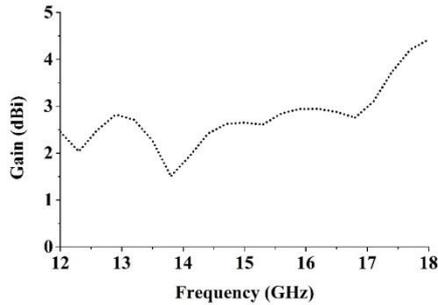


Fig. 9. Measured gain of the proposed antenna.

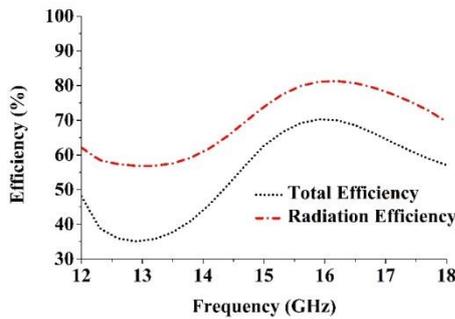


Fig. 10. Efficiency of the Ku-band proposed antenna.

Fig. 11 demonstrates the current distribution of the proposed Ku-band antenna for a) 15 GHz and b) 15.30 GHz, c) 15.70 GHz and b) 15.95 GHz. It can be seen that a large amount of current flows at the center of the patch and the feeding line. Electric field is initiated much in these points. Current distribution is much stable on the entire frequency band. The creation of electric field near slots is reasonable. As a result, excitation is strong in the entire parts of the antenna on the operating band. In current distribution, electrical fringes are important factors. The electrical region around 15.40 GHz is responsible for creating resonance, which is realized from the current distribution plot. Electrical fringes have been overcome in this resonance due to stability in distributing current around 15.40 GHz.

Fig. 12 illustrates the measured radiation pattern of the proposed Ku-band antenna on the E-plane and H-plane at resonant frequency of 15 GHz, 15.3 GHz, 15.6 GHz and 15.9 GHz. It is observed that radiation patterns of good broadside exist, and the resonant frequency has the identical polarization plane. The cross-polarization level is comparatively large in the H-plane, which is desired level owing to the diffractions from the edges of the ground. By

enhancing the ground plane size, this cross-polarization level can be reduced. It is observed from the graphs that durable nearly Omni-directional radiation pattern is attained along the E-plane and H-plane respectively. This property is advantageous, since the propagation condition of wireless communication devices is normally much involutedly in practice. As a result, the radiation pattern of the proposed patch antenna is almost appropriate for Ku-band applications. The measured Smith chart of the proposed Ku-band antenna is plotted in Fig.13 as below. Single resonance  $m_1$  is specified clearly from this chart has validated the evidences.

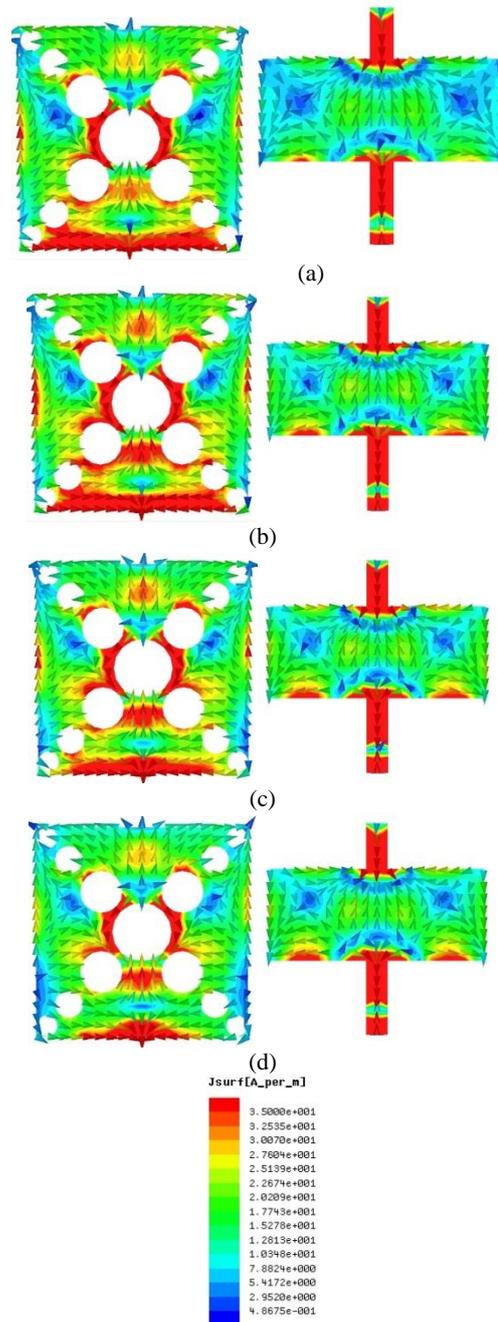


Fig. 11. Current distribution at a) 15 GHz, b) 15.3 GHz, c) 15.7 GHz, and d) 15.95 GHz.

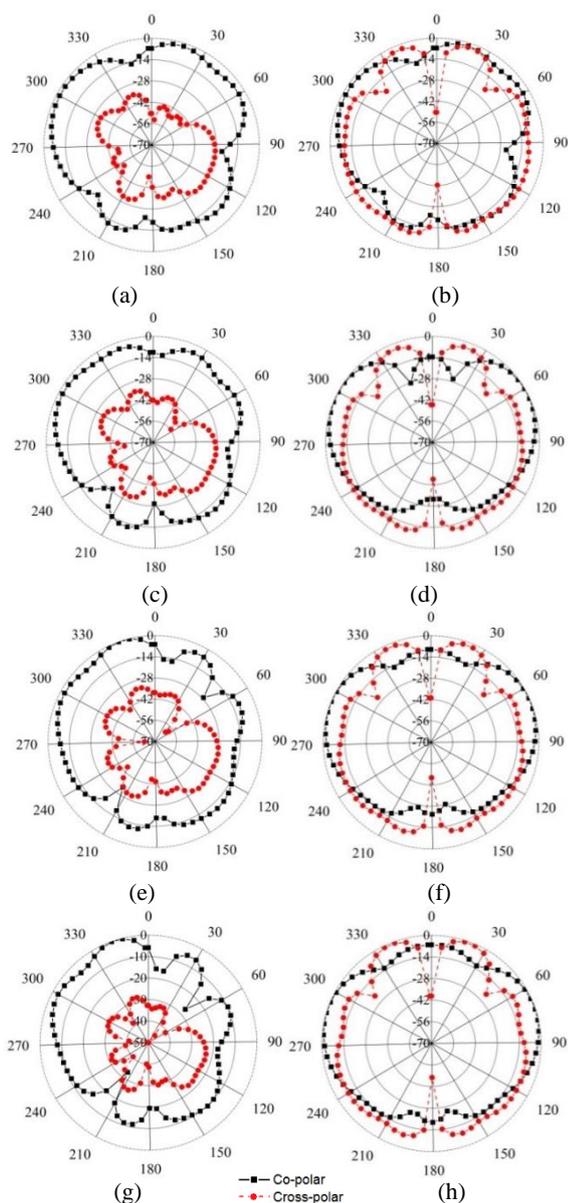


Fig. 12. Measured radiation pattern at a) 15 GHz, b) 15.3 GHz, c) 15.6 GHz, and d) 15.9 GHz.

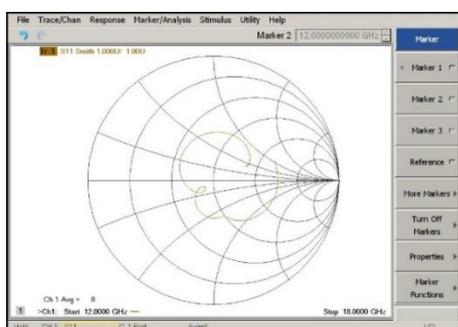


Fig. 13. The measured Smith chart of the proposed antenna.

#### 4. Conclusion

A printed Ku-band patch antenna is proposed with bandwidth improvement in this research. All results

discover that the proposed Ku-band patch antenna is reasonably developed with adding rectangular slots on the ground plane and circular slots on the patch. The Ku-band patch antenna shows average gain of 3.66 dBi, radiation efficiency of 86.65%, an impedance bandwidth of 2.70 GHz, radiation patterns of nearly Omni-directional. This antenna is significant for enhancing bandwidth sharply based on these properties. That is why; this proposed printed antenna is a promising candidate for Ku-band applications.

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#### References

- [1] M. M. Islam, M. R. I. Faruque, W. Hueyshin, J. S. Mandeep, T. Islam, International Journal of Antennas and Propagation, **2014**, Article ID 791521, 2014.
- [2] M. M. Islam, M. T. Islam, M. R. I. Faruque, The Scientific World Journal, **2013**, Article ID 378420, 2013.
- [3] M. M. Islam, M. R. I. Faruque, R. Azim, M. T. Islam, T. Alam, 30<sup>th</sup> Annual Review of Progress in Applied Computational Electromagnetics, USA, pp. 89-94, March, 2014.
- [4] M. Ojaroudi, N. Ojaroudi, N. Ghadimi, Applied Computational Electromagnetics Society Journal, **28**(2), 156 (2013).
- [5] H. Iwasaki, IEEE Transactions on Antennas and Propagation, **44**, 1399 (1996).
- [6] M. Ojaroudi, N. Ojaroudi, S. A. Mirhashemi, Applied Computational Electromagnetics Society Journal, **28**(1), 64 (2013).
- [7] K. L. Wong, New York: J. Wiley and Sons, 2002.
- [8] L. Zhang, Y. C. Jiao, G. Zhao, Y. Song, X. M. Wang, F.-S. Zhang, Journal of Electromagnetic Waves and Applications, **22**(5-6), 741 (2008).
- [9] N. Ojaroudi, M. Ojaroudi, Sh. Amiri, Applied Computational Electromagnetics Society Journal, **27**(8), 685 (2012).
- [10] M. Samsuzzaman, M. T. Islam, M. R. I. Faruque, Journal of Telecommunications and Information Technology, **2**, 19 (2013).
- [11] S. K. Dubey, S. K. Pathak, K. K. Modh, Proceedings of IEEE, **80**(1), (2011).
- [12] R. Azim, M. T. Islam, N. Misran, Informacije MIDEM, **41**(2), 114 (2011).
- [13] M. Samsuzzaman, M. T. Islam, B. Yatim, M. A. M. Ali, Przegląd Elektrotechniczny, **89**(1) A, 275 (2013).
- [14] N. Misran, M. T. Islam, N. M. Yusob, A. T. Mobashsher, Proceedings of IEEE, **80**(1), 2009.

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