Turkish Journal of Computer and Mathematics Education *Vol.12 No.8(2021), 1978-1986*

Research Article

The self- complementary bow-tie vacant dipole with log periodic characteristic quad-band antenna design

Sunanda Roy[a], Jun Jiat Tiang[b], Mardeni Bin Roslee[c], Md Tanvir Ahmed[d], M A Parvez Mahmud[e]

[a,b,c,d,] Faculty of Engineering (FOE), Multimedia University, Persiaran Multimedia, Cyberjaya, Selangor 63100, Malaysia
[e] School of Engineering, Deakin University, Waurn Ponds, Geelong, Victoria 3216 Australia

Article History: Received: 10 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 20 April 2021

Abstract: In this paper, the diagonally symmetrical pair of modified cross dipole inscribed in a circle with equilateral triangular shaped bow-tie log-periodic characteristic quad band antenna is proposed for wireless energy harvesting application. The suggested quad band antenna is capable of satisfying wider bandwidth for available RF frequency bands including GSM 900 (880 MHz-960 MHz), GSM 1800 (1710 MHz-1880 MHz), 3G (1920 MHz-2300 MHz) and Wi-Fi (2.4 GHz-2.45 GHz) in ambient level. The performance characteristic of the antenna is analyzed in terms of scattering parameter, maximum realized gain, total and radiation efficiency, VSWR, surface current distribution and radiation characteristic. The novel configuration of this design achieves directional radiation pattern maintaining a circularly polarized (CP) radiation characteristics. The measurement result of prototype shows that maximum return loss (RL) of this bow-tie antenna is -28 dB, 4.81 dB realized gain and 6.8 dBi directivity at 2.4 GHz, 1.8 GHz resonating frequencies respectively. The excellent characteristic of wider bandwidths over four resonant frequency bands and high gain of the suggested antenna make it promising candidate for multiple wireless communications as well as energy harvesting system.

Keywords: Bow-tie antenna, vacant dipole, inscribed circle with equilateral triangle, energy harvesting, cross dipole.

1. Introduction

Ambient energy harvested from RF signals has the capacity to power microelectronic devices such as wireless sensors and medical implants. This provides an opportunity for the researchers since this can be a feasible alternative to batteries with a very short life span. In order to transform the AC signal into a DC signal consisting of an antenna, a corresponding circuit and a rectifier circuit, this method has a relatively simple formulation. This paper proposes a novel microstrip antenna for harvesting of RF energy for broadband frequency ranging from 500 MHz to 3000 MHz which applies on a variety of wireless systems. The spectrum contains mobile and Wi-Fi signals [1-7] as well as Digital TV signals. Many researchers have been exploring different types of antenna for energy harvesting technology. These proposed antennas are designed with various geometric shapes and are mostly laid on microstrip bases. In order to increase the amount of harvested power, some multiband antennas contain array configuration to increase the gain. Whereas some other researchers focus on multiband operation to increase the amount harvested power. Quite a number of antennas have been presented for operating single band [8, 9]. Proposal has been made for dual bands too [10, 11]. However, Researchers have been focusing on multiband operation of antennas and relentless efforts have been going on to enhance the bandwidth for the operation of multiband antennas. The reason behind this is mainly due to the fact that energy harvesting can be feasible with the multiband operation [1-7].

In [5] an antenna with gain of 2 dBi and spectrum of 850 MHz to 1.94 GHz has been presented. The antenna is bent and triangular in shape. Whereas in [6], the antenna is collar-shaped consisting of two folded dipoles laying on a FR-4 substrate. It has an operating frequency from 1.7 GHz to 3.6 GHz. Additionally, another broadband antenna with a spectrum of 900 MHz to 3GHz has been presented which has energy harvesting capacity too[7]. In [8], a conical shaped wideband antenna with a frequency bandwidth from 2.17 to 4.2 GHz is seen. However, this antenna lacks mobile signals. In [9] another triple band antenna with bandwidth of 900MHz, 1900 MHz and 2.4 MHz is proposed for energy harvesting. An antenna with frequency ranging from 2.1 GHz to 7 GHz (lacking GSM signals) has been reported in [10]. To increase the antenna gain researchers have been implementing an antenna array configuration for capturing more energy [12-14]. Although higher gain can be achieved by this formation, this also results in larger antenna structures. Additionally, energy harvesting applications have also seen circularly polarized antenna structures [15-17]. But an interesting concept has been suggested in recent years to remove the need for a matching circuit. This antenna matches the rectifier's input impedance to remove the need for the matching circuit. The proposed multiband antenna in this paper has operating frequency band within 0.5 GHz to 3 GHz. This quad band antenna is well fit for energy harvesting applications. The size and design of the antenna is feasible and has a broad frequency spectrum for various wireless applications. Hence it emerges as an amazing option for energy harvesting applications. The applicable frequency ranges are: GSM 900 (880 MHz-960 MHz), GSM1800 (1710 MHz-1880 MHz), 3G (1920 MHz-2300 MHz) and WiFi (2.4 GHz-2.45 GHz) in ambient level. Both sides of the design (cross dipole with triangle shape inside a circle) are fabricated by thin film technique and photolithographic process in the Fabrication Laboratory at the Multimedia University.

2.Geometry of the proposed antenna

The geometric details (design process of evolution) of the proposed advanced patch antenna is shown in Figure 1. The antenna is printed on 1.6 mm thick FR4 substrates with a relative permittivity of 4.4 and a loss tangent of 0.02, while the total square shaped region is 154×160 mm^2.

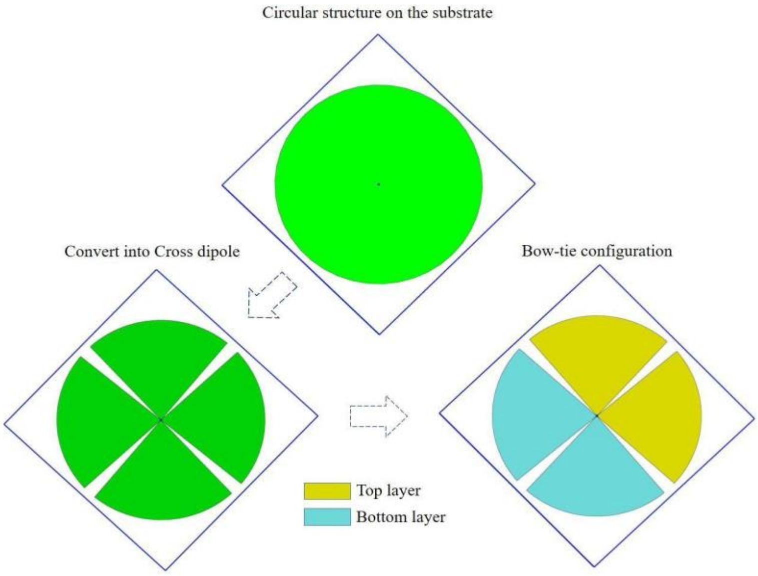


Figure 1. The process of evolution of proposed antenna.

The proposed antenna consists of a self-complementary vacant cross dipole on a Circular patch and together the front and back side dipole make a bow-tie configuration. There are two equilateral triangle shapes with an internal circle inside the vacant dipole, one in front side and the other on the back side. There is a coaxial feeding in the back side as well. In order to build and simulate the proposed antenna, the CST microwave studio 2015 program was used.

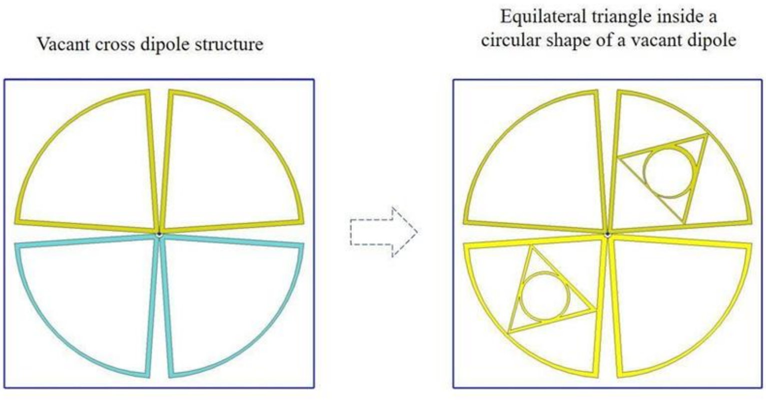


Figure 2. A bow-tie cross dipole with diagonally equilateral triangle inside circular shaped

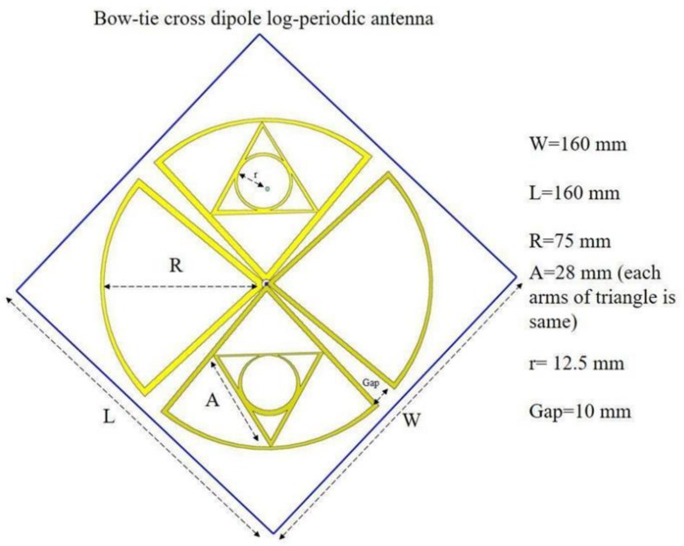


Figure 3. A bow-tie cross dipole with diagonally equilateral triangle inside circular shaped

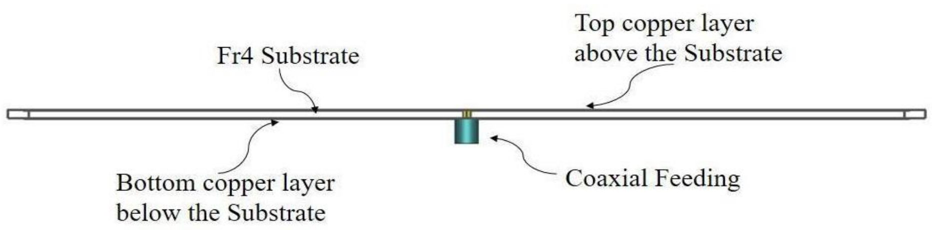


Figure 4. The novel coaxial feeding with top and bottom view of proposed antenna.

3.Antenna performance

Figure 5 displays the frequency response of the proposed antenna's computed return loss (S11). The slotted bowtie antenna operates between 0.89 GHz and 3 GHz and gives four resonant frequencies at 0.89 GHz, 1.83 GHz, 2.18 GHz and 2.45 GHz at their respective frequency bands. The plot shows return loss value of S11 = -14.42 dB at resonating frequency 0.89 GHz, S11 = -20.15 dB at resonating frequency 1.83 GHz, -21 dB at resonating frequency 2.18 GHz and S11 = -14.32 dB at resonating frequency 2.45 GHz. It can be observed (from Fig.4) that reference multiband antenna resonates at 1 GHz with a bandwidth (258 MHz) but the impedance matching performance is poor (less than -8 dB). In order to get higher bandwidth within a higher frequency range (800 MHz to 2.7 GHz), the self-complementary bow-tie dipole shape is adapted to a frequency-independent log-periodic cross dipole with incircle equilateral triangle, as depicted in Figure 2.

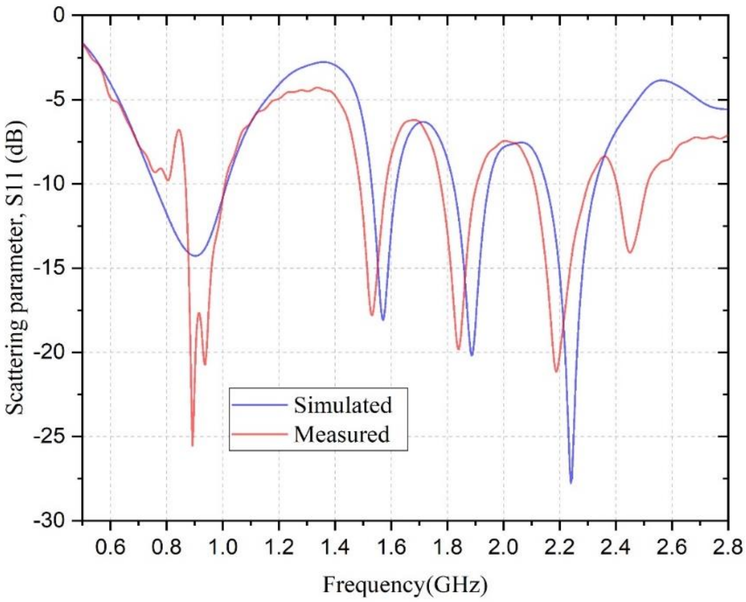


Figure 5. Comparison of S-parameter of the proposed antenna.

In order to increase the scattering parameter of the proposed antenna, the diagonal set of dipoles are modified with a triangle inside a circular shape which is connected to a novel coaxial feeding that can produce the dual circular polarized radiation field to progress the performance parameters of self–complementary new dipoles structure. The dual pairs of cross dipoles are connected by a 50 ohm coaxial feeding in the center of the antenna to generate a 90-degree phase delay and in the front and back of the antenna, a right hand circular polarization radiation field and left hand circular polarization radiation field are created, as shown in Figure 3. It is noticeable that the impedance matching is able to develop by using coaxial feeding technique. The average signal level of simulated scattering parameter (S11) beyond the bandwidth has been increased from -9.2 dB to -20 dB. Moreover, an equilateral triangle with 2.5 mm wide arms is designed inside the dipoles on the substrate to cover the frequency bands lower 1GHz. The single complementary set of modified dipole structure is situated in the diagonal position of the proposed antenna. A circular shape is designed inside a triangle on top of the front and back side of the PCB board to occupy the last target frequency band. In order to fulfil the condition for circular polarized radiation pattern (Figure 4) and to improve the impedance matching, a single complementary pair of vacant-dipole is designed in either layer of the single diagonal position of the proposed bow-tie multiband antenna. The antenna gain values with the frequency are shown in Figure 6.

Average gains range from 3.95 dB to 4.84 dB in all four bands, indicating that the antenna can provide stable gains in the four working frequency bands. The suggested antenna maximum realized gain in 0.89 GHz resonance band is about 3.95-3.99 dBi; highest gain in 1.83 GHz is about 4.45-4.47 dBi; peak realized gain in 2.19 GHz is about 4.42-4.45 dBi; peak realized gain in 2.45 GHz is 4.80-4.83 dBi for lower and higher frequency bands, respectively. The variation of realized gain are smaller than 1.46 dBi. The efficiency results (Figure 7) demonstrate that the total efficiency of the antenna varies from 99.9% to 96.34%, hence it can be predicted that the antenna works with very high efficiency within its operational bandwidth. Table I represents the measured efficiencies for various resonance frequencies of the proposed antenna. Figure. 8 represents the comparison of measured and simulated result of the VSWR plot for the proposed antenna. The value of VSWR is less than 1.3 and higher than 1, in the range from 0.89 GHz to 2.45 GHz. to perform efficiently, the simulated VSWR result should be in between the value of 1 to 2[18], hence it assures the good impedance matching over the operation frequency bands. It is suitable level of VSWR of the proposed antenna for the multiband operation efficiently. In order to realize the radiation mechanism of the physical behavior of the bow-tie log periodic antenna, current distributions both the top and bottom surface are depicted in Figure 9. The current distribution at the four resonance frequencies of the suggested antenna are 0.89 GHz, 1.83 GHz, 2.18 GHz and 2.45 GHz respectively. It can be seen that for all the different frequencies, there is a significantly higher current distribution around the triangle. At 0.89 GHz and 2.45 GHz frequency bands, the comparatively higher density current distributions are exhibited on the center and inner structures of the cross dipole, where domain mood and lower resonant mood mainly contributed. The surface current distribution in the diagonal dipole at 1.83 GHz and 2.19 GHz frequencies have slightly lower density, as shown in Figure 9.

Table 1. Different efficiencies at different frequency bands.

Frequency (GHz)	0.98 GHz.	1.84 GHz	2.19 GHz.	2.45 GHz
Total Efficiency (%)	99.9	97.47	98.15	96.35

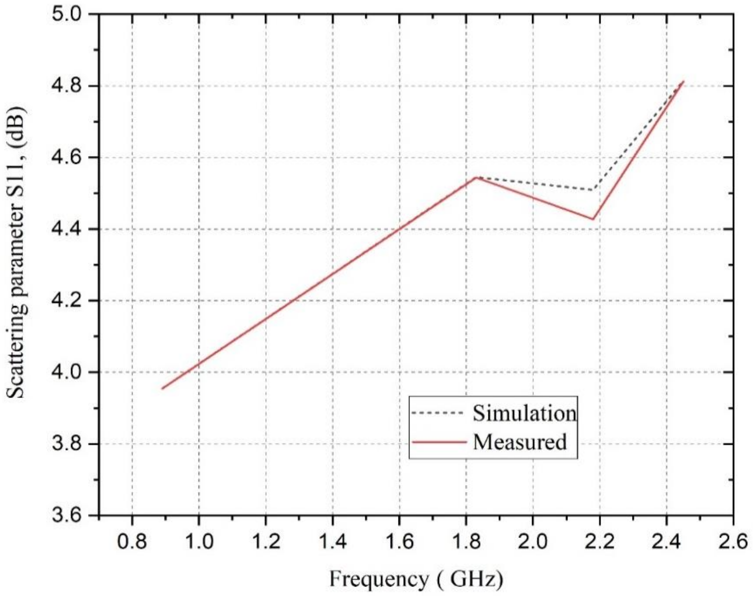


Figure 6. The comparison of realized gain of the proposed antenna.

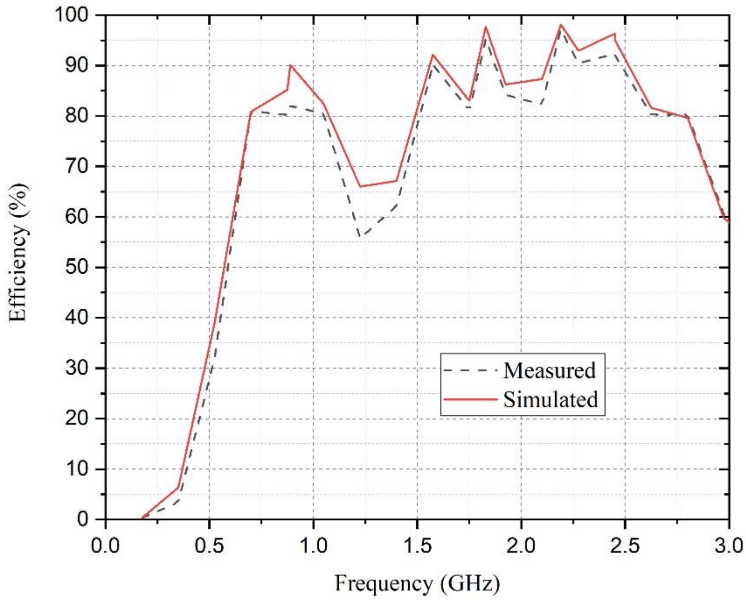


Figure 7. Comparison between simulated and measured total efficiency of the proposed antenna

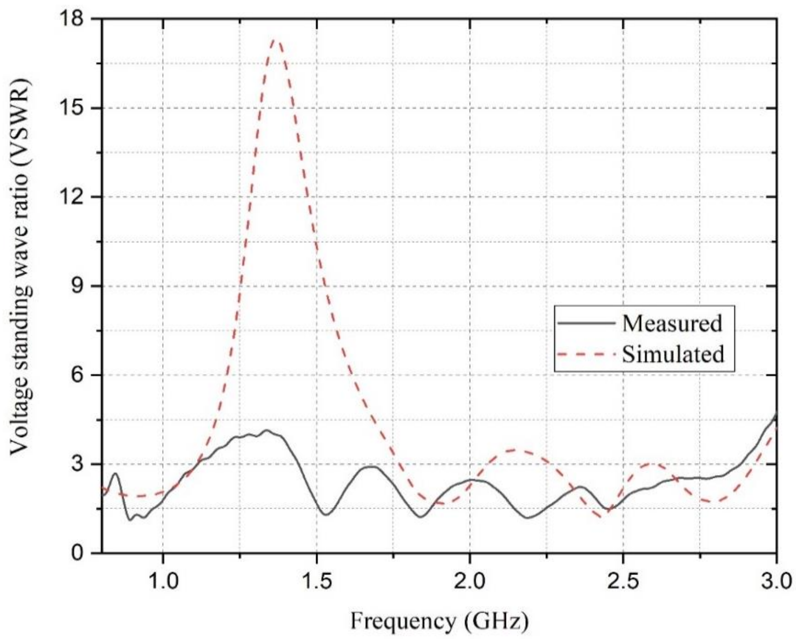


Figure 8. Comparison between simulated and measured vvoltage standing wave ratio (VSWR) versus the frequency.

For performance analysis of the far-field radiation pattern of the suggested bow-tie log periodic quad band antenna, we exhibit measured co and cross polarization of radiation pattern at E- and H-planes at the four resonance bands at 0.89 GHz, 1.83 GHz, 2.19 GHz and 2.45 GHz respectively. The broadside radiation pattern are noticed to be more stable for operation at the four resonance frequencies. As stated by the far-field radiation patterns are depicted in Figure 10, it is indicated that the bow-tie antenna is circular in the x-y plane (H field) with low co-polarization.

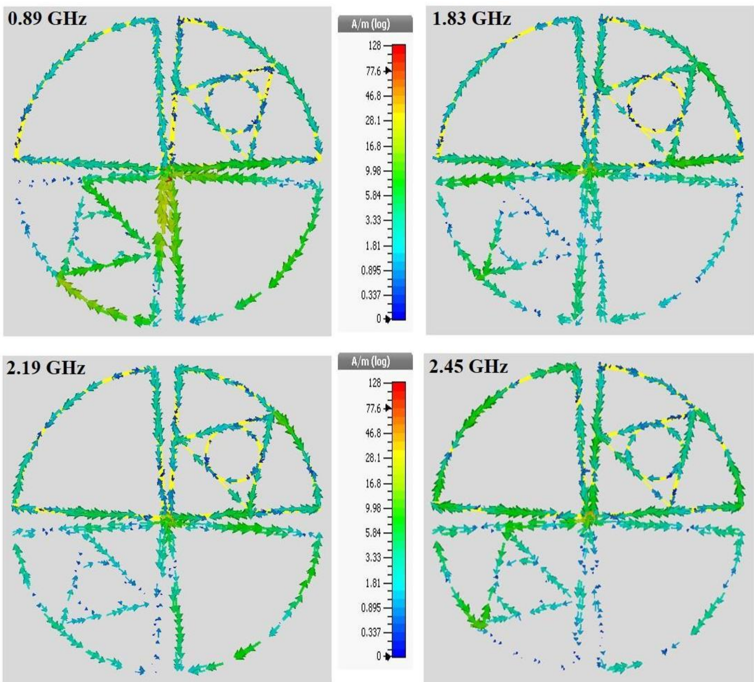


Figure 9. The surface current distribution at different resonance frequency.

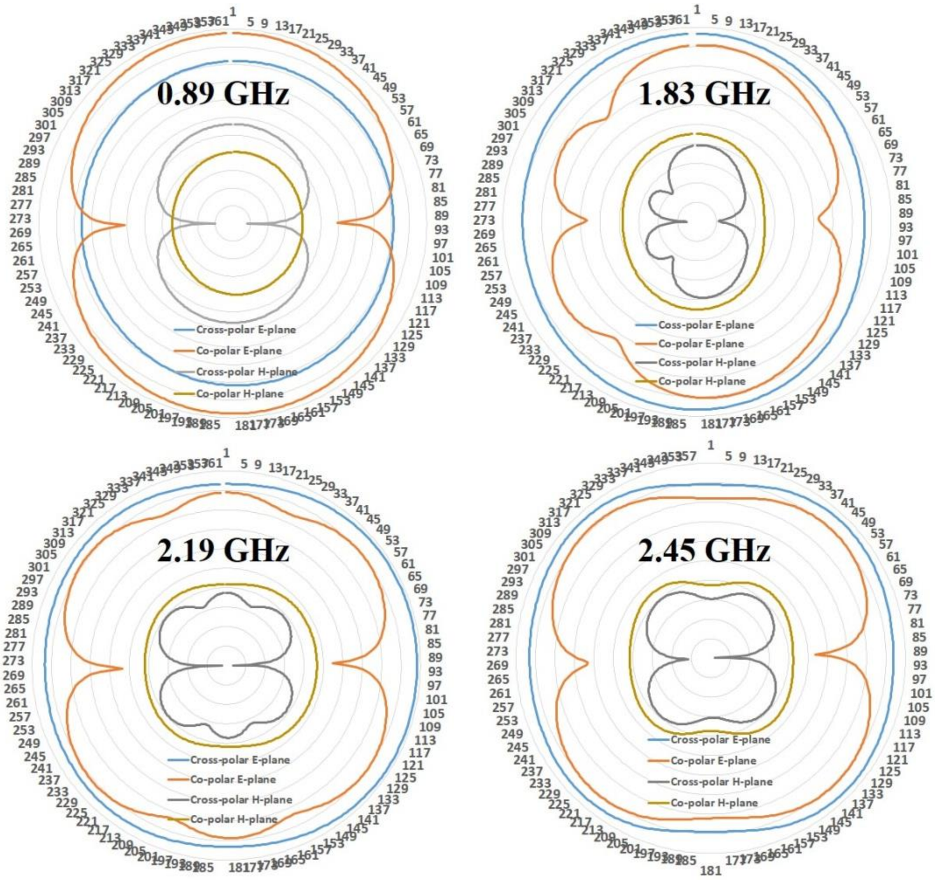


Figure 10. The measure radiation pattern at different frequency bands.

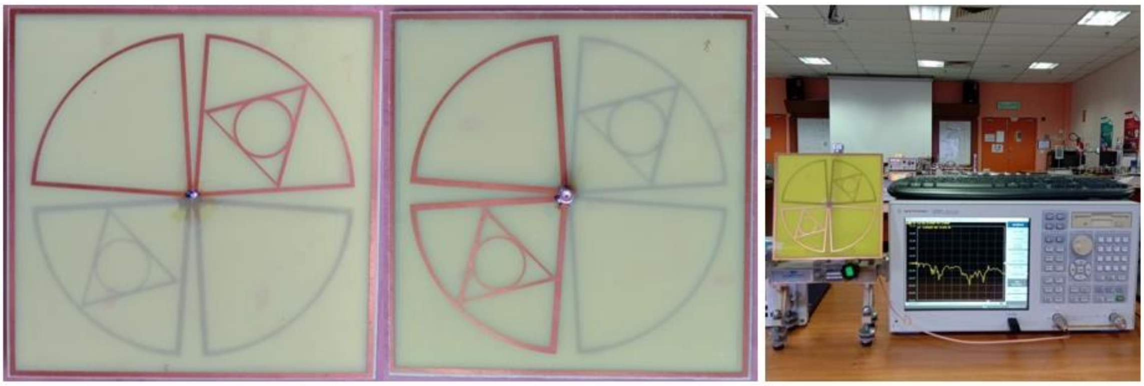
Table 2. A slightly more complex table with a narrow caption.

Frequenc y (GHz)	Directivit y (dBi)	Gain (dB)	E-Field (dBV/m	*H-Field (dBA/m)*	Power Pattern (dBVA/m2))
0.89	3.72	3.94	95.9	42.4	110.9
1.83	4.59	4.49	82.2	40.9	110.8
2.19	4.56	4.47	83.3	42.4	110.9
4.45	4.86	4.64	87.4	40.4	110.6

The E field polarization in x-z plane is more stable in cross polarization too. Whatever, the co –polarization is slightly stronger in y-z plane. It is concluded that the far- filed radiation patterns of bow-tie antenna with higher co-polarization than cross-polarization broadside radiation in both E and H planes with some discrepancies at different resonance frequencies as well. By analyzing the value it can be deduced that it is a highly directive antenna and directivity is consistent for all frequency bands. The directivity at various resonances frequencies of the proposed antenna are shown in Figure 10. Table 2 shows the different performance parameters (directivity, gain, E-Field, H-Field and power pattern) of the proposed antenna. Besides its directional radiation patterns, the wide bandwidth of the antenna makes the proposed antenna an excellent candidate for RF energy harvesting.

4.Measurement Result

In order to prove the validification of the proposed antenna, fabricated prototype is measured in the lab. The photography of the fabricated antenna structure is shown in Figure 11. The ENA series Network Analyzer E5062A is used to determine the antenna performance parameters (S-parameter, VSWR, AR, gain and radiation pattern). Overall, the simulated antenna parameters are in excellent agreement with measurements except few discrepancies.



(a) (b) (c)

Figure 11. Prototype image of proposed antenna (a) Font side (b) Back side (c) Measurement in lab.

Figure 5 shows the simulated and measured scattering parameter of the suggested antenna. It is noticed that simulated performance of |S11| suitably matched with measured result. Similarly, measured result in realized gain, efficiency and VSWR of the proposed antenna are good agreement with simulated results.

5.Conclusion

An advanced quad band bow-tie antenna has been designed and investigated in this article. This antenna provides an option which can be incorporated into numerous energy harvesting devices. It has a feasible and distinguished design of a bow-tie patch element with a circular shape inside a triangle. This antenna operates within 500 MHz to 3000 MHz which can be applied to GSM, 3G, LTE and Wi-Fi as well as many other similar wireless communication platforms. The realized gain, VSWR, radiation pattern, current distribution and total efficiency level at different operating frequencies shows good performance parameters and acceptable measured results. Considering all this, it can be a promising candidate for the demanding field of energy harvesting applications as well as multiband wireless applications

References

1. M. Arrawatia, M. S. Baghini, and G. Kumar, “Broadband Bent Triangular Omnidirectional Antenna for RF Energy Harvesting”, in IEEE Antennas and Wireless Propagation Letters, vol. 15, no., pp. 36-39, 2016
2. Juan Wen, D. Xie, X. Liu, H. Guo, Ch. Liu , and Xinmi Yang, “Wideband collar-shaped antenna for RF energy harvesting”, 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Shenzhen, 2016, pp. 253-255
3. X. Wang, Z. Zhao, G. Chen, and F. He, “RF energy harvesting with broadband antenna”, 2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific), Beijing, 2014, pp. 1-5
4. N. A. Zainuddin et al., “Design of wideband antenna for RF energy harvesting system”, 2013 3rd International Conference on Instrumentation, Communications, Information Technology and Biomedical Engineering (ICICI-BME), Bandung, 2013, pp. 162- 166
5. B. L. Pham, and A. V. Pham, “Triple bands antenna and high efficiency rectifier design for RF energy harvesting at 900, 1900 and 2400 MHz”, 2013 IEEE MTT-S International Microwave Symposium Digest (MTT), Seattle, WA, 2013, pp. 1-3
6. R. Maher, E. Tammam, A. I. Galal , and H. F. Hamed, “Design of a broadband planar antenna for RF energy harvesting”, 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), Chennai, 2016, pp. 1808- 1810
7. Z. Zhou, W. Liao, Q. Zhang, F. Han, and Y. Chen, “A multi-band fractal antenna for RF energy harvesting”, 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, 2016, pp. 617-618
8. M. Zeng, A. S. Andrenko, Hong-Zhou Tan, Chong Lu and Xianluo Liu, “Fractal loop antenna with novel impedance matching for RF energy harvesting”, 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility (APEMC), Shenzhen, 2016, pp. 966-968
9. M. S. Khan, and H. Deng, “Design and implementation of a highly efficient UHF energy harvesting antenna”, 2016 IEEE International Symposium on Antennas and Propagation (APSURSI), Fajardo, 2016, pp. 611-612

10. M. Saad-Bin-Alam , and S. Moury, “Multiple-band antenna coupled rectifier circuit for ambient RF energy harvesting for WSN”, 2014 International Conference on Informatics, Electronics & Vision (ICIEV), Dhaka, 2014, pp. 1-4
11. S. S. Sarma, and M. J. Akhtar, “A dual band meandered printed dipole antenna for RF energy harvesting applications”, 2016 IEEE 5th Asia-Pacific Conference on Antennas and Propagation (APCAP), Kaohsiung, 2016, pp. 93-94
12. M. Mathur, A. Agarwal, G. Singh, and S. K. Bhatnagar, “The array structure of 2 × 2 coplanar monopole antenna with Wilkinson power combiner for RF energy harvesting application”, 2016 International Conference on Recent Advances and Innovations in Engineering (ICRAIE), Jaipur, 2016, pp. 1-4
13. L. j. Xu, B. Huang, X. Bai, and H. p. Mao, “A dualband and broadband antenna array for ambient RF energy harvesting”, 2016 IEEE International Conference on Ubiquitous Wireless Broadband (ICUWB), Nanjing, 2016, pp. 1-3
14. Y. Tawk, F. Ayoub, C. G. Christodoulou , and J. Costantine, “An array of inverted-F antennas for RF energy harvesting”, 2015 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting, Vancouver, BC, 2015, pp. 1278-1279
    A. M. Jie, Nasimuddin, M. F. Karim, L. Bin, F. Chin, and M. Ong, “A proximity-coupled circularly polarized slotted-circular patch antenna for RF energy harvesting applications”, 2016 IEEE Region 10 Conference (TENCON), Singapore, 2016, pp. 2027-2030
    S. Roy, M. A. Samad and S. Podder, “Effect of complementary triangular split ring resonator on microstrip patch antenna", 2015 2nd International Conference on Electrical Information and Communication Technologies (EICT), Khulna, 2015, pp. 353-358
    B. Song et al., “Matching Network Elimination in Broadband Rectennas for High-Efficiency Wireless Power Transfer and Energy Harvesting”, in IEEE Transactions on Industrial Electronics, vol. 64, no. 5, pp. 3950-3961, May 2017
15. Kamo, B., Cakaj, S., Koliçi, V., Mulla, F., “Simulation and Measurements of VSWR for Microwave Communication Systems”, International Journal of Com-munications, Network and System Sciences, 5, 767-773

Acknowledgments
This research was funded by TM R&D project account: MMUE/190001 and Research Grant No. MMUE/190001.02