A double annular ring slot printed antenna for multifrequency band communications using epoxy resin fiber substrate

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This letter presents a new design of a compact multi-frequency band antenna, which is composed of two concentric annular ring slots and a circular patch. The antenna resonates at around 1.48, 2.1, 2.3, 3.85 and 4.6 GHz while its bandwidths cover from 1.41-1.50 GHz, 1.88-2.65 GHz and 3.30-4.85 GHz at S_{11}<-10 dB (VSWR 2:1). It has a compact overall dimension of 0.14λ × 0.186λ and a small partial ground of 0.03λ × 0.14λ, where λ considered at the lowest resonance. With a very simple configuration, the antenna operating range supports multiple wireless applications, covering the PCS/GSM1900 (1850–1990 MHz), UMTS (1850–1990/ 1920–2170 MHz), ISM/Bluetooth/ZigBee/RFID/WLAN/ Wi-Fi (2400-2485 MHz), WiMAX (3300-3600 MHz), and LTE (1427-1500/ 1850-1990/ 1910-1930/ 1920-2170/ 1900-2620/ 2010-2600/ 2300-2400/ 2500-2690/ 2570-2620/ 3400-3600/ 3600-3800 MHz) frequency bands. Moreover, the antenna obtained good polarization purity, radiation efficiency and an average peak gain of 4.5 dBi over the bands. For practical validation, the proposed antenna has been prototyped and tested; the measured results agreed very well to the simulations.

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1. Introduction

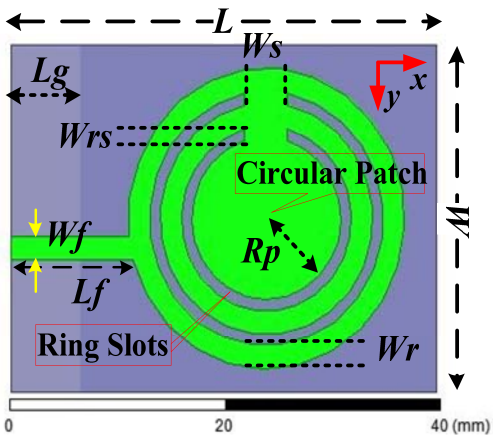
With the ever-growing use of wireless communication devices at multiple standard frequencies, there is a huge demand for multiband antennas that can adapt to those standard frequency bands. Moreover, mobile communication systems are rapidly advancing and thus requiring a single device to be compatible with multiple operating bands such as global systems for mobile (GSM) 1900/personal communication systems (PCS) (1850–1990 MHz), universal mobile telecommunication systems (UMTS) (1850–1990/1920–2170 MHz) and 2.4 GHz Bluetooth, wireless local area network (WLAN). Besides, the state-of-the-art multifunctional smart mobile phones and wireless sensor modules for the handy devices compels multiband antennas. Moreover, those antennas have to be suitable for the recent most 4G/long-term evolution (LTE) technology as well along with the before said bands.

A substantial research effort has been given to obtain multi-resonant characteristics from a single antenna element like a planar monopole, inverted-F and slot antennas [1-8]. Printed antennas are very much attractive from the perspective of their flexibility, frequency tunability and ease of construction [9]. Different techniques have been incorporated to design multiband printed monopoles like a monopole with coupled strips, a coupled-fed shorted monopole and a CPW-fed LI-shaped monopole [1, 2, 4, 9]. In [1], a coupled-fed planar antenna realized with a two-branch feeding strip, a 113 mm long meandered coupling strip and a chip inductor of 2.7 nH for improved impedance matching at LTE/GSM/UMTS bands. However, the gain is low, and the reflection coefficient level is moderate. Another coupled-fed antenna proposed in [2] is a complex combination of coupling pad, feeding pad, coupling strip, shorting strip and long-short radiators. Two different radiators are placed on the top and bottom side of a large 118mm x 47 mm substrate, while its gain varied from -1.9 to 4.6 dBi at different bands. Similarly, the multiband antenna designed with a two-strip monopole (S and inverted-F strip) and a meandered strip in [3] supports several bands and the peak gain was found between 1.5 to 3.2 dBi. Besides the various type of substrate, material has been used to design a patch for different applications [10-12]. In this research, we have designed a compact slotted patch antenna with low-cost epoxy resin substrate. A coplanar waveguide (CPW)-fed multiband bow-tie monopole antenna was proposed. This antenna can be easily designed to meet the requirement of multiple operating frequencies by using the proposed approach. Multiple bent monopoles, which correspond to different operating frequencies, are generated by etching slots of different lengths in a bow-tie patch. This study demonstrates a triple-band slotted bow-tie monopole antenna for WLAN/WiMAX/LTE applications with bands of 2.4–2.7 GHz, 3.4–3.7 GHz, and 5.2–5.8 GHz [13]. A folded loop antenna having a very compact size of with multiband operation for ultra-thin smartphone 5×8×60 mm^3applications was presented. The antenna generates four resonant modes, the traditional 0.5-λ, 1-λ and 1.5-λ resonant modes and an extra higher-order 2-λ resonant mode, to cover the GSM850, GSM900, DCS1800, PCS1900, UMTS, TD-SCDMA, LTE2300 and WLAN systems [14]. The design of a four-band slot antenna for the global positioning system (GPS), worldwide interoperability for microwave access (WiMAX), and wireless area network (WLAN) was proposed. The antenna consists of a rectangular slot with an area of 0.37λg × 0.14λg = 48 × 18 mm^2 (where λg is the guide wavelength), a T-shaped feed patch, an inverted T-shaped stub, and two E-shaped stubs to generate four frequency bands. The radiating portion and total size of the antenna are less than those of the tri-band antennas studied in the literature[15]. A quad-band circularly polarized (CP) antenna for 2.4/5.3/5.8-GHz WLAN and 3.5-GHz WiMAX applications was presented. Three CP modes operating at the 2.4/3.5/5.8-GHz frequency bands are first achieved by a patch antenna composed of an inverted-U-shaped radiator with additional I-shaped and L-shaped strips, all rotated by 45 degrees around the horizontal axis [16]. This communication introduces an approach for designing miniaturized single-feed multiband patch antennas. The size reduction is obtained by loading shorting metalized vias on one edge of the radiating patch, while multiband is obtained by etching multiple inverted U-shapes. A dual-band antenna with a large measured frequency ratio of 2.74 is first discussed. Then triple-band and further quad-band antennas are, respectively, designed [17].

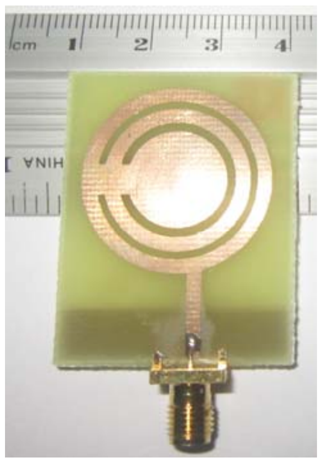
In this letter, we propose a simple, compact multiband antenna configuration, realized with a circular patch surrounded by two annular ring slots and two interconnected ring radiators. The antenna operating bands cover multiple wireless applications including GSM/PCS1900, UMTS1900/2100, 2.4 GHz ISM/Bluetooth/ZigBee/RFID/WLAN/Wi-Fi, WiMAX and several LTE bands, with an acceptable gain around 4.5 dBi. The antenna design and performances are detailed in the following sections.

2. Antenna configuration

The proposed multiband antenna comprises two concentric annular ring slots that surround a circle at the center, as depicted in Fig. 1. The central patch has a radius of R_p while the ring slots have a width of *Wrs*. Thus, two ring radiators of W_r strip width are produced around the patch, and they help to achieve multiple resonances. However, the rings are connected to the central patch through a straight strip of W_s width. The main radiator is printed on the front side of a 1.6 mm thick FR4 dielectric material (relative permittivity = 4.6, loss tangent = 0.02), while a partial ground is printed on the backside of the substrate. A 50-Ω microstrip line with a width of W_f = 2.2 mm is used to excite the antenna from the −x-direction. Overall, the antenna has a compact dimension of 0.14λ × 0.186λ and a small partial ground of 0.03λ × 0.14λ, where λ is considered concerning the lowest resonance. Additionally, the small ground plane size of the proposed antenna makes it suitable for almost any portable device. The microstrip line feeding technique is used to excite the antenna where the feed line is offset, connected to the outer ring and has a dimension of W_f × L_f. The design mentioned above parameters are tuned through a large number of electromagnetic simulations in 3D electromagnetic High Frequency Structured Simulator (HFSS), a finite element method based on the electromagnetic solver. From the simulations, the optimized design parameters are as: *Rp*=6.98, *Wr*=2.1, *Ws*=3.84, *Wrs*=0.95, *Wf*=2.2, *Lf*=11.48, *Lg*=6.5, *W*=30 and *L*=40, all in mm unit. These parameters have been chosen to maintain the multi-resonance characteristics in the GSM, PCS, UMTS, ISM, WLAN, WiMAX, LTE, etc. bands while the overall antenna size remains as small as possible.



(a)

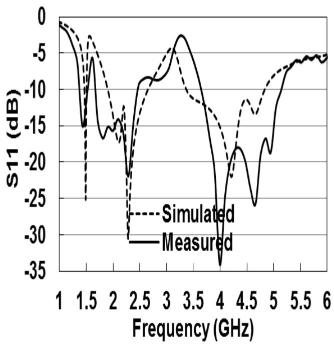


(b)

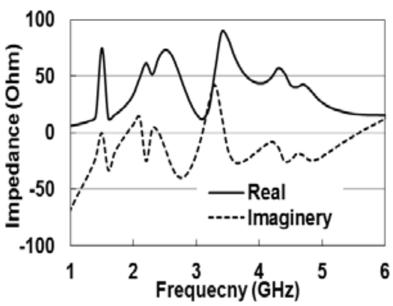
Fig. 1. The proposed double annular ring slot multiband antenna (a) Antenna geometry (b) Fabricated prototype

3. Antenna performance analysis

Based on the optimized parameter of the proposed multi-band annular ring monopole antenna, the proposed antenna was fabricated and tested. Apart from the simulations, a lab prototype of the proposed antenna has been fabricated with the optimized parameters, as shown in Fig. 1*b*. For practical verification, the antenna was tested using a far-field measurement setup facilitated with an Agilent E8362C vector network analyzer. Fig. 2*a* showed the simulated and measured S_{11} parameter curves against the operating frequency. Basically, three distinct operating bands are found at S_{11}<-10 dB (VSWR 2:1), with an impedance bandwidth of 90 MHz (1.41-1.5 GHz), 770 MHz (1.88-2.65 GHz) and 1550 MHz (3.3-4.85 GHz), respectively. The resonant frequencies are at around 1.48, 2.1, 2.3, 3.85 and 4.6 GHz, respectively. The feeding point is offset from the center, and the microstrip feed line size is adjusted for better impedance matching. However, the measured 10 dB impedance bandwidth is 100 MHz (1.42-1.52 GHz), 770 MHz (1.71-2.48 GHz) and 1430 MHz (3.71-5.14 GHz). Fig. 2*b* depicts the impedance characteristics of the antenna over the operating bands. The annular ring slots played an important role in obtaining multiple bands since they created two ring radiators and lengthened the electric current path. The ring edges contribute to radiate at some frequencies while the lengthy electric path helps to achieve a lower resonance.



(a)



(b)

Fig. 2. Antenna resonance characteristics (a) Simulated and measured S_{11} parameters (b) Impedance characteristics

The slot contributions can further be analyzed by observing the surface current density at different frequencies, as described in Fig. 3. At the lowest resonance of 1.48 GHz, the ring radiators are the main contributor while the inner ring and the circular patch radiates at 2.1 and 2.4 GHz. However, the circular patch becomes less radiating at 3.6 GHz, but the inner ring is still excited and radiate at this frequency.

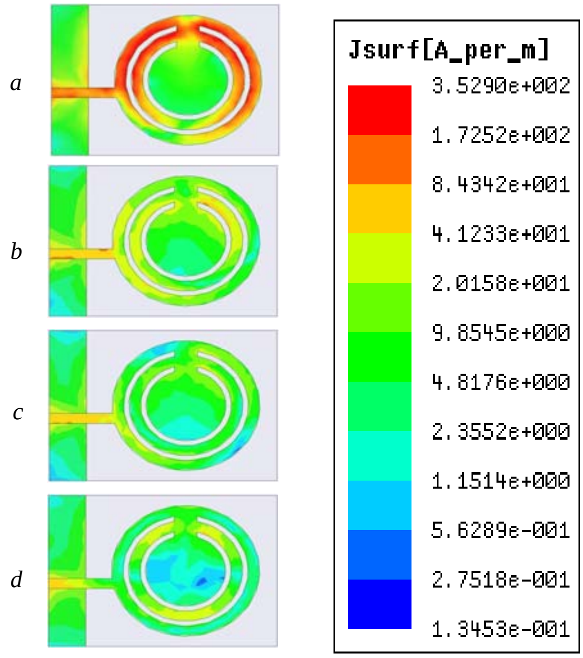
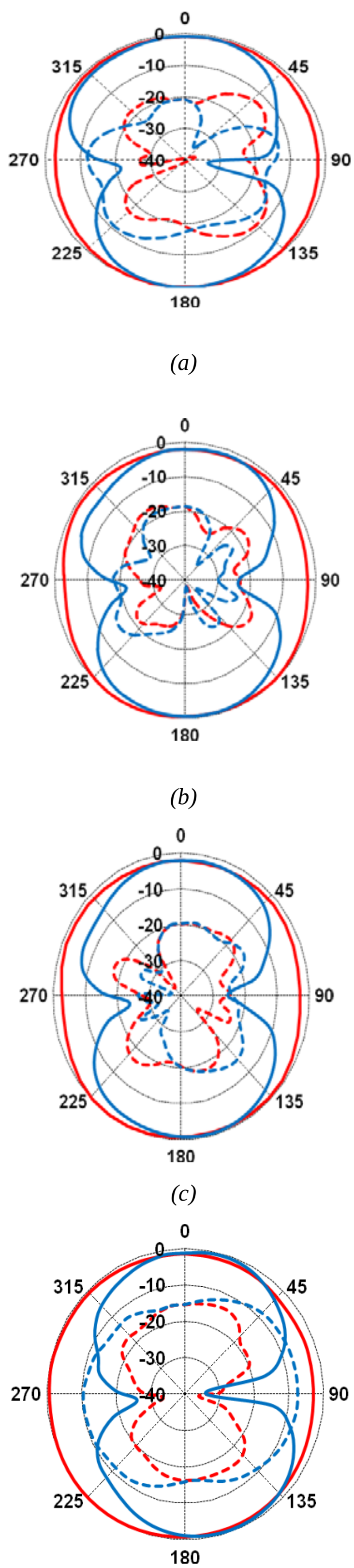


Fig. 3. Surface current distribution on the main radiator at (a) 1.48 (b) 2.1 (c) 2.4 and (d) 3.6 GHz

Fig. 4 depicts the normalized radiation characteristics of the antenna at different frequencies. Clearly it can be seen that the antenna has omnidirectional radiation in the *y-z* plane while it is donut/dumbbell shape in the *x-z* plane, almost at all resonant frequencies. The cross-polar component is also as low as -15 dB/-20 dB at these frequencies except at 3.6 GHz, where the *x-z* plane cross component becomes slightly larger, but still, it is below -10 dB. It would be worth to mention that, usually, the cross-component effect becomes noticeable with increasing frequency due to the excited higher order modes. Nonetheless, the antenna exhibits very promising radiation performances at the respective frequencies, which are very much useful for wireless applications like GSM, PCS, RFID, Bluetooth, WLAN, Wi-Fi, WiMAX, etc. and the most recent 4G/LTE technology.



(a)

(b)

(c)

(d)

Fig. 4. Normalized radiation characteristics of the proposed antenna (a) 1.48 (b) 2.1 (c) 2.4 and (d) 3.6 GHz. [y-z plane: Red lines and x-z plane: Blue lines; Co-pol: Pure lines and Cross-pol: Dashed lines]

The simulated gain of the antenna is compared with the measured one, in Fig. 5. The three antenna gain measurement technique is used to measure and calculate the practical gain over the three operating bands. One can see that, the measured gain peaks are about 4.7, 3.9, 5.2 and 3.6 dBi at 1.48, 1.9, 2.4 and 3.7 GHz, respectively. Despite some mismatches due to fabrication imperfection, misalignment and measurement tolerances, the simulations are pretty close to the measurement. Since the antenna aperture is not so wide compared to its multiple resonant characteristics, thus the gain is not very high, but still well acceptable as found in the state-of-the-art in this area.

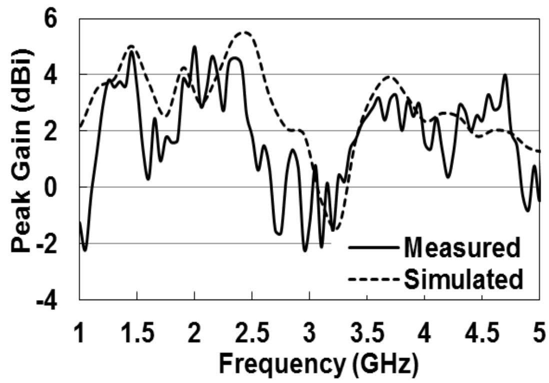


Fig. 5. The simulated and measured peak gain of the proposed antenna

4. Conclusion

A novel concentric double annular ring slot, circular patch multiband antenna is designed, prototyped and tested. The proposed multiband antenna comprises two concentric annular ring slots that surround a circle at the centre. The two ring radiators are produced around the patch, and they help to achieve multiple resonances. The rings are connected to the central patch through a straight strip, which makes the compact dimension (40mm × 30mm × 1.6mm). The antenna has a compact size and can support multiple wireless applications in the PCS/GSM1900, UMTS1900/2100, 2.4 GHz ISM, Bluetooth, ZigBee, RFID, Wi-Fi, 3.6 GHz WiMAX, and several LTE frequency bands, covering the frequency range from 1.41 to 4.85 GHz. Moreover, it has 4.5 dBi peak gain on average over the bands, good polarization purity, and FB ratio, which make it very suitable for those mentioned applications and portable devices.

Acknowledgments

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References

[1] C. T. Lee, S. W. Su, Microwave Opt. Technol. Lett. **54**, 109 (2012).
[2] D.-G. Kang, Y. Sung, IET Microwaves, Antennas & Propagation **6**, 1007 (2012).
[3] J. Janapsatya, K. P. Esselle,T. Bird, Microwave Opt. Technol. Lett. **50**, 138 (2008).
[4] H.-W. Liu, C.-F. Yang, Electron. Lett. **46**, 21 (2010).
[5] T. Zhang, R. Li, G. Jin, G. Wei, M. M. Tentzeris, IEEE Trans. Antennas Propag. **59**, 4209 (2011).
[6] Y.-L. Ban, J.-H. Chen, J. L.-W. Li, Y. Wu, IET Microwaves, Antennas & Propagation **7**, 399 (2013).
[7] Y. Jee, Y.-M. Seo, Electron. Lett. **45**, 446 (2009).
[8] M. I. Hossain, M. R. I. Faruque, M. T. Islam, J. Optoelectron. Adv. M. **18**(1-2), 148 (2016).
[9] M. S. Alam, M. T. Islam, N. Misran, Electron. Lett. **49**, 86 (2013).
[10] M. Samsuzzaman, M. T. Islam, J. S. Mandeep, Optoelectron. Adv. Mat. **7**(9-10), 760 (2013).
[11] M. M. Islam, M. T. Islam, M. Samsuzzaman, M. R. I. Faruque, Optoelectron. Adv. Mat. **9**(5-6), 831 (2015).
[12] T. Alam, M. R. I. Faruque, M. T. Islam, M. Samsuzzaman, Optoelectron. Adv. Mat. **9**(7-8), 1058 (2015).
[13] M.-T. Wu, M.-L. Chuang, IEEE Antennas Wirel. Propag. Lett. **14**, 887 (2015).
[14] D. Wu, S. Cheung, T. Yuk, IEEE Trans. Antennas Propag. **63**, 2745 (2015).
[15] Y. Cao, S. Cheung, T. Yuk, IEEE Trans. Antennas Propag. **63**, 952 (2015).
[16] T. V. Hoang, T. T. Le, Q. Y. Li, H. C. Park, IEEE Antennas Wirel. Propag. Lett. **15**, 1032 (2016).
[17] A. Boukarkar, X. Q. Lin, Y. Jiang, Y. Q. Yu, IEEE Trans. Antennas Propag. **65**, 850 (2017).

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