A Design of a Metamaterial Integrated Triple Band Antenna for Wireless Applications

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***Abstract*—This paper represents a metamaterial (MTM) integrated antenna for multi-band operation. MTMs are integrated on the top and bottom sides of a slot-ring antenna. The basic slot-ring antenna operates at 2.4 GHz. A single complementary split ring resonator (CSRR) is placed on the ground plane and a circular shaped split ring resonator (SRR) is integrated on the top of the substrate. Integration of CSRR gives rise to a new resonant frequency at 1.5 GHz. After using SRR, a third band generates at 3.1 GHz. By using this structure, a single antenna can cover three operating bands. A microstrip line is used to feed the antenna. The triple band antenna is compact because MTM unit cells size is smaller than their wavelength used to produce resonance at a lower frequency. To analyze the performance of the proposed antenna reflection coefficient, radiation pattern, and gain are analyzed. The simulated gains are 0.71 dBi, 2.9 dBi, and 3.2 dBi corresponding to bands of 1.5 GHz, 2.4 GHz, and 3.1 GHz, respectively. The impedance bandwidths are 1.33%, 9.17%, 5.5% at the 1.5/2.4/3.1 GHz, respectively. Good separation between co- and cross-polarizations is achieved. The three operating bands at 1.5/2.4/3.1 GHz support the allotted bands for GPS, WLAN and RADAR applications.**

Keywords*—*CSRR, metamaterial antenna, multi-band, negative-index material, SRR, slot-ring antenna, unit cell

I. Introduction

Fostering a tremendous way to attain the peak of success, mobile communication is now possessing a vast field for research which includes network with radio frequency identification (RFID), wireless sensor, harvesting of microwave energy, wireless local area network (WLAN), worldwide interoperability for microwave access (WiMAX), multiple input, multiple output (MIMO) systems, quality of service (QoS), satellite communication system etc. For wireless communication system, antenna is a key element which can make the whole system efficient with its high performance. Resonance, bandwidth, gain, directivity, etc. are some basic features to improve the antenna's performance. Along with them, compactness and multi-mode are of great importance for antennas that are used in the present days. These two characteristics can be achieved by designing a multi-band antenna which is disseminated in wireless communication with its attributes like compact size, reduced number of antenna frugality, and so on.

With the development of various communication services like Wi-Fi, Bluetooth, global positioning system (GPS), long term evolution (LTE), etc., the need for multi-band antenna is growing faster than ever. But as it can be activated for different bandwidths, the gain could be sometimes lower than average or the size can be larger. This problem can be solved by adding metamaterials with split ring resonator.

Metamaterials are artificially synthesized composite of periodic and non-periodic structures with unnatural macroscopic properties [1]. They exhibit negative index of refraction for certain wavelengths which is capable to affect the electromagnetic radiation. Metamaterials with negative permeability can enhance the radiated power of antenna. Though, antenna with low resonance point is usually larger in size than a high frequency antenna, the use of metamaterials in antenna can lessen the antenna dimension, improve the directivity, and besides make the frequency tunable.

To design an effective multi-band antenna, multiple resonators can be used to acquire multiple modes. An antenna having dual-band operation has been reported in [2] where metamaterial consists of an inner SRR and an outer circular ring resonator. A novel approach for antenna miniaturization is illustrated in [3] in which loading of SRR in conjunction with an L-shaped radiator results in size reduction. A single-cell metamaterial is integrated with the monopole that operates in triple bands has been reported in [4]. In antenna design, metamaterials having negative values of refraction or alternatively called left-handed materials (LHMs) and electromagnetic band-gap (EBG) structure have been widely used [5-6]. In [7], two novel metamaterial antennas having electric-LC component and EBG structure working in WLAN and WiMAX. Another multi-band antenna having a monopole and radiating patch etched with an inverted L- shaped slot and the ground plane stacked metamaterial unit cell been demonstrated in [8]. In this antenna, monopole and L-shaped slot create two resonant modes. Another third resonance generates after loading metamaterial. In 2002, an ultra-wideband (UWB) antenna consist of complementary SRR has been reported which has band notch characteristics over a large frequency range [9]. A two-layer metamaterial-based UWB antenna has been reported in [10]. In this configuration, the radiating patch is comprised of π-shaped unit cells and crossed-shaped slot incorporated in the bottom plane for metamaterial structure. Single and multilayered metamaterials have been used to increase the gain and directivity of vivaldi antenna reported in [11]. A novel kind of circularly polarized and dual-frequency linearly polarized antenna where polarizations are controlled by the gap orientation of complementary split ring resonator is presented in [12]. A quad-band metamaterial antenna has been reported in [13] where a circular SRR is integrated with a square fashioned patch antenna having two parasitic components and three slots on the backside of the substrate. In works [14], two triple-band antennas are proposed, where the first design is integrated with metamaterial in the practice of complementary split ring

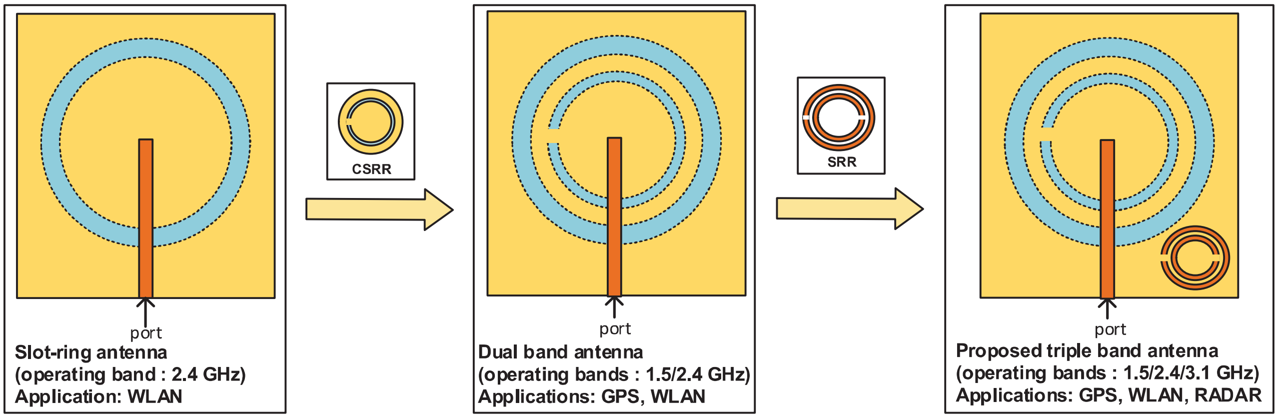


Fig. 1. Design mechanism of the proposed antenna.

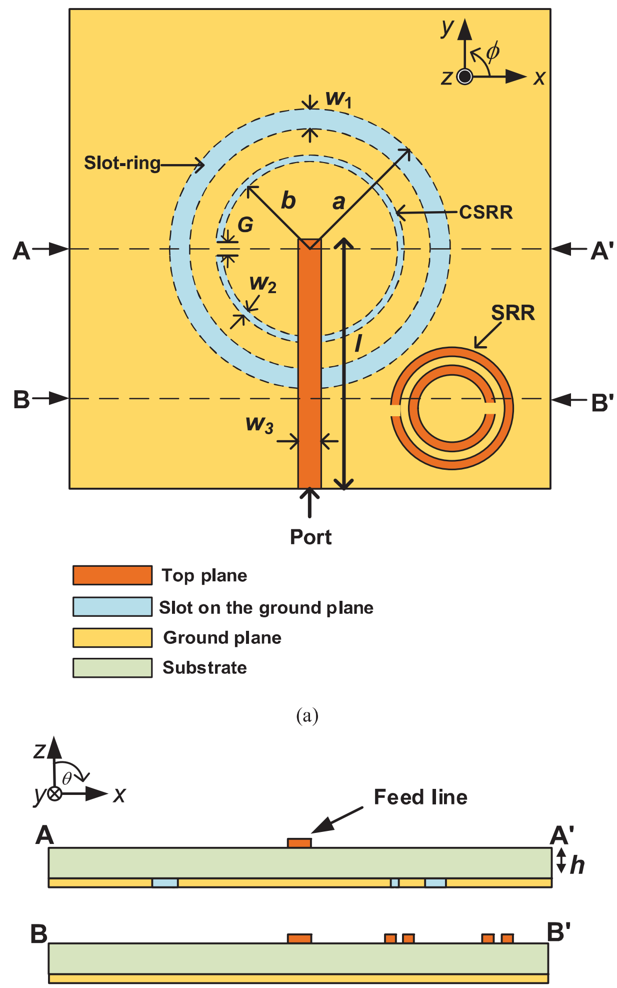
resonator (CSRR) left-handed TL and the second one is with diminutive size with the help of interdigital capacitors.

In this work, a triple band antenna is designed by employing metamaterial cells on both sides of the substrate. The basic concept is to the use of non-natural magnetic conductors in the form of CSRR and SRR with a slot-ring antenna to design a multiband antenna. Basically, the slot-ring antenna is used to generate a resonance at 2.4 GHz. By integrating CSRR and SRR, another two bands at 1.5 GHz and 3.1 GHz are created. Integration of CSRR generates a zeroth-order resonant frequency at 1.5 GHz. The proposed design is compact which uses a simple feeding technique and could be useful for GPS, Wi-Fi, and S-band applications.

II. Antenna Design

The design mechanism of the proposed multi-band antenna is illustrated in Fig. 1. In the beginning, a microstrip line feed slot-ring antenna is designed at 2.4 GHz. To turn this single band antenna into a dual-band, an SRR is integrated on the top of the substrate and a single CSRR is incorporated in the ground plane. A single cell SRR is composed of a couple of metallic circles with splits in them at inverse closures. A magnetic flux infiltrating the metal rings will incite pivoting flows of current in the rings, which produce their very own motion to improve or contradict the occurrence field (contingent upon the SRRs resounding properties). The electrical analogous of the split ring resonator is an LC circuit. And the separation between two rings produces large capacitance. By varying the separation between two rings, lower resonance can be achieved [3]. The CSRR is the dual of SRR where the electrical and magnetic properties of the CSRR are opposite to the SRR. In this design, a single CSRR is placed on the ground plane and an SRR is placed on the top of the substrate, near the right side of the feed line. The integration of single CSRR causes the quasi-static resonant frequency at 1.5 GHz and SRR causes the creation of a resonant frequency at 3.1 GHz.

The schematic layout and cross-sectional views of the proposed multi-band antenna are presented in Fig. 2. Basically, a basic circular slot-ring antenna having outer radius of a, and slot width of w_1 is incorporated on the ground plane. A simple microstrip line of height l and width w_3 is used to feed the slot-ring antenna. The feed line is positioned



(a)

(b)

Fig. 2. Geometry of the proposed MTM triple band antenna. (a) schematic layout, (b) cross sectional view (AA' and BB').

on the top of the substrate. Rogers RO4003 is used as substrate whose effective permittivity is 3.36 and height (h) is 2.1 mm. To ensure the maximum power transfer to the slot, the feed line is extended along the y-axis by a length of $\lambda/4$ from the bottom of the slot. The overall size of the antenna is 25×25 mm^2. This slot-ring antenna is designed to resonate at 2.4 GHz. To produce a lower resonant frequency, a CSRR is

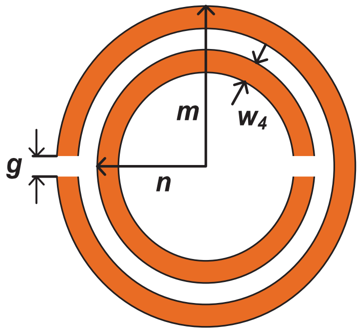


Fig. 3. Unit cell of the SRR.

TABLE I. DIMENSON OF THE SUGGESTED ANTENNA

Parameter	Dimension (mm)	Parameter	Dimension (mm)
a	8	*m*	6.2
w_1	0.8	*n*	5.4
l	13	*G*	0.4
b	5.5	w_2	0.3
ε	3.36	*h*	2.1
w_4	0.4	*g*	0.4
w_3	0.8	*t*	0.018

placed on the ground plane, having an inner radius of *b*, width of w_2 and thickness of *t*. The CSRR is designed to produce negative index around 1.5 GHz. As a result, the CSRR loaded structure adds another lower resonant frequency at 1.5 GHz without changing the fundamental resonant frequency of the basic slot-ring antenna. Moreover, the size of the resonator is much smaller than the guided wavelength. Therefore, this lower frequency band is also achieved without increasing the size of the antenna. Addition of SRR at the right side of the feed line causes the antenna resonate at new frequency band of 3.1 GHz. The same resonant frequency is generated, if the SRR is placed on the left side of the feed line. The unit cell of SRR used in the proposed antenna is shown in Fig. 3. The radius of the outer ring and inner ring are *m* and *n*. The width of the strip is w_4 and split gap *g* are of same size. The resonant frequency of the SRR is related to its physical dimensions by the following simplified equation given by [1].

$$f_{SRR} = \frac{c}{2\pi^2}\sqrt{\frac{3(m-n-w_4)}{\mathrm{Re}(\varepsilon_r)n^3}} \tag{1}$$

where the speed of light is *c* and relative permittivity is ε_r. So, the proposed antenna operates in three bands at 1.5/2.4/3.1 GHz. All the dimensions of the worked antenna are listed in TABLE I.

III. PARAMETRIC ANALYSIS

With an aim to find how resonant frequencies are related to the basic parameters of the structure, a parametric investigation is done. Fig. 4. illustrate the deviation of the reflection co-efficient when the value of radius '*b*' is varied from 13.6 to 14.2 mm in an interval of 2 mm. It is noticeable that when *b* decreases, lower resonant frequency at 1.5 GHz is shifted to the left side. Increase in *b* causes lower resonant

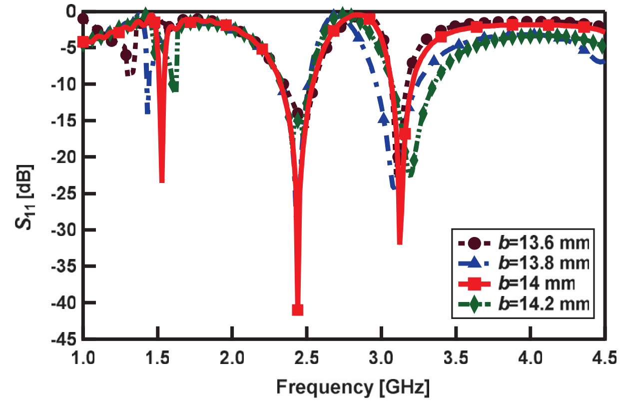


Fig. 4. Influence of the variation of *b* on the reflection co-efficient.

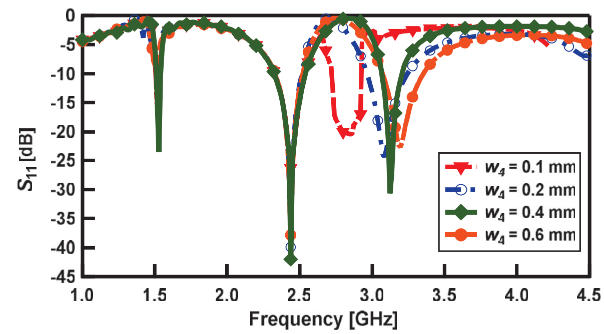


Fig. 5. The consequence of the alteration of w_4 on the reflection coefficient.

frequency shifted to the right side. The variation of 2.4 GHz band is shifted to the right side. The variation of 2.4 GHz band is negligible and the resonance at 3.1 GHz is slightly affected by the variation of *b*. The optimum value of *b* is 14 mm.

Fig. 5 illustrates the effect of the variation of ring width w_4 on the reflection co-efficient curve. At w_4 = 0.4 mm, a good resonance occurs at 3.1 GHz. Lowering the value of w_4 causes lower resonant frequency shifted to the left side and increase in ring width causes resonant frequency shifted to rightwards. The variation of the other two bands due to w_4 is not remarkable.

IV. SIMULATION RESULTS AND DISCUSSION

The simulated reflection co-efficient curves of multi-band antennas are shown in Fig. 6. From Fig. 6, the simulated impedance bandwidth of slot-ring antenna is 220 MHz, corresponding to percentage bandwidth of 9.17% at 2.4 GHz. When a CSRR integrated on the ground plane, without changing the resonant frequency of slot-ring antenna, a lower resonance occurred at 1.5 GHz. At 1.5 GHz, the operating bandwidth is 20 MHz, corresponding to percentage bandwidth of 1.33%. This frequency is sovereign of the structural span of the antenna. That means a closely spaced zeroth-order resonance occurred after CSRR loading. Integration of SRR with CSRR loaded slot-ring antenna gives rise to another new operating band at 3.1 GHz, without disturbing the operation of another two bands. The impedance bandwidth is 5.5% (bandwidth of 170 MHz) at 3.1 GHz.

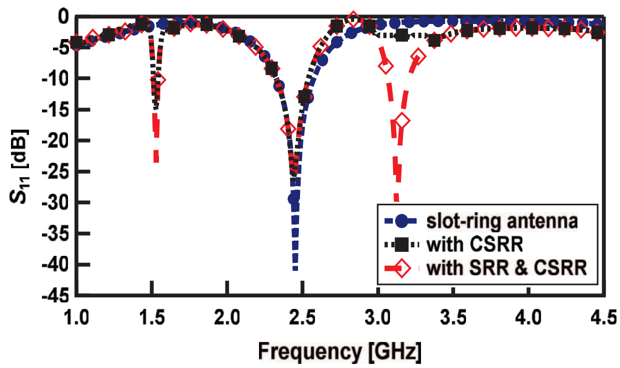


Fig. 6. Reflection co-efficient curves of the designed antenna.

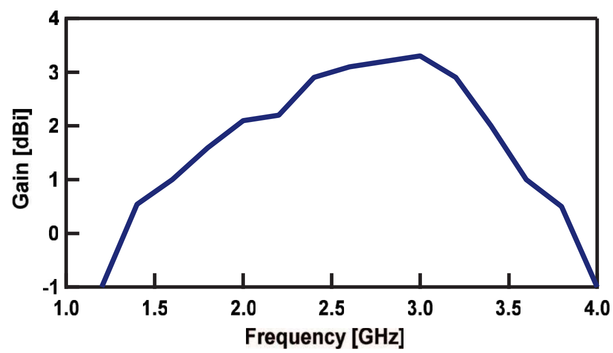


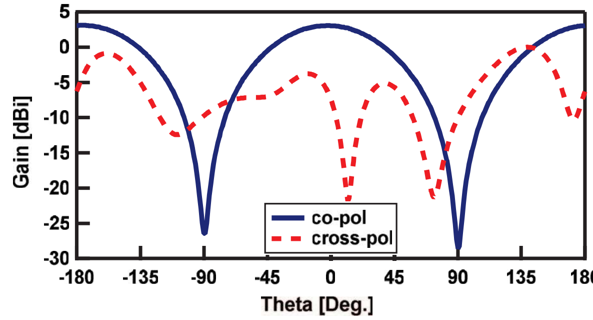
Fig. 7. Gain of the suggested triple band antenna.

To ensure the optimum performance of the designed multi-band antenna, various parameters such as co-polarizations, cross-polarizations, and gain at the three frequency bands are investigated.

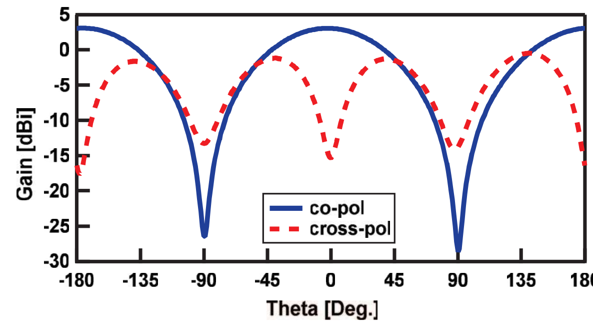
The gain of proposed design is depicted in Fig. 7. The antenna gains at 1.5/2.4/3.1 GHz bands are 0.71dBi, 2.9 dBi, and 3.2 dBi, correspondingly. At 1.5 GHz, the gain is low because the physical dimension is lower associated with the resonant frequency. The size of the dipole antenna is half of its wavelength and maximum gain is around 2.23 dBi. But the proposed antenna is smaller than its actual size. As a result, gain decreases at 1.5 GHz.

The proposed antennas radiation performances at 1.5 GHz, 2.4 GHz, and 3.1 GHz in the *x-z* plane are depicted in Fig. 8. From these radiation patterns, it is noticeable that isolation between co and cross polarizations are more than 20 dBi.

A comparative study is enumerated in TABLE II, in which size of the antenna, impedance bandwidth, gain are highlighted from the literature. From this comparative study, it is seen that compared to the designs reported in [2], [7], and [14], the size of the proposed antenna is small. Moreover, the proposed design uses a very simple feeding technique having moderate percentage bandwidth and gain. The configuration of the proposed design is very compact compared to the quad-band structure reported in [13]. The benefit of the proposed multi-band antenna is that it does not require any band stop



(a)



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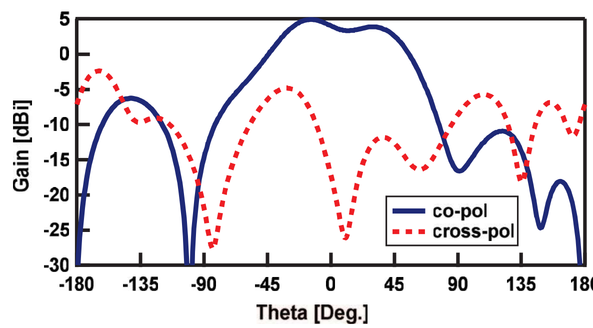

(c)

Fig. 8. The radiation pattern of the triple band antenna in the *x-z* plane. (a) 1.5 GHz, (b) 2.4 GHz, (c) 3.1 GHz.

filter compared to an ultra-wideband antenna for operating in three individual bands. The size of the antenna for GPS application is smaller than the guided wavelengths. So, the proposed antenna is compact as compared to the dual, triple and quad-band antennas listed in TABLE II along with simple configuration and could be used for various communication devices.

V. CONCLUSION

A metamaterial-based triple band antenna has been designed to accommodate the GPS (1.5 GHz), Wi-Fi (2.4 GHz), S-band RADAR (3.1 GHz) applications. The CSRR integrated slot-ring metamaterial antenna is able to produce a lower operating band at 1.5 GHz and the integration of SRR give rise to a new operating band at 3.1 GHz. The simulated

TABLE II. COMPARATIVE STUDY OF THE PROPOSED MULTIBAND ANTENNA

Reference	Dimension (mm^2)	Frequency band (GHz)	10-dB Impedance BW (%)	Gain (dBi)	Configuration
[2]	31.7×27	2.6/3.6	2.3/29	0.532/1.983	simple
[7]	35×35	2.5/3.5/5.5	2.4/20.35/18.36	----	simple
[13]	25×38	2.47/3.2/5.39/8.78	4.45/28.4/8.95/18.31	2.6/2.4/4.1/3	simple
[14]	75×70	0.9/1.25/2.4	0.5/2.5/2	---	simple
Proposed antenna	25×25	1.5/2.4/3.1	1.33/9.17/5.5	0.71/2.9/3.2	very simple

percentage bandwidths are 1.33%, 9.17%, and 5.5% at 1.5 GHz, 2.4 GHz, and 3.1 GHz, respectively. The antenna gains are 0.71, 2.9, and 3.2 dBi at the 1.5, 2.4, and 3.1 GHz frequency bands. Moreover, the proposed work shows good radiation performance in the three operating bands. The size of the antenna for GPS applications is smaller than the guided wavelength. Another advantage of the proposed design is that it does not require any band stop filter for triple band activity, unlike to the UWB antenna. So, the proposed antenna is compact, simple configuration and could be a potential candidate for various modern wireless devices.

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