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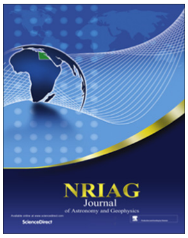

Tri-band small monopole antenna based on SRR units

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Abstract In this paper a novel design for a tri-band monopole antenna coupled with metamaterial units is introduced. The proposed antenna was designed to cover WiMAX (2.5, 3.5) and WLAN (5.2) bands. In our proposal, a coplanar waveguide (CPW) fed circular-disk monopole antenna is coupled with three split ring resonator (SRR) units which exist on its back side. In our design a monopole antenna and SRR units are designed first to resonate at 5.2 GHz and 2.5 GHz respectively. In addition, antenna is loaded with post to force resonance at 3.5 GHz. SRR units are used for 2.5 GHz resonance to miniaturize antenna size, and our proposed antenna considered an electrically small antenna (ESA) at its first resonance frequency. Simulated and measured results exhibit a good agreement that validate our design.

1. Introduction

Spreading of wireless communication networks gives a great attention to the design of multi-band antennas that have low cost, low profile, compact size and light weight. Printed antennas have these advantages and can be designed to realize broadband or multi-bands responses.

Many printed monopole antennas were designed and fabricated for dual or multi-bands wireless applications (Liu and Wu, 2007; Song et al., 2011). Miniaturization is required, especially for new wireless generation devices. Many researchers rely on split ring resonators (SRR) to achieve electrically small antenna (ESA). For example, Alici et al. (2010) fabricated an antenna with size less than $\lambda/10$. In this design, two perpendicular SRRs with different electrical sizes were excited to resonate at 4.72 GHz and 5.76 GHz with efficiencies 15% and 40% respectively. They also studied in Alici and Ozbay (2007a) an ESA that is composed of monopole and SRR, in which the antenna resonates at 3.62 GHz with 43% efficiency. Malik and Kartikeyan (2012) reduced the physical size of microstrip patch antenna by loading patch with complementary split ring resonator (CSRR). Si and Lv (2008) composed a closed ring resonator and SRR for a compact multi-band planar antenna design.

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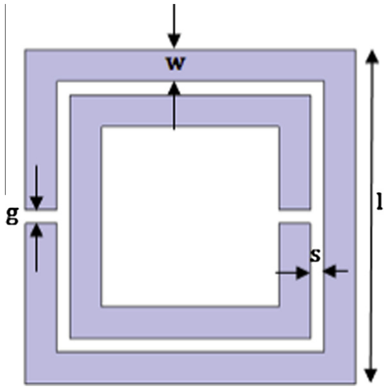


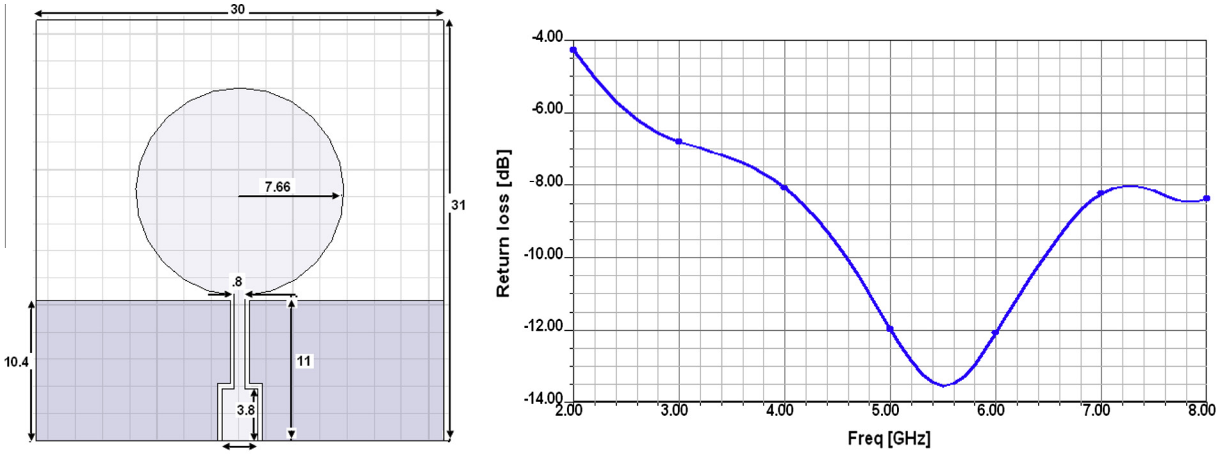
Figure 1 Split ring resonator with design parameters.

In addition to the reduction of antennas size, SRR can also be used for filtering purposes. Yin et al. (2008) designed a circular monopole ultra wideband antenna with multiple band notches using SRR and L-type band stop filter. Kim et al. (2006) etched slot type SRR near the feeding point of UWB antenna to notch the antenna band at 5.2 GHz which is used for WLAN services. The composite closed ring resonators and SRR introduced in Si and Lv (2008) show a frequency notching function to achieve multi-band operation.

Our proposed antenna first relies on composing SRR units with monopole antenna to realize dual band; monopole antenna has a wide band response, and coupling SRR units with monopole result in dual band response exploiting filtering function of SRR. Second, using post with reactive loads to realize and adjust tri-band response.

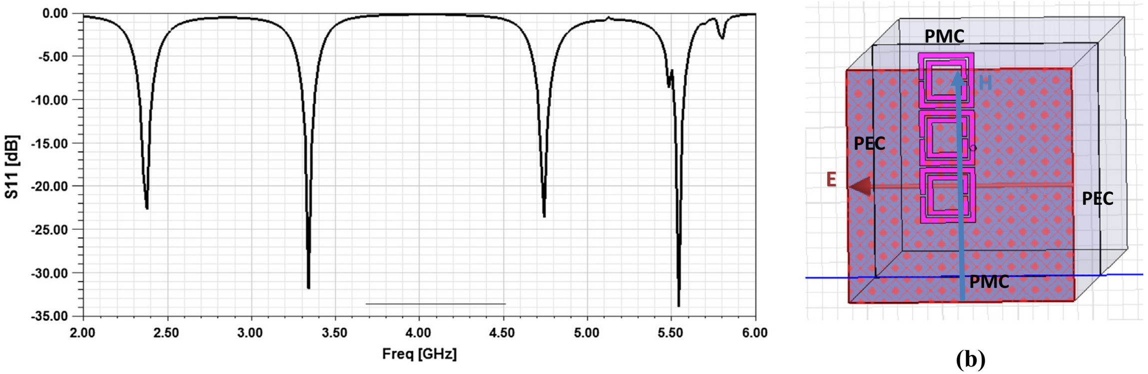
A genetic search optimization algorithm is used to optimize the location of the SRR units with respect to the radiating sections of the monopole antenna, and to optimize the location and dimensions of the reactive elements added to the antenna.

The dimensions of proposed antenna realize the limits of electrically small antenna at its first operating frequency 2.5 GHz, which is defined by Wheeler (1947), who defines electrically small antenna as one with maximum dimension less than $\lambda_0/(2\pi)$, or $k.a < 1$ where $k = 2\pi/\lambda_0$, λ_0 is the free space wavelength, and a is the radius of sphere enclosing the maximum dimension of the antenna.



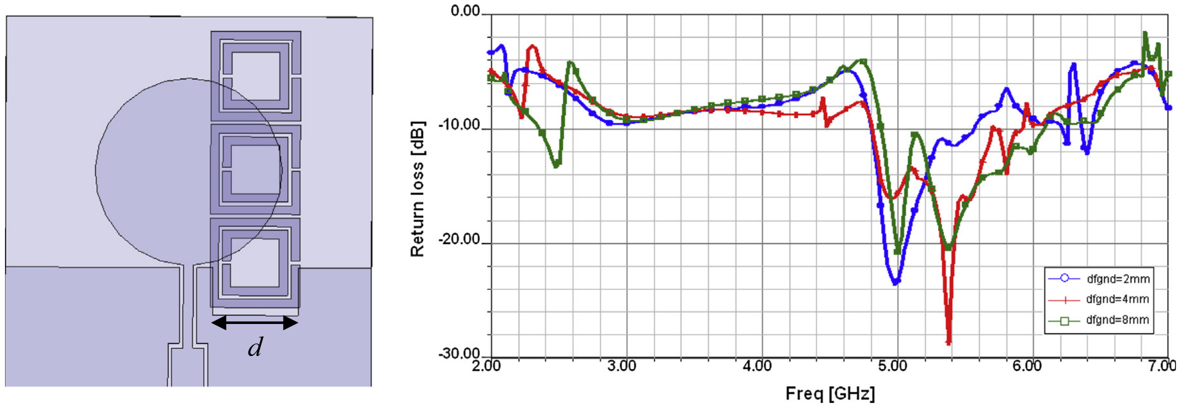
(a) **(b)**

Figure 2 Monopole antenna with modified feeding structure (dimensions in mm) (a) geometry and (b) simulated return loss.



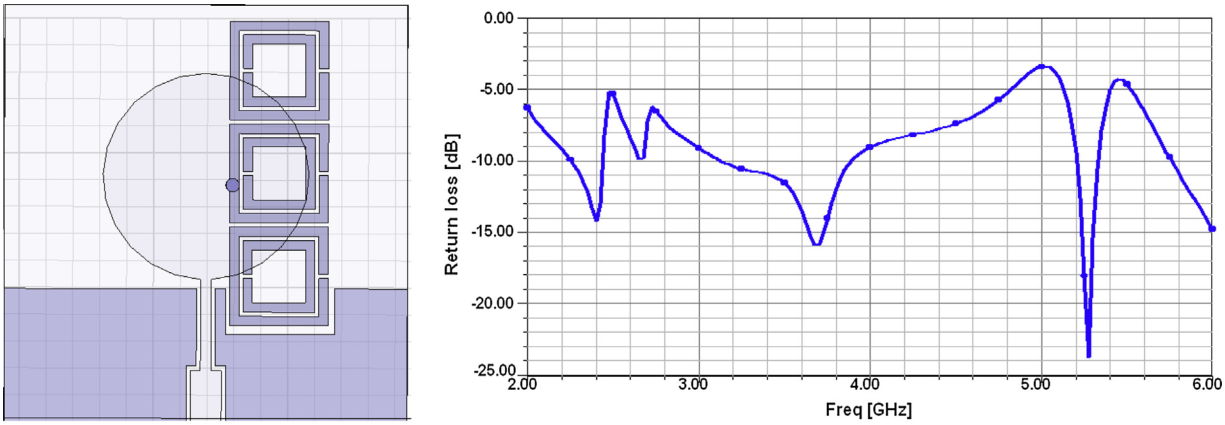
(a) **(b)**

Figure 3 (a) Simulated return loss of plane wave incident to post loaded SRRs array. (b) Boundary conditions of simulated incident plane wave on post loaded SRRs array.



(a) (b)

Figure 4 Disk monopole antenna with SRR units (a) geometry and (b) simulated return loss for different notch width (*d*).



(a) (b)

Figure 5 Disk monopole antenna with SRR units and loaded pin (a) geometry and (b) simulated return loss.

2. The design of a single SRR unit

SRR is used to build left hand metamaterial (LHM). The concept of LHM was first introduced by Veselago (1968), but the first artificial LHM was actually implemented by Smith et al. (2000). SRR unit is an artificial magnetic resonator which resonates at a frequency with a λ_0 that is much larger than the SRR length. The resonance occurs when a time varying magnetic field is applied perpendicular to the plane that contains the SRR units. This results in inducing circulating surface currents on its rings, and the distribution of these currents (Gay-Balmaz and Martin, 2002) shows that charges of opposite sign accumulated across the gaps and form a large distributed capacitance, which in turn results in producing very high positive and negative values of effective permeability at the vicinity of the magnetic plasma frequency (Pendry et al., 1999), where SRR strongly resonates.

A SRR unit consists of two square loops which are made of nonmagnetic metal, such as copper, and has small gaps between them. The two loops are split in an opposite ends manner as shown in Fig. 1. In the study by Bilotti et al. (2007) a model and design equations were introduced for Multiple Split Ring Resonator (MSRR). MSRR modeled simply as L C resonant circuit with resonant frequency depends on MSRR dimensions namely the side length of external ring *l*, width of the strips *w*, and separation between two parallel strips *s*.

The inclusion of multiple SRR units in an antenna results in varying the resonant frequency by a little amount (Alici and Ozbay, 2007b). In order to restore the desired resonant frequency at 2.5 GHz, the length *l* of the SRR units was included in our Genetic Algorithm (GA) search with limited changes for it. The resultant length from the GA search was 7.35 mm. Other dimensions (i.e. *g*, *w*, and *s*) were chosen to be fixed.

3. Monopole design

Initially we used the design equation described in the study by Balanis (2005) to determine the radius of the circular disk resonator in order to produce resonance at 5.2 GHz.

The circular disk monopole antenna is fed with coplanar waveguide (CPW) transmission line that is divided into two sections. The first section provides 50 Ω with 2.32 mm feed width. The second section's length was designed to narrowing impedance matching at 5 GHz band. If antenna fed with uniform CPW it would have 4 GHz band width which is reduced

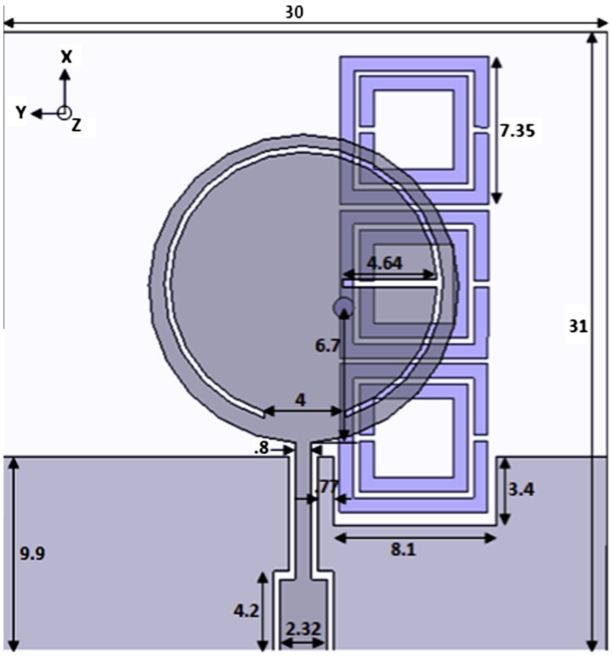


Figure 6 Geometry of the proposed antenna, all dimensions in mm.

to 1.8 GHz with modified feeding structure as shown in Fig. 2. Second section is adjusted to $\lambda_0/4\sqrt{\varepsilon_r}$ (6.8 mm at 5.2 GHz). The length of the first section and the width of the second section were obtained using extensive search using Ansoft High Frequency structure Simulator HFSS 10. This resulted in having a length of 3.8 mm for the first section, and a width of 0.8 mm for the second section.

4. Coupling SRR units with monopole antenna

The three distinct bands required for WiMAX/WLAN applications are realized by combining SRR units with tuning elements in a proper way in terms of their positions and dimensions.

The developments illustrated in this section (Figs. 4 and 5) used GA output location and dimensions for antenna elements except for the element under investigation.

Coupling SRR units with monopole produce dual band antenna, notching the ground is an important matter to enhance the resonance at 2.5 GHz. The effect of coupling metamaterial units to monopole patch with different dimensions for ground notch is illustrated in Fig. 4. The width of the notch added to ground not only enhances resonance produced by SRR units at 2.5 GHz but also affects resonance produced by circular disk monopole at 5 GHz band as seen in Fig. 4.

Extensive search was done to investigate the influence of adding tuning elements, i.e. slot, slit, and pin, to the disk monopole. Loading pin enhanced resonance near 3.5 GHz as seen in Fig. 5. Slot and slit are reactive elements that are loaded to the antenna for final tuning purposes. Proper design for reactive elements locations and dimensions was obtained using GA search.

5. Plane wave incident on an array of SRR units loaded with post

SRR units with circular patch and post formed equivalent circuit resonate at three desired frequencies; thus, currents distributed differently on SRR units with patch and post in the three resonance frequencies. To examine resonance for SRR array loaded with post, final design parameters of post and SRRs on dielectric are excited by magnetic fields from plane wave. The designed array of SRR units with post connected to middle unit shows a resonance at quad band as electromagnetic plane wave incident to it. Post and geometrical parameters of split rings such as dimensions, orientation and position are tuning parameters to control SRR magnetic resonance frequencies. These resonance frequencies arise near desired ones as illustrated in Fig. 3. Connecting monopole antenna with defected ground to this structure adjusts resonance at 2.5 GHz and other desired frequencies.

6. Genetic search

GA search is performed to adjust the exact dimensions and locations for proper impedance match at desired tri-band. In our implementation, the GA main program was written in MATLAB, and a visual basic (VB) script is written to operate HFSS 10 from MATLAB.

During the application of the GA algorithm, binary code is used; 64 bits are set to define antenna parameters. Each chromosome includes 13 genes to define circular slot radius, slit

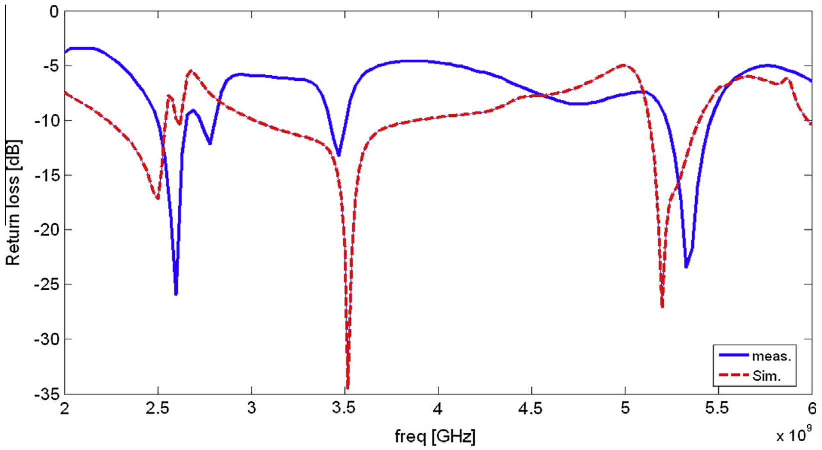


Figure 7 Measured and simulated return loss.

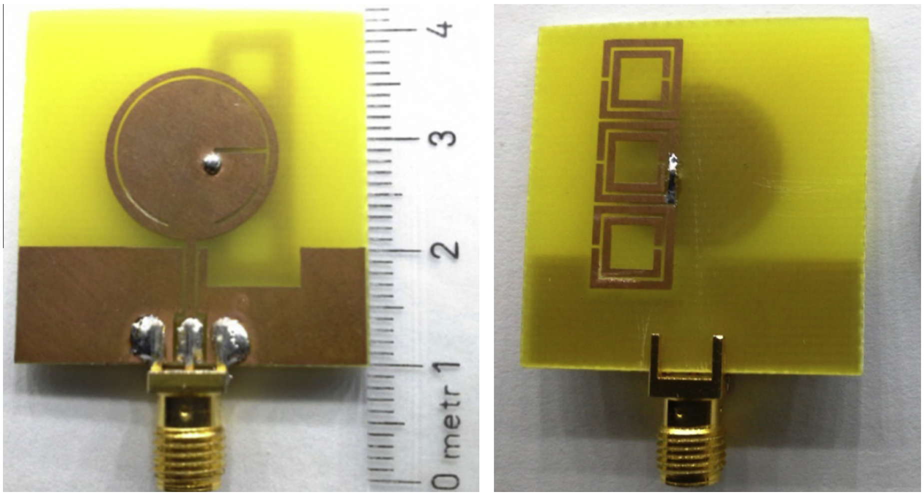
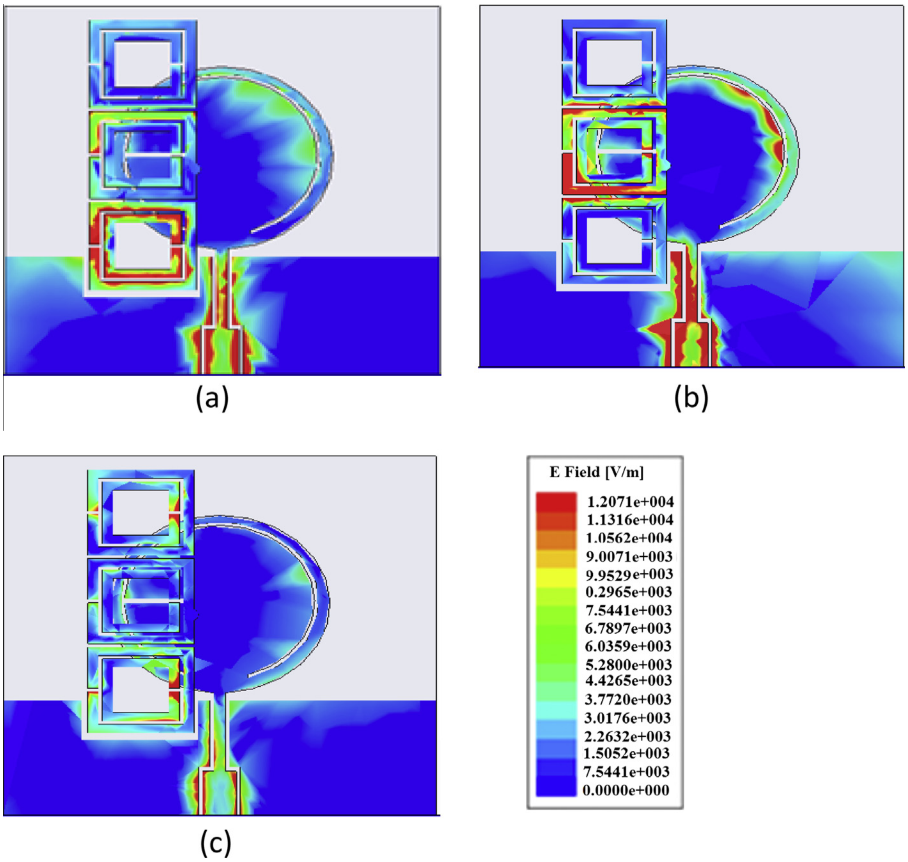


Figure 8 Photograph of fabricated antenna.


(a)

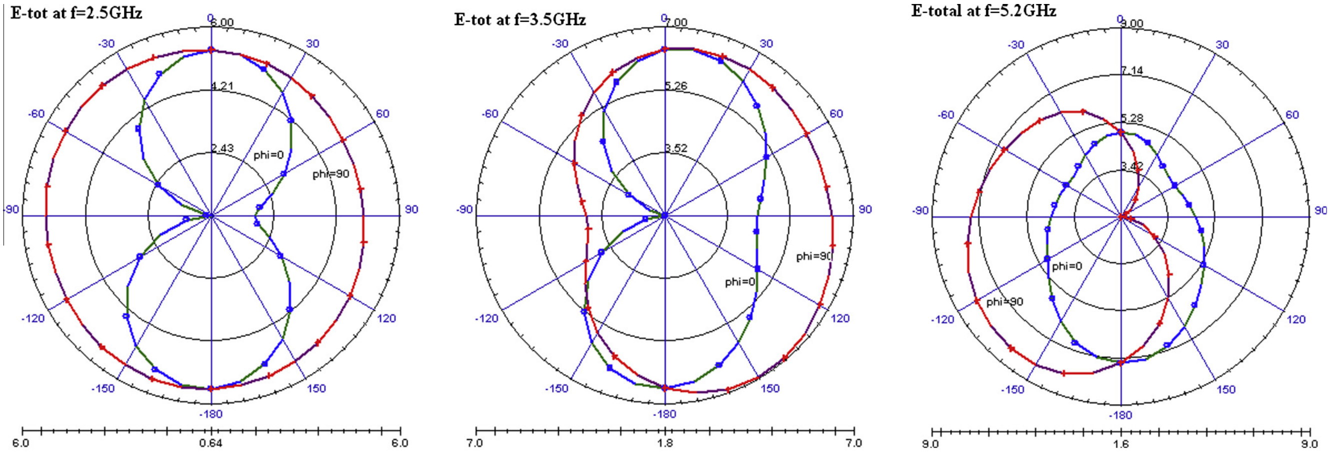
(b)

(c)

Figure 9 Simulated magnitude of induced *E* at (a) 2.5 GHz, (b) 3.5 GHz and (c) 5.2 GHz.

length and position, shorting pin position, SRR units' side length and position, length of ground, length and width of notch at the ground. Those search elements control the output resonance. The disk monopole radius, feed, and quarter feed are not included in the search process because they were adjusted for 5.2 GHz resonance.

Binary genes were converted to its equivalent decimal before passing to visual basic script, and visual basic script controls HFSS to draw suggested antenna and extract its analysis results, whereas binary form of genes is used through genetic optimization process. Twenty-five generations are examined to converge toward the desire design. Twenty individuals in each generation are evaluated. The fitness function is computed for each individual as the summation of return losses at 2.5, 3.5, and 5.2 GHz frequencies as illustrated in Eq. (1). The optimization process focuses only on return losses



(a) (b) (c)

Figure 10 Simulated radiation pattern for proposed antenna at phi = 0° and phi = 90° for (a) 2.5 GHz, (b) 3.5 GHz and (c) 5.2 GHz.

at desired resonant frequencies; no constrain added for radiation characteristics. Weighted random pairing selection method is used for new individuals' creation. Only 10% of the individuals' bits are mutated within a generation. Higher fitness individuals are kept for new generation.

$$\text{Cost} = \sum_{i=1}^{3} s_{11}(f_i) \tag{1}$$

The antenna was manufactured on a 1.5 mm low cost FR-4 epoxy with $\varepsilon_r = 4.4$ and dielectric loss tangent = .02. The radius of circular monopole disk antenna is 7.66 mm. The feed gap between the disk and the ground plane = 0.69 mm, pin radius = 0.5 mm, inner slot width = 0.3 mm and slit width = 0.4 mm. The remaining dimensions of antenna elements are depicted in Fig. 6.

7. Results

The proposed antenna was fabricated at the National Telecommunication Institute (NTI) in Egypt. The return loss was measured using HP8719ES vector network analyzer. Measured and simulated return loss responses are depicted in Fig. 7, and the resonance at 3.5 GHz is weaker than simulated because of inaccuracy of pin manufacturing. The fabricated antenna is shown in Fig. 8. The simulated radiation efficiency is 96% at 2.5 GHz, 85% at 3.5 GHz and 70.6% at 5.2 GHz. The distribution of induced electric field is illustrated in Fig. 9; this figure illustrates the contribution of the SRR units at the three resonance bands. Simulated radiation patterns for proposed antenna at the tri resonance frequencies are depicted in Fig. 10. Electrically small antenna has a negative gain in dB, as effective captured area of this antenna is small. The approximated relation between effective capture area of the antenna A_e and antenna gain G is given by $G = 4\pi A_e/\lambda^2$. The simulated peak gain for proposed antenna exhibits negative value at its first resonance (antenna considered ESA at this resonance frequency). Simulated peak gain at three resonance frequencies equals to −2.7 dBi, −0.07 dBi and 1.76 dBi at 2.5, 3.5, and 5.2 GHz respectively.

8. Conclusions

A novel combination of SRR units with monopole antenna is introduced in this paper. This combination realizes a tri-band response which can be used for WLAN/WiMAX applications as well as small antenna size. The SRR units are designed to have its first resonance at 2.5 GHz and monopole is designed to resonate at 5.2 GHz. Tuning elements were added to the monopole antenna radiators to reach the required tri-band response. All elements which are added to the monopole antenna were optimized for their position and dimensions using a GA search. The final design was fabricated and measured. A good agreement between the simulated and measured results validates our design.

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