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A Frequency Reconfigurable UWB Monopole Antenna with Slotted Ground Structure

Karthika Rajan[1], Sherin P Elias[2]
[1]P G Scholar, College of Engineering, Kidangoor.
karthikarajan1991@gmail.com
[2]P G Scholar, College of Engineering, Kidangoor.
sherinpelias@gmail.com

Abstract: In this modern world, there has been a significant drive to increase the functional density of consumer devices, especially hand-held electronics. In order to meet this challenge all the components need to be miniaturized. Most commonly used component in modern electronics is an antenna. The size of an antenna is directly related to its operational frequency. Frequency tunable miniaturized antennas are required for next generation electronics. In the existing system a multi-layered metamaterial-inspired antenna with a pixel grid loading structure is explained. In order to produce desired performance appropriate pixel configuration need to be selected. Simulations show that the antenna can be tuned over a wide frequency range by appropriate choice of pixel states. Here we are proposing a novel compact frequency-reconfigurable monopole antenna with various switchable states. Using a switchable slotted structure on the ground plane, the antenna can achieve frequency configuration capability. The proposed antenna has a combined UWB and narrowband functionality, has a good potential for use in cognitive radio. The simulations are done using HFSS (High Frequency Structure Simulator) software.

Keywords: miniaturized antennas, tunable antennas, monopole antennas, metamaterials, cognitive radio (CR), reconfigurable, ultrawideband (UWB).

1. Introduction

Due to the rapid growth in wireless communication, and the ever increasing demand for high data rate mobile systems, number of radios on mobile platforms has reached a point that the available space for the antennas has become a serious problem. The IEEE Standard Definitions of Terms for Antennas defines the antenna or aerial as ―a means for radiating or receiving radio waves. For a wireless communication system, antenna is one of the most critical component. . Hence, miniaturized antennas have become an imperative research area for both the academia and the industry. Through a variety of techniques, the operating frequency of an antenna can be reduced without changing its dimensions. This effectively miniaturizes the antenna, as the operational frequency is inversely proportional to the size of the antenna. Above all, tunable miniaturized antennas are desirable for the next generation of hand-held electronics [1].

Perhaps the simplest miniaturization technique involves the use of LC structures as loading elements to reduce the resonant frequency of an antenna. In [2], a series of loaded slits are used to miniaturize a slot antenna fed with a CPW line. This method allows for a 42% reduction in resonant frequency, while preserving the radiation properties of the antenna. In [3], a simple monopole antenna is miniaturized using shorting pins which are inductively and capacitively coupled through an in-plane capacitive structure. Multiple antenna types are miniaturized using fractal structures where size reductions are achieved by using Sierpinski fractals in place of a traditional patch antenna geometry [4]. These structures cause the current residing on the surface of the antenna to travel along a longer path than on a rectangular patch, requiring less realization area. Antennas can also be miniaturized by corrugating the structure and altering the geometry of the ground plane as in [5]. By utilizing an ellipse shaped ground plane with small corrugations along the antennas periphery, an ultrawideband antenna is miniaturized by nearly 50% as reported in [6].

Antenna miniaturization can also be achieved by using metamaterials as loading structures. Metamaterial structures, such as split ring resonators (SRRs), are commonly used as loading devices placed along an antenna in order to reduce the resonant frequency to that of the SRRs [7] - [9].

In [10], an in situ optimization technique is used to alter the geometry of a pixelized patch that is placed above a loop antenna. Based on the optimized geometry of the patch, the resonant frequency of the loop antenna can be driven downward. A similar optimization technique is used in [11] to miniaturize a planar monopole antenna. The antenna is fed with a coplanar waveguide, and surrounded by a metallic pixelized patch. The patch is split into 134 pixels, the composition of which is determined by a binary genetic algorithm (GA). The geometry of the patch is optimized with each pixel corresponding to a 1 or 0 (i.e., the presence or absence of a metal pixel). The overall pixel combination is determined based on the desired resonant frequency of the antenna, which can correspond to a size reduction to $\lambda/26$.

Frequency tuning systems are necessary for miniaturized antenna to increase their use in potential applications [12]. A number of antenna frequency tuning techniques have been introduced [13]. One common way of tuning antennas is by utilizing varactor diodes. In [14], an antenna miniaturized with SRRs is tuned using varactor diodes, increasing the available tuning range of the antenna. MEMS have also been used in antenna tuning [15], where they are used as capacitive switches. However, most of these methods only provide a small frequency tuning range, and have limited flexibility in antenna design.

In the existing system, a new approach to frequency tuned miniaturized antenna is introduced. A distributed pixel grid structure is placed on a thin dielectric film directly on top of the miniaturized antenna introduced in [11]. The antenna consists of two patterned metal layers separated by a thin dielectric film. The first layer contains a folded monopole antenna surrounded by a metal pixel-based loading structure. The second layer is added so that the tuning range is increased. HFSS simulations show that the antenna can be tuned over a wide frequency range by appropriate choice of pixel states on the second layer [1]. But in practice it is difficult to choose an apt pixel configuration for a particular application. Also, dual substrate increases the size of the antenna and fabrication cost.

In this paper we are proposing a novel compact frequency-reconfigurable monopole antenna with various switchable states. Most of frequency-reconfigurable antennas are antennas only capable of switching between different narrowband modes [16]–[17]. In [16], a switchable quad-band antenna by using a microelectromechanical systems (MEMS) switch has been proposed. By controlling the states of switches, the patch antenna in [17] can operate in four different frequencies.

In this letter, we propose a novel frequency-reconfigurable antenna with the capability to switch between UWB and narrowband. The antenna, which uses a switchable slotted structure for reconfigurability, has a simple structure and compact size.

2. Multilayered Metamaterial Inspired Miniaturized Tunable Antenna

In this paper miniaturization is achieved by optimizing the geometry of the pixelated patch surrounding the monopole antenna. Tuning of the antenna is implemented by varying the capacitance value of the capacitor loaded between the pixelated metallic patch and the ground plane [11]. This section discusses the step by step design of the antenna.

2.1 Folded Monopole Antenna

A coplanar waveguide (CPW) is used to excite a small folded monopole antenna that is inscribed on a half-disk of radius 5.2 mm. The CPW enables a convenient connection between the antenna and neighboring circuit components. The dimensions of the monopole antenna are widths: W1 = 2.6 mm and W2 = 0.728 mm and lengths: L1 = 4.94 mm and L2 = 1.092 mm. The dimensions of the ground plane are 3.12 mm by 10.4 mm and the gaps between the ground plane and the monopole antenna are G1 = 0.728 mm and G2 = 0.15 mm. The ground plane, monopole antenna and the pixelated patch are backed by a 0.5 mm Rogers RO4003 substrate with a dielectric constant ε_r = 3.55 and a loss tangent δ = 0.0027 as in [11].The structure of simple folded monopole antenna is shown in Figure 1.

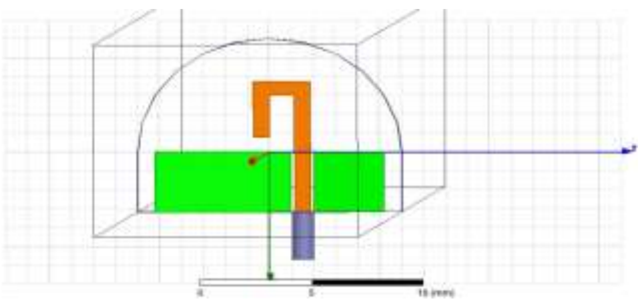

Figure 1: Structure of simple folded monopole antenna

Figure 2 shows plot of the simulated reflection coefficient of the simple folded monopole antenna. It is clear that the initial resonance of the monopole antenna is at 7.5 GHz. Our goal of the optimization is to find a pixel configuration that creates resonances below the initial resonance.

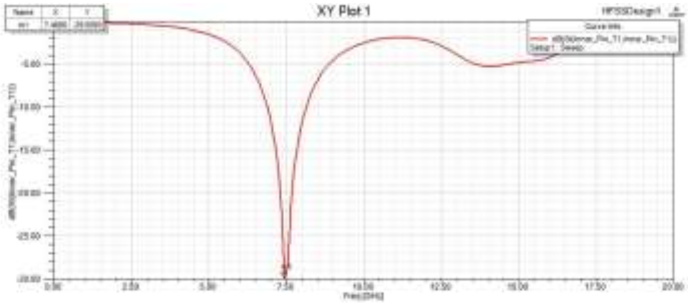

Figure 2: Reflection Coefficient plot of simple folded monopole antenna

2.2 Pixel Antenna

In order to optimize the design we utilize the pixellization approach where a distributed pixel grid structure is placed on a thin dielectric film directly on the top of a monopole antenna. The monopole antenna and pixelated patch are placed on a 0.5mm thick Rogers RO4003 substrate, along with the co-planar ground plane. All the components of the antenna are contained within a semicircular half-disk with a radius of 5.2mm as shown in Figure 3. The individual pixel geometry is selected such that each pixel corresponds to a 500 µm by 500 µm square. The entire grid is made of 134 pixels surrounding the monopole antenna. The total number of pixel configurations is 2^n where n is the number of pixels composing the patch. In this work, the patch is parameterized into 134 pixels leading to a total of 2^{134} possible pixel configurations. Here two capacitors are added by replacing two pixels in direct contact with the ground plane and frequency tuning is achieved by varying the capacitance of these capacitors.

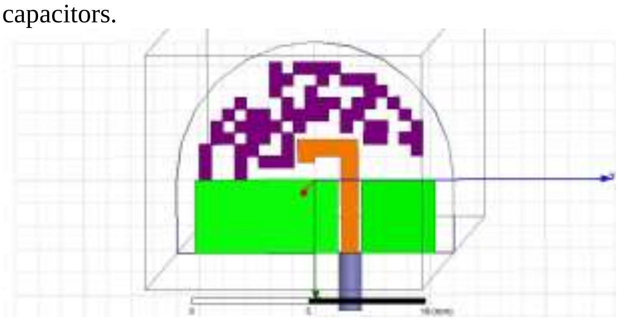

Figure 3: Structure of pixelated monopole antenna

Figure 4 shows plot of the simulated reflection coefficient of the optimized antenna where we can see that the resonance occurs at 3.1 GHz. We can also see that the return loss is high for this antenna.

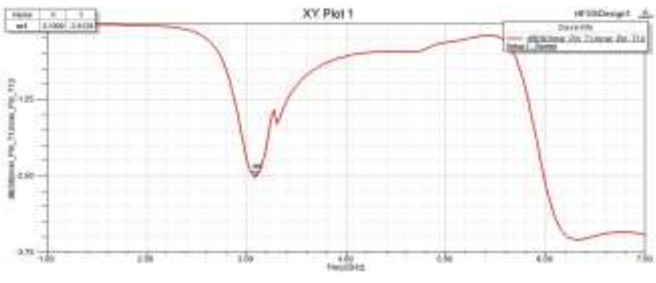

Figure 4: Reflection Coefficient of pixelated monopole antenna

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2.3 Multilayered Antenna

Figure 5 shows the final design of the existing system, multilayered metamaterial inspired miniaturized antenna. The antenna consists of two patterned metal layers separated by a thin dielectric film. The first layer contains a folded monopole antenna surrounded by a metal pixel-based loading structure. The second layer is added so that the tuning range is increased. This effect is primarily due to an increased capacitive coupling between the top layer pixels and the monopole antenna. The optimized values of the capacitors used are 100 pF and 0.5 pF. The second layer of the antenna also provides additional degrees of freedom in the design and fabrication of the antenna [1]. Figure 6 shows plot of the simulated reflection coefficient of the optimized antenna where we can see that the resonance occurs at 2.89 GHz and has higher return loss which is not a desirable feature for antenna design.

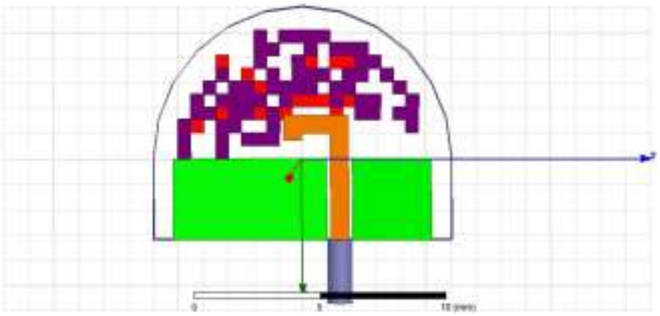

Figure 5: Structure of multilayered metamaterial inspired miniaturized antenna

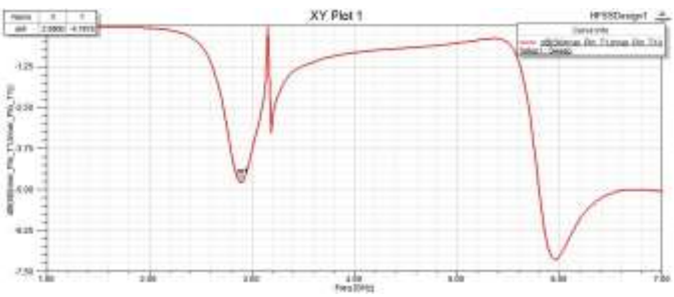

Figure 6: Reflection Coefficient plot of multilayered antenna

3. Frequency Reconfigurable Metamaterial Inspired UWB Monopole Antenna

In this paper we are proposing a novel compact frequency-reconfigurable monopole antenna with various switchable states. A reconfigurable antenna has the tunable fundamental characteristics, including operating frequency, impedance bandwidth, radiation pattern, and polarization, is a well-suited candidate for providing multi-functionality. Cognitive radio (CR), which is considered as the future of communications, needs a sensing antenna with the capability to monitor the spectrum, and a communicating antenna that can be reconfigured to communicate over a chosen frequency band. This has led to an elevated interest in the development of frequency reconfigurable antennas to utilize the spectrum efficiently [18]. Also can be used for multiradio wireless applications, and satellite communication. UWB technology has been used in the areas of radar, sensing and military communications during the past 20 years. A substantial surge of research interest has occurred recently when the FCC issued a ruling that UWB could be used for data communications as well as for radar and safety applications. Since then, UWB technology has been rapidly advancing as a promising high data rate wireless communication technology for various applications. For the design of a reconfigurable antenna we require a wide band antenna. So, a UWB monopole antenna has taken as the basic antenna. By including slots and switches appropriately in the designed structure the antenna can be reconfigured in the UWB range.

3.1 UWB Monopole Antenna

A circular monopole antenna has been chosen as a basic structure due to the fact that it can operate over wide bandwidth and has good radiation characteristics. Figure 7 shows the configuration of the proposed UWB monopole antenna. The antenna is constructed on an FR4 substrate with the relative permittivity of 4.4 and thickness of 1.6 mm. The size of the substrate is 40×40 mm. The radiating element is a circular patch with radius of 10 mm, which is fed with a 50Ω microstrip feed line with the length of 20 mm and width of 2.86 mm. On the bottom of substrate, there is a ground plane with 19×40 mm dimensions below the microstrip feed line. Figure 8 reflection coefficient plot of UWB monopole antenna with operating frequency band of 3.2-10.4 GHz.

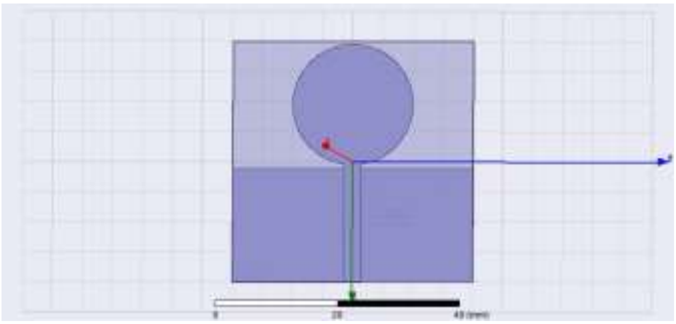

Figure 7: Structure of UWB monopole antenna

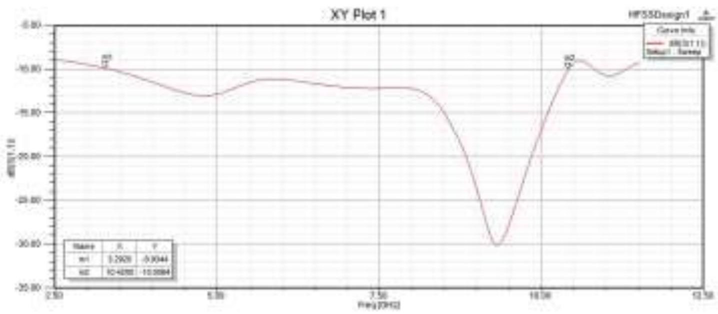

Figure 8: Reflection Coefficient plot of UWB monopole antenna

3.2 Frequency Reconfigurable Monopole Antenna

The UWB monopole antenna can be reconfigured by using a slotted structure placed on the ground plane as shown in Figure 9. This structure, which acts as a filter, is designed to suppress frequencies outside the desired frequency band. On the other hand, the embedded slot below feed line causes stopbands in the UWB range and leaves a passband between them. Moreover, the bandwidth of each filtering structure is controllable with changing the length of parallel vertical arms. [19]. The created passband can be controlled by changing the length and shape of main slot.

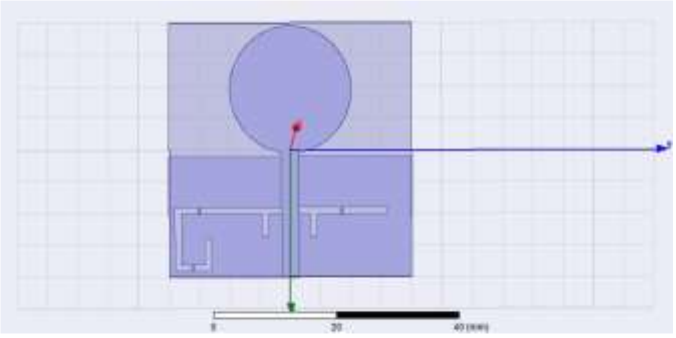

Figure 9: Structure of Frequency Reconfigurable monopole antenna

The frequency-reconfigurable capability of the antenna is achieved by placing lumped elements (capacitor, inductor, resistor) inside the slotted ground structure. The presence and absence of these lumped elements in the conducting strips varies the current distribution in the monopole antenna. By tuning values of these elements, the metal strips get connected to the ground plane and become a part of it. The desired frequency band can be selected by varying the values of lumped elements, which changes the total equivalent length of the slot. This equivalent length will determines the operating frequency of the antenna at that state and thereby we can achieve reconfigurable antenna operating in uwb and narrowband.

Here we are going to analyze various cases of frequency reconfigurable UWB monopole antenna with slotted ground structure. Figure 10 shows the simulated reflection coefficient plot for various cases.

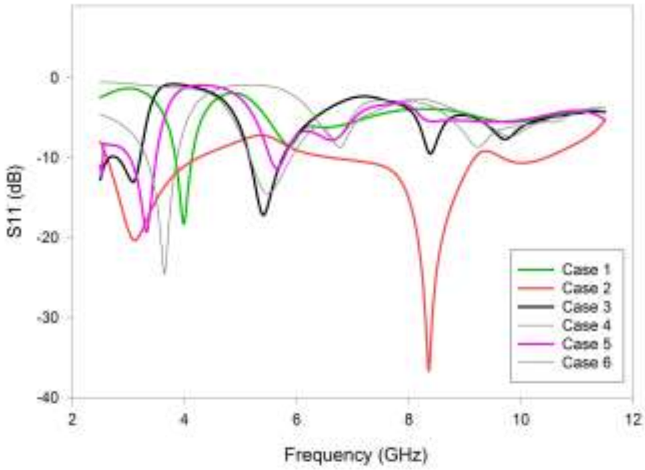

Figure 10: Simulated Reflection Coefficient plot of the antenna for various cases

Case 1: four slots are present along the length of the structure where we can see the antenna will operate in its dual-band mode covering 2.6–4.1 GHz and 6.7–9.1 GHz frequency bands. Case 2: all the four slots are connected to the ground plane using the presence of lumped elements where can see the antenna's operating frequency band is 3.8-4.1 GHz. Case 3: the slot just below the feed line is connected to ground plane using lumped elements and in this case too the antenna will operate in its dual-band mode covering 2.8-3.2 GHz and 5.1-5.7 GHz frequency bands. Case 4: last slot is connected to ground plane using lumped elements and in this case the antenna's operating frequency band is 5.1-5.9 GHz. Case 5: first slot and last slot are connected to ground plane and the antenna's operating frequency band is 3-3.4 GHz. Case 6: first and last slot are not connected to ground plane and the antenna's operating frequency band is 3.4-3.7 GHz.

From these six cases it is clear that a UWB monopole antenna can be reconfigured into various bands including narrow band and dual band using a slotted ground structure. Here we presented two dual band modes and narrow band modes. The designed UWB antenna now operates at two different narrowband frequencies 2.8-3.2 GHz and 5.1-5.7 GHz). The software used to model and simulate the proposed antenna was Ansoft HFSS, which is an industry-standard simulation tool for 3D full-wave electromagnetic field simulation.

4. Conclusion

In the existing system a multi-layered metamaterial inspired antenna capable of dynamic tunability through a photoconductive pixel grid is presented. Simulated results show that many pixel configurations can be achieved that produce a large range of antenna tuning. But in practice it is difficult to choose an apt pixel configuration for a particular application. Frequency reconfigurability for this antenna is very difficult to attain. Also, dual substrate increases the size of the antenna and fabrication cost. In this paper novel reconfigurable monopole antenna with completely switchable frequency bands has been presented. The antenna uses a slotted structure on the ground plane to deliver the reconfigurable capability using lumped elements. The proposed antenna is simple to design and has a very compact structure. The antenna is able to operate at different switching states with a reasonable return loss. More narrow bands can be achieved by inserting additional slots inside the structure. The antenna is intended for use in multiradio wireless applications and cognitive radio.

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Author Profile

Karthika Rajan received the B.Tech degree in Electronics and Communication Engineering from M. G. University College of Engineering in 2014. She is currently pursuing her Master of Technology in Wireless Technology at College of Engineering, Kidangoor.