

Frequency reconfigurable microstrip patch antenna for multiband applications

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Abstract

Wireless communication is a well-established technology for which several types of antennas have been developed specifically. However, antenna performance and communication system development need to be enhanced to adapt to the present era. The performance of the antenna is significantly influenced by its design. As a result, this work developed a novel wideband antenna design using a frequency reconfigurable approach. Shunt-series microelectromechanical systems (MEMS) were used in the proposed study to switch frequencies in wideband applications using microstrip patch antennas (MPAs). The suggested antenna with two integrated switches is tested in ON-ON, OFF-ON, and OFF-OFF switching scenarios. A range of antenna performance metrics, including as gain, bandwidth, return loss, radiation pattern, and voltage standing wave ratio (VSWR), are used to assess the suggested antenna's performance in each switching situation. The simulation's findings indicate that the ideal antenna design for wireless communication systems is one that works well with a shunt-series MEMS switch.

1. INTRODUCTION

The reconfigurable antenna (RA) is a more desired design alternative than the fixed antenna since it may provide changeable radiating properties like resonance for wireless communications systems. This extra degree of control may make it possible to compensate for manufacturing defects, future-proof a system against changing standards, and modify in the field to satisfy a particular need. In delicate wireless setup device tuning, a varactor diode or a tuned resistance are often used. Recently, there has been a lot of interest in the potential uses of RAs in communications, electronic surveillance, and countermeasures. In RAs, switching enables the shape of the radiating element to be altered. Antennas that support a broad range of wireless protocols will be required in the future for cognitive communication systems [1]–[5]. Because they can cover many frequencies with a single antenna, multiband antennas are particularly useful in modern wireless applications. But in order to better block out-of-band interference, fixed multiband antennas can need sophisticated filters with strict standards. Any communication system may get more complicated since the filter is often rather huge. These limitations could be addressed with RAs, which enhance out-of-band noise rejection. RAs are antennas with the ability to alter their frequency, pattern, polarization, and other characteristics in response to external inputs. Several unique features may be included in reconfiguration, depending on the application. There are three possible categories into which RAs might be divided. For the first category, the starting point is reconfigurable frequency. Optimizing the antenna's operating frequency and building a small terminal with a single multifunctional antenna for several applications are the goals [6]–[10]. Since the advent of groundbreaking ideas in wireless communication, such cognitive radio, which makes use of programmable narrowband transmission and wideband sensing, there has been a lot of interest in frequency reconfiguration. In order to satisfy system requirements based on pattern reconfigurability, the second categorization modifies the radiation pattern while maintaining the same frequency range. The capacity to switch

between linear and circular polarization, as well as between left-hand (LHCP) and right-hand (RHCP) circular polarization, provides the basis for the third category. Many switching technologies, including as optical switches, field-effect transistors (FETs), PIN diodes, and radio frequency-microelectromechanical systems (RF-MEMS) switches, may accomplish reconfigurability. The presenting of RF-MEMS antenna devices has been the subject of several research projects. Nevertheless, RF-MEMS integration with the antenna has not yet been fully demonstrated. In this study, a novel frequency-RA design is proposed. RF-MEMS switching devices are employed. Altering the switch statuses may achieve an electrical reconfiguration of the aperture. Because of their better RF characteristics, such as linearity, insertion loss, isolation, and power consumption up to around 40 GHz, we selected microelectromechanical systems (MEMS) switches as switching components rather than FET switches and conventional PIN diodes [11]–[15]. Wireless local area network (WLAN), personal communication system-digital communication system (PCS-DCS), universal mobile telecommunications system (UMTS), and global interoperability for microwave access (Wi-MAX) applications are all covered by the recommended antenna. This antenna can simultaneously resonate in three frequencies for WLAN and Wi-MAX applications. Since RAs may provide a range of features in terms of operating frequency, polarization, and emission pattern, they are very beneficial for contemporary communication systems. An antenna's emission pattern may be used to find target signals while avoiding electrical noise or interference. These antennas are often used to improve the security of communications. Radars, satellite communications, wireless communications, and associated businesses are in high demand as a result of the previously described reasons [16]–[22]. Although phase-shifted antenna arrays often include pattern reconfiguration capabilities, many applications may not be able to use them because of their size, weight, and installation difficulty. The majority of reconfiguration antenna designs that have been proposed recently rely on switching mechanisms to modify current routes, control current distribution, and provide behavior that may be altered in response to patterns. The characteristics of microstrip patch antennas (MPAs), such as their small size, low profile, light weight, and compatibility with microwave monolithic integrated circuit (MMIC) design, make them important in the field of RAs. RF-MEMS switches are a popular option in wireless communication systems because of their minimal insert loss and excellent isolation. A novel reconfigurable micro strip antenna is proposed in this study. Instead of utilizing "off and on" switches to manage RF-MEMS switches, the Ansoft high frequency structure simulator (HFSS) software uses metal strips and air gaps to replicate the antenna's states. For work associated with this study, the authors want to build a prototype antenna using a low-cost FR4 epoxy substrate

2. PROPOSED METHOD

RAs have a wide range of creative and adaptable uses. The reconfigurable feature has several benefits in wireless applications, including mobile terminals of the fourth and fifth generations (4G and 5G). A RA needs sufficient active components to be able to change its characteristics. The networks that regulate the circuitry grow more costly and complex in terms of biasing as a result of these premium active components. The radiating patch's current distribution, which can be altered by changing the patch's current flow, determines an antenna's properties. A varactor diode, PIN diodes, or MEMS switches are examples of the active element (or switches) needed to alter the current distribution in the radiating patch. Accordingly, the other authors have suggested and we have assessed RAs for enhanced wireless terminals. If the front-end circuitry's characteristics, including frequency, pattern, and polarisation, are programmable, a wireless system may become more simple, smaller, and less expensive. RAs have been used more often in recent years to maximise RF system performance. Future cutting-edge wireless communication and mobility systems may benefit from these sorts of antennas. Other methods to meet the requirements might include the usage of active components like switches or capacitors.

However, the number of re-configurable parameters that are accessible is determined by the use of active components. Antenna properties may be altered via varactor diodes, PIN diodes, optically actuated

switches, and RF-MEMS switches. A fast-switching rate is particularly useful to quickly change the functioning of

the antennas. The majority of RF-MEMS switch applications usually function in the region of 1-200 ns. An antenna using an integrated varactor diode may sacrifice a large tuning range in exchange for very high nonlinearity. However, PIN diodes may be used in RA system designs due to their short switching periods (100–200 ns), which allow for quick dynamic reconfiguration. This review research has investigated several types of RA s for wireless systems with single and multiple reconfiguration features. The frequency reconfigurable antenna (FRA) design requires careful consideration of fundamental aspects because to the physical constraints of contemporary wireless devices like as smartphones and tablets, as well as their ability to switch between frequency bands dynamically or continuously within a certain frequency range. Certain methods are effective in changing the configuration of an antenna system.

Using PIN diodes is the most often used technique for altering the electrical length of an antenna radiator. The working band may be changed by the varactor diode, enabling the switching from wideband to narrowband or vice versa. The resonance frequency may be determined using the matching network. Four more approaches are as follows: either altering the input-impedance or planning the antenna arrangement to include a shorting post. This is why changing an antenna's working spectrum to the appropriate frequency range may be done in a variety of ways. To alter the antenna's working band, a varactor is placed into the meander-line slot. The suggested construction is based on a composite right/left-handed gearbox line, as shown in figure composite right/left handed-transmission line (CRLH-TL). A series capacitance and a shunt capacitance are the two capacitances/inductances included in the CRLH-TL. Because of its remarkable frequency-reconfigurable capabilities, the operating frequency range of 4.13 to 4.50 GHz at 0-36 V may be appropriate for 5G base applications.

This field includes the frequency and pattern of radiation. It is possible to improve system performance, lower noise levels, and save energy by altering an antenna's radiation pattern for omnidirectional, end-fire, and broadside modes. Less interference occurs between different wireless providers. There are several benefits to lowering the quantity of antennas needed for frequency tuning. Frequencies are switched by active components like PIN diodes and varactors. The current distribution throughout an antenna's radiating patch is a critical component in pattern reconfiguration. By adjusting the antenna's current distribution via the use of the slot or slit structure, the radiation pattern is directed more successfully. The antenna may function in three distinct frequency bands thanks to the radiator patch of the suggested design, which is made up of four similar parts. Twelve parasitic elements are symmetrically matched with six radiators in the circular aperture to define radiation pattern and frequency. For WLAN, broadband, Zigbee, and satellite-digital multimedia broadcasting (S-DMB) services, diode switching states allow 450-step radiation pattern steering. To enable the change of the operating bandwidth from narrowband to wideband or vice versa, a corresponding network or reconfigurable filter is included into the structure's feed line. It has been utilised to modify the ground plane specifically for patch or monopole antennas. In order to regulate the current flow of the radiation patch, a 2 PIN diode is positioned in the centre of the slot. For many wireless applications, it is very desirable to be able to achieve an impedance bandwidth spanning from 22% to 78%. Additionally, wideband services and other wireless systems like 4G, WLAN, WiMAX, and satellite phones are kept apart by using the Narrowband/Wideband reconfiguration capabilities. This improves the adaptability of the antenna system and qualifies it for multi-mode wireless communications.

Applications like as imaging, sensing, tracking, and radar benefit greatly from the combination of reconfigurable frequency and polarisation. The most efficient use of the available spectrum requires frequency reconfiguration, even while polarisation diversity helps to reduce multipath fading effects and increase channel capacity. Many other designs have been suggested because of how intriguing this combo is. To allow reconfigurability in an antenna system, switches placed on top of the antenna resonator are made possible by the electromagnetic band gap (EBG) or meta-surface structure technology. Still, the most popular approach is to combine active components like PIN diodes and varactor diodes to provide frequency and polarisation reconfigurability. 2.4 and 3.4 GHz are possible frequency adjustments for 4G/5G multi-mode communication systems with varying polarisation. This study provides a thorough examination of FRAs with both single- and multiple-reconfiguration capabilities. To enhance the design parameters and provide size reduction strategies in a categorised way, additional methodologies were used. Reduced attention was paid to low frequency designs as high frequency designs were the suggested study option. The low FRA design, including geometrical aspects, appropriate for wireless applications, has been carefully investigated in this study in light of the aforementioned material. Along with pattern reconfiguration, polarisation characteristics, and simultaneous and flexible reconfiguration, this article also offers design guidelines and processes.

MEMS devices combine sensors, actuators, electronics, and mechanical components onto a single silicon substrate via the use of microfabrication techniques. In micro-fabrication, batch micromachining based on lithography is a popular process with several benefits, one of them being cost-effectiveness in large- scale production. Quartz and high-resistance gallium arsenide (GaAs) wafers are also used as MEMS

substrates in semiconductor microfabrication procedures. MEMS switches may have the mechanical form of a thin metal cantilever, an air bridge, or a diaphragm. They may be electrically linked to an RF transmission line

either in series or parallel. Depending on how the MEMS switch is operated, polar ceramics like barium- strontium titanate (Ba,Sr)TiO₃ (BSTO) may have a capacitive (metal-insulator-metal) or resistive (metal-to- metal) contact state. Every kind of switch offers a different set of benefits, whether it is in terms of manufacturability or performance. Changeable ferroelectrics have a lot of promising applications in tunable microwave devices. The spring constant, k , of RF-MEMS

switches governs their primary mechanical functions in everything that was used. Since the deflection of the beam relies on the spring constant k and we want a bigger deflection with a given force, we always desire less k , or less stiff material, for a given RF- MEMS switch. In this study, we used a meander form of the Serpentine flexure type to reduce the k value.

Microstrip antennas are well recognised for their cost, low weight, rigidity, low profile, and ability to accommodate both planar and non-planar surfaces. They also have a reputation for being simple to install. They are primarily used in mobile communications devices because to their adaptable designs and affordable prices. Reconfigurable aperture (RECAP) and microstrip antenna topologies have been prioritised in order to get multiple octave tunability. The development of RF-MEMS switches has led to an upsurge in research on reconfigurable multiband slot antennas. Neural networks (NNs) and evolutionary algorithms have been used in reconfigurable multiband antenna designs much more often in the last several years. Fractal antennas have a self-similarity property that may be built upon to create multiple-frequency antennas. One benefit of these antennas is that their patterns radiate similarly over a wide range of frequencies. The Sierpinski gasket, which has been extensively investigated, is the main predecessor. Several self-similar fractal patterns have impacted multi-band or small antenna designs. Diverse fractal geometries, including Koch Island, Sierpinski gasket, Sierpinski carpet, Hilbert curve, and Minkowski, have been used in fractal antenna projects. This work has built and simulated multiple-frequency fractal antenna meander-based RF-MEMS switches. Altering the sequence of iterations or electronically adjusting the antenna to a certain frequency is further options. The number of losses is decreased by using MEMS switches. This is necessary in order to provide high reconfigurability and prevent mismatched systems from developing from switch connections or disconnections. Furthermore, the design of the system is limited by the integration of the switches with the antenna. The same materials must be used for the construction of the antenna and the switch structure. The size limitation of the antenna system is minimal, and the maximum power that it can transmit is great, since the switches' dimensions are often set. Additional devices that might use this technology include military- grade antenna designs, tunable filters, and signal splitters.

In addition, a fractal-shaped microstrip antenna is proposed in this study, together with information on its return loss, voltage standing wave ratio (VSWR), and radiation pattern. The results demonstrate that it has the qualities required to function for a variety of wireless communication applications. It provides return losses of less than -10 dB at several frequencies, enabling multiband applications. Switches are replaced with short, open channels as a proof of concept. Additionally, omnidirectional radiation with a VSWR of less than two is present. It is so tiny since it is a microstrip antenna. Therefore, the suggested antenna satisfies the requirements for being modest in size and supporting several bands.

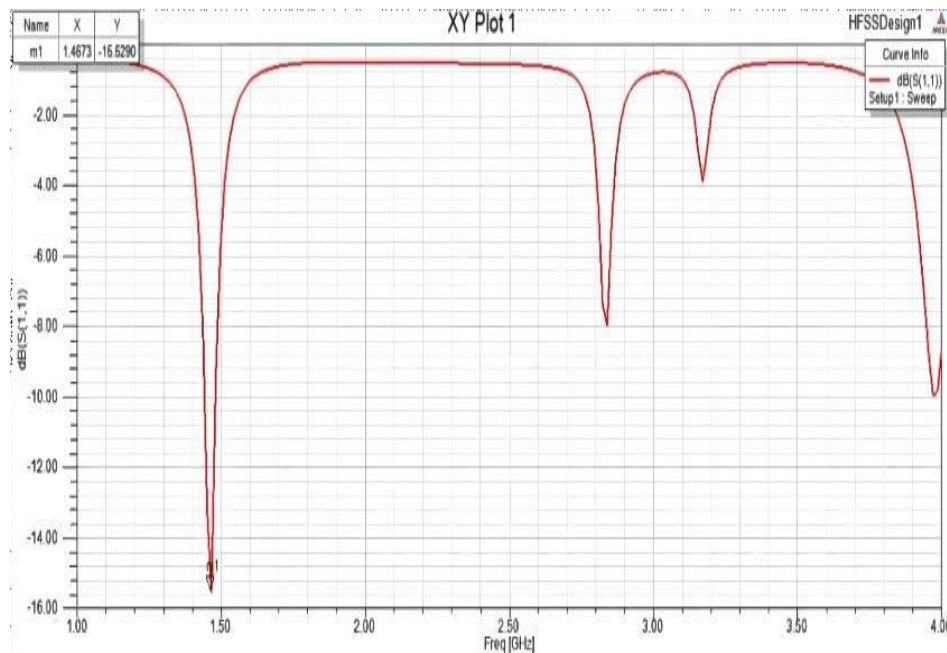
$$Pl = Pl_{eff} - 2\Delta Pl \tag{1}$$

$$= \frac{2c}{f_{res} \sqrt{\epsilon_{res} + 1}} \tag{2}$$

In this case, Pl stands for the patch's length, Pw for its width, ΔPl for its length extension, Pl_{eff} for its effective length, f_{res} for the resonance frequency, ϵ_{res} for the dielectric constant value, and c for the light's speed, which is 3×10^8 . Here, (3) and (4) are used to determine the effective length Pl_{eff} and the extension of length ΔPl , respectively.

reversible polarization for broadband applications is shown in Figure 2. It is a two-arm unidirectional radiation antenna mounted on a huge ground plane. To provide distinct polarizations, two water tubes are positioned above the ground plane. It is possible to make the antenna polarize in a left- or right-handed circular pattern by altering the water flow via the water channels. The frequency range in which the antenna works is 1.2-1.84 GHz. A fresh RA design is provided by the usage of intelligent materials. A coaxially fed patch antenna's frequency may be changed by using transformer oil with a high frequency and low loss. Between the radiating patch and the ground plane of the proposed antenna is a two-layer substrate. The effective permittivity of the whole patch radiator substrate is changed to achieve the frequency reconfiguration by varying the height of the oil layer, which affects the volume ratio of liquid to air. The surface of the ground plane is made of aluminum plate.

Traditional microstrip antennas have a single operating frequency, a small impedance range, little gain, a



larger dimension, and polarization problems. Traditional microstrip antenna performance may be enhanced in a variety of ways, including stacking, photonic band gaps (FSS), metamaterial, EBG, photonic band gaps (PBG), and alternate feeding techniques. Out of all the documented parameter optimization solutions, the microwave component with defective ground structure (DGS) has shown to be more common due to its simple structural architecture. "Defective ground structure" refers to carved slots or other flaws in the microstrip circuit's ground plane. A single ground plane flaw or several deficiencies may be linked to DGS. DGS for filters thinner than the microstrip line was first reported. DGS has been used to minimize mutual coupling, lower higher mode harmonics, and provide band-stop characteristics below the microstrip line. DGS is now in great demand for a number of applications as it has been employed successfully in the filter sector. This article discusses the origins and evolution of DGS. The basic concepts, use instructions, and matching models of the several DGS forms are explained. By boosting bandwidth and gain, suppressing higher mode harmonics, and lowering cross-polarization and mutual coupling between adjacent components, DGS has been used to enhance the radiation parameters of microstrip antennas. An overview of DGS's This study discusses microwave technology applications and its usage in antennas. Antennas that are tiny, low-profile, broadband, high-performance, and reasonably priced may often satisfy the exacting requirements of modern wireless communication systems. Modern communication depends on portable, efficient devices that can operate at low signal intensities and fast data rates. In an effort to meet the latest requirements, scientists have been developing and improving RF front ends. Numerous novel methods have been proposed to enhance the performance of a microwave component. Figure 3 displays the return loss while both diodes are off. The ground plane's periodic structure serves as a rejection band. It is especially difficult to simulate the PBG structure for microwave and millimeter-wave components, however. A number of properties, including the number of lattices, shapes, distances, and percentage of relative volume, affect the PBG band gap parameters. Figure 4 displays the return loss when D2 is switched on and D1 is turned off. Radiation is an additional parameter. from etched faults that repeat. The only instrument used in an additional ground plane aperture (GPA) approach is a microstrip line implanted with a central slit at the ground plane. Bandpass and 3 dB edge coupler filters are well-known products from GPA. The width of the GPA has a significant impact on the characteristic impedance of the microstrip line and determines the degree of return loss. The return loss for the ON and OFF stages of both diodes is shown in Figure 5.

Figure 3. Return loss with both diodes are OFF

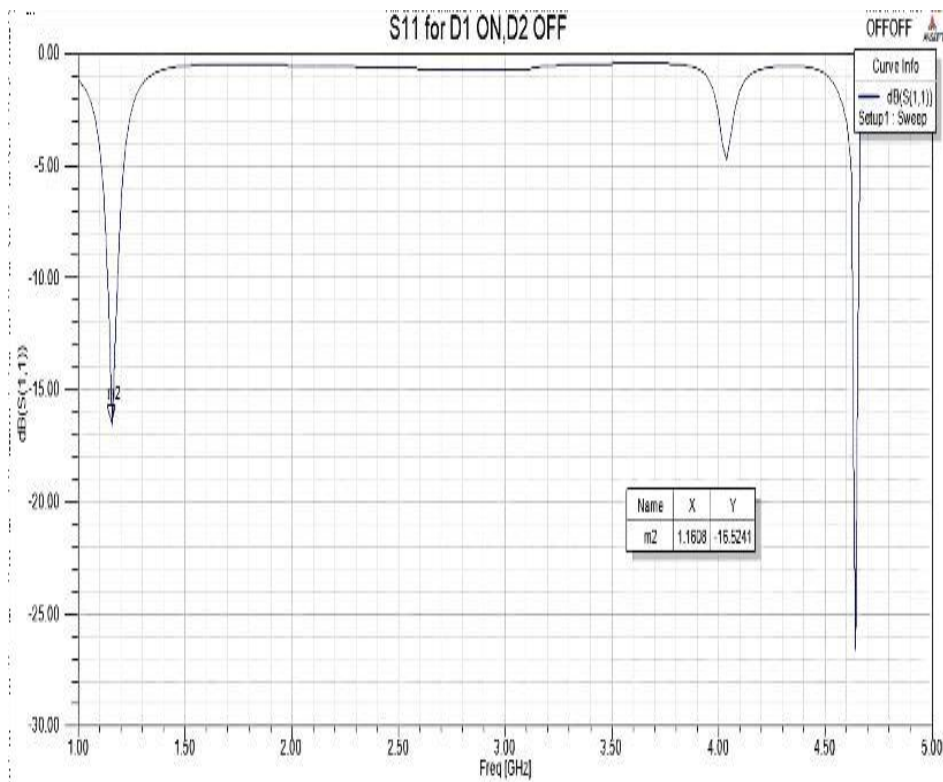
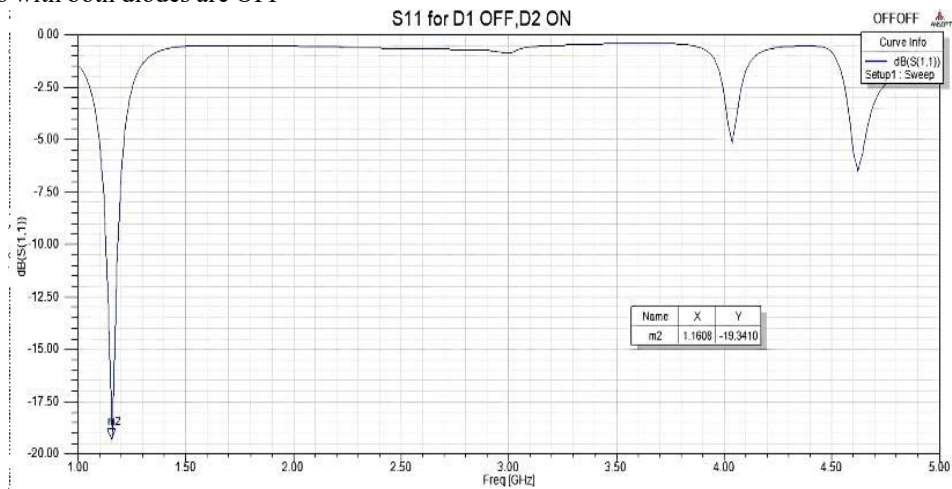


Figure 5. Return loss with D1 ON and D2 OFF

DGS, a term used to indicate a single defect shaped like a dumbbell, was first created in order to solve these problems. It is possible to think of the EBG structure as being simplified similarly to the DGS since it too includes a band-stop feature. Scientists studying microwaves on a range of topics may employ DGS. Numerous novel DGSs and applications in microwave circuits have been proposed and extensively studied. Figure 6 displays the return loss when both diodes are turned on. The development of DGS has been the subject of considerable debate. Since then, three books on DGS-based microstrip antennas have been published.



Figure 6. Return loss with both diodes are ON

Rapid improvements in wireless communications are driving the industry's demand for small, affordable, and interoperable RAs and antenna arrays. A single antenna that can be dynamically adjusted to broadcast and/or receive on many frequency bands is crucial for many military and commercial applications. Reconfigurable multiband antennas have become more popular as a result. These antennas are used in electronic intelligence aircraft, unmanned aerial vehicles, communication satellites, space-based radar, and several other communications and sensing applications.

One of the most significant developments in lowering size and cost is the ability to integrate the antenna, transmit/receive switch, and RF circuitry into a single monolithic batch production process. RF-MEMS switches are used in a number of shapes and geometries to provide a variety of applications, such as spiral, fractal, E-shape, S-shape, and planar inverted F-shape antennas (PIFA). Since RAs are multi-scale devices, they cannot be sufficiently quantified using a single analytical instrument. However, applying several analytical methods to a single structure becomes a computationally taxing procedure that uses a lot of computer resources. These days, NNs may be used to a variety of input-output interactions as efficient modeling tools. NNs have a wide range of applications in engineering because of their exceptional capacity to reproduce nonlinear correlations, generalize patterns seen in data, and learn from data [6]. Neural networks and evolutionary algorithms are the mainstays of the most recent reconfigurable multiband antenna designs.

Electromagnetic radiation is transmitted and received using metal structures known as antennas. An antenna is a device that acts as a link between free space and a guiding system, such a transmission line or waveguide. An antenna is the part of a transmitting or receiving system designed to send or receive electromagnetic waves. The well-known characteristics of microstrip antennas are their rigidity, low profile, cheap cost, and flexibility in terms of installation on both planar and non-planar surfaces. They are mostly used in mobile communications devices because to their flexible designs and reasonable costs. Microstrip and RECAP antenna topologies have garnered attention as means of offering tunability across a wide range of octaves. Recently, there has been a rise in interest in reconfigurable multiband slot antennas due to the introduction of RF-MEMS switches. Microstrip antennas are sometimes known as patch antennas. The radiating components and feed lines are usually photo-etched into the dielectric substrate. Any shape may be used for the radiating patch, such as triangles, elliptical forms, squares, rectangles, circles, and thin strips (dipoles). Figure 7 displays the radiation pattern.

Because of their attractive radiation characteristics and low cross-polarization radiation, the most common forms are square, rectangular, dipole (strip), and circular. Additionally, these forms are the simplest to create and evaluate. These antennas have the advantage of having patterns that radiate similarly throughout a broad frequency range. The primary antecedent is the well studied Sierpinski gasket. Micro-antenna or multi-band The many fractal patterns that display self-similarity have impacted designs. Numerous fractal geometries, including as the Koch island, Hilbert curve, Minskowski, Sierpinski gasket, and Sierpinski carpet, have been used to create fractal antennas.

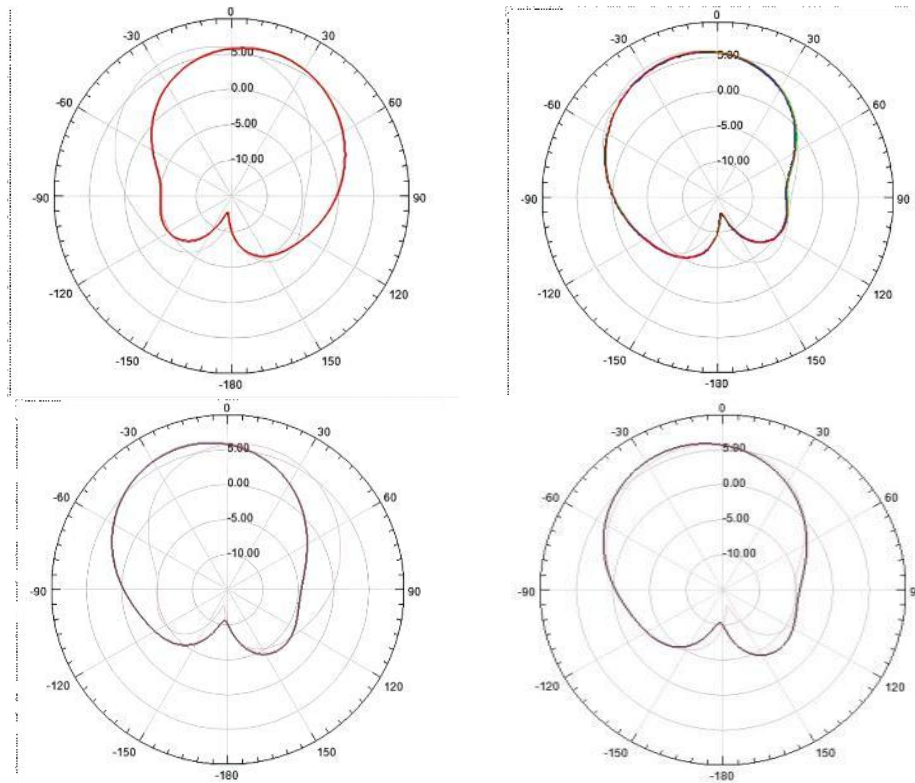


Figure 7. Radiation pattern of the proposed antenna

4. CONCLUSION

5. The main objective of this research is to use a shunt-series RF-MEMS switch for frequency modification in order to construct a reliable MPA for wireless communication networks. Here, the HFSS software is utilized for the design and simulation process, using ON-ON, OFF-ON, ON-OFF, and OFF-OFF switching circumstances. Another phase that uses the Maxwell equations is designing parameter values. First, the MPA is built using the shunt-series RF-MEMS switch in HFSS. Following that, the three switching scenarios of ON-ON, OFF-ON, and OFF-OFF are used to carry out the simulation approach. Antenna performance measures including radiation pattern, bandwidth, gain, VSWR, and return loss are used to evaluate the effectiveness of the proposed antenna design. The simulation results for each of the three situations are derived using the performance matrices. Lastly, the results demonstrate the effectiveness and suitability of the proposed frequency reconfigurable MPA for the wireless communication system.

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