# A Reconfigurable Antenna for IoT Applications with Enhanced Performance by Adding Metamaterial

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***Abstract*—In this study, the use of a complementary four Split Ring Resonators (SRR)-based metamaterial is studied to develop a frequency-reconfigurable antenna for wireless communication. The tangent loss (tan) is 0.0009, and the dimensions of the Rogers RT5880 dielectric are (38×21×1.6) m$^3$ with a relative permittivity of 2.2. This is the substrate on which the proposed antenna is printed. A frequency range of 1.82 GHz to 6.44 GHz is observed for the antenna's tuning. The proposed antenna exhibits a Voltage Standing Waves Ratio (VSWR) that does not exceed 1.5 in all resonant bands, affirming its reliability and efficiency. The proposed buildings' radiation efficiency ranges from 70.73% to 98.91%. The antenna operates in three different Modes depending on the antenna's switching scenario. Antenna Mode 1 operates in a single-band (3.03 GHz). Mode 2 is a double-band (2.34 and 5.06 GHz), and finally, the tri-band or Mode 3 (1.82, 4.2, and 6.44 GHz). Using a fed microstrip line, it is possible to use a quarter-wavelength transformer line to get 50 characteristic impedance and good impedance matching. The method for extracting the parameters from the SRR's meta-material property is covered in depth, which is how the existence of negative permeability and the new resonance frequencies are confirmed. The suggested antenna offers many benefits, such as straightforward construction, low return loss, and switching frequencies using a PIN diode (SMP1340-079LF).**

***Keywords*—metamaterial, reconfigurable, Positive Intrinsic Negative (PIN) diode, Internet of Things (IoT), Computer Simulation Technology (CST)**

## I. INTRODUCTION

The increasing popularity of mobile communication systems, smartphones, portable tablets, GPS receivers, and wireless Internet devices has increased the need for the miniaturization and integration of many functionalities inside communication equipment. Such development calls for minimizing the components in mobile devices, and at the same time, it must be able to perform several functions and operate over multiple frequency bands. One such component is an antenna. In today's so-called smart devices, antennas must be small, compact, and compatible with different mobile communication systems' frequencies because of their unusual qualities, including negative magnetic (permeability) and electrical (permittivity) properties. The discovery of metamaterial, a revolutionary man-made material, has transformed wireless communication and electronics [1, 2]. When dealing with a single wireless device that is needed to work under many communication services and frequencies, Frequency Reconfigurable Antennas (FRAs) are the perfect choice for such devices. Frequency reconfigurability has emerged as a key characteristic in wireless systems to handle several wireless standards and create wireless devices that are small, affordable, and easy to use [3]. A compact antenna system with a wider bandwidth and can simultaneously operate in several frequency bands is desirable [4]. To suit various applications, a Reconfigurable Antenna (RA) may alter its operating frequency, beam pattern, and polarization. Dynamic tuning may be accomplished by adjusting the state of mechanical, physical, optical, or electrical switches. Recent years have seen a lot of research and development towards FRA inspired by metamaterials. The Internet of Things (IoT) is an infrastructure for connecting diverse low-power wireless devices that can communicate with one another. Packet collisions increase power consumption and decrease network efficiency due to the retransmitting of lost packets for large data sets and expanding communication channels. Today's technological developments are pushing towards using larger frequency bands to enable greater data speeds. The antennas installed on IoT devices play a crucial role in facilitating the establishment of communication connections between wireless gadgets.

By electronically reconfiguring the surface currents on the antenna some features of antennas may be changed including operating frequency, polarization, and radiation patterns. The methods used to reconfigure the antennas surface current are biasing of diodes, digitally adjusted capacitors, shorting pins, and other methods. As many communication linkages between devices are required in technologies like the IoT, FRAs fulfill the need to function

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at more than one operational frequency [5–13]. Due to its independence from the actual length of the antenna construction, this resonance can allow for the miniaturization of the antenna. The suggested RA's geometry. Adjusting the switch's state allows a PIN diode to reposition the antenna to work in six distinct frequency bands. Antenna design and wireless communication have benefited from this article's fresh perspective. The suggested antenna design brings a new method that improves the RA's flexibility and overall performance by including ring resonators as components that regulate frequencies. The suggested antenna uses ring resonators' special qualities to provide reconfigurability, allowing for fine-grained frequency adjustment, unlike the component-centric approach frequently used in traditional designs. The antenna's versatility is enhanced by adding RF switches, which enable dynamic switching between resonance frequencies and bandwidths. Hence the antenna becomes ideal for a variety of wireless ranges and communication applications. The complete manipulation of electromagnetic wave properties has evolved through time to become the primary objective of several contemporary technologies [14]. Numerous academics have successfully attained this objective through Split Ring Resonators (SRR) and extensive frontier exploration. A structured metal element surface was designed to improve light's interaction with matter in quantum photonics and nano-optics using the optical bound state in the continuum (BIC) [15]. This improved the resonance field in plasmonic metasurfaces.

Pin diodes are used as a traditional method for frequency reconfiguration. Loading the metasurfaces onto the antenna is necessary to achieve frequency reconfiguration [16]. An inherent advantage of implementing this approach is the safeguarding it offers to antennas and communication devices from potential heat-related harm. The diode in the antenna for reconfiguration overheats and damages the device. Metamaterial loading reduces antenna size, cost, and structural complexity [17–19].

The proposed layout is based on research and analysis of a small, metamaterial-based frequency-configurable patch antenna. We look at the antenna's emission pattern, reflection coefficient, bandwidth, and gain to learn more about its performance.

The article continues with the following structure: The methodology and geometry behind the design of the proposed switchable multiband antenna are described in Section II. This study comes to a close after describing the simulated analysis in Section III and IV.

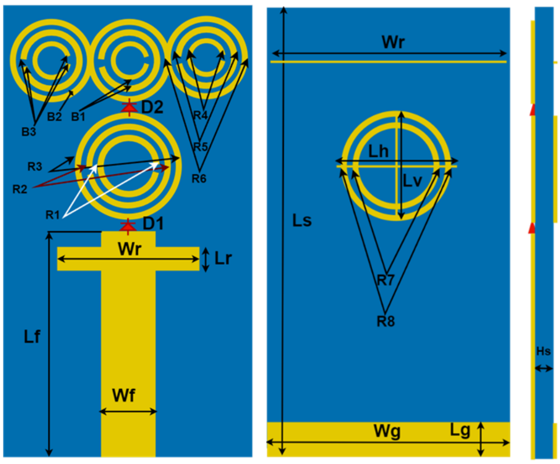
## II. MATERIALS AND METHODS

### A. *Proposed Antenna Design*

The metamaterial-based RA's theory, basic geometry, and switching mechanisms, and design are covered here. The antenna was modified with lumped element switches to operate in three frequency bands. The measurement setup circuit can be rewired with the help of PIN diodes. The implementation of a partial ground plane has resulted in a significant enhancement of far-field operational efficiency.

### B. *Structural Geometry*

Fig. 1 shows a hexa-band FRA for WiMAX, WLAN, 5G, WiFi Fixed Mobile Communication (FMC) Application, and Radio Altimeter. The Rogers RT5880 dielectric is used as the antenna substrate and has the Rogers RT5880 radiating element printed on it (r = 2.2, tan = 0.0009, h = 1.6 mm). The antenna is made out of 0.035 mm thick standard copper cladding. A 4.6 mm wide, 50-ohm microstrip line excites the antenna. We utilize the waveguide port designed for the feed line to stimulate the intended apparatus. Two slots with a 1 mm width can be used to include lumped element switches in the radiating construction, as shown in Fig. 1. As described, this recommended antenna has the following measurements: (38×21×1.6) $mm^3$. Exact measurements of the proposed building are displayed in Table I.




Front view Back view Side view

Fig. 1. The geometry of the suggested antenna's.

TABLE I. THE DIMENSIONS OF THE PLANNED ANTENNA'S

| Parameters | Value (mm) | Parameters | Value (mm) |
|---|---|---|---|
| Ls | 38 | B2 | 0.5 |
| Wg | 21 | B3 | 0.4 |
| Lg | 3 | R1 | 5 |
| Lf | 19 | R2 | 7 |
| Wf | 4.6 | R3 | 9 |
| Wr | 12 | R4 | 3 |
| Lr | 2 | R5 | 5 |
| Wr | 20.4 | R6 | 7 |
| Lh | 10 | R7 | 7 |
| Lv | 9 | R6 | 9 |
| B1 | 0.5 | Hs | 1.6 |

The transmission line model theory calculates effective resonant lengths at necessary frequencies [20]. Eqs. (1) and (2) calculate the effective permittivity $\varepsilon_{eff}$ and effective resonant length Lf for the chosen operating frequency f.

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\left(\frac{w}{h}\right)\right)^{-0.5} \quad (1)$$

$$\mathrm{Lf} = \frac{\mathrm{Cv}}{4\mathrm{f}\sqrt{\varepsilon_{\mathrm{eff}}}} \qquad (2)$$

Where $c_v$ stands for the light speed in a vacuum, $\varepsilon_r$ is relative permittivity, h is substrate thickness or height, and w is substrate width.

### C. *Reconfigurability*

The proposed antenna design can perform frequency reconfiguration by cycling between ON and OFF states for each PIN diode, causing open and short circuit behavior between radiating patches. The antenna can operate in three different Modes, and each Mode has its own specific resonant frequencies. The antenna exhibits single-band behavior with a 3.02 GHz frequency range in Mode 1 (D1 and D2 are both OFF). Also, in Mode 2 (D1 is ON while D2 is OFF), the antenna generated 2.34 GHz and 5.05 GHz as two distinct bands. At Mode 3 (D1 and D 2 are both ON), the antenna exhibits tri-band activity, covering frequencies of 1.82, 4.2, and 6.44 GHz. Table II lists the Mode s and the resonant bands associated with them for PIN diodes.

TABLE II. THE POSSIBLE TUNING STATES FOR A HEXA-BAND ANTENNA

| Modes | D1 | D2 | Frequency band GHz) |
|---|---|---|---|
| 1 | OFF | OFF | 3.02 |
| 2 | ON | OFF | 2.34 and 5.06 |
| 3 | ON | ON | 1.82, 4.2, and 6.44 |

### D. *Switching Techniques*

As the RF behavior of two-PIN diodes (SMP1340-079LF) is analogous to a variable resistor, they are frequently employed for switching. It can routinely operate between 10 MHz and 10 GHz. The antenna's effective resonant length changes as PIN diodes are added, causing a shift in operating frequency. The PIN diodes exhibit characteristics of both short-circuit and open-circuit behavior. Fig. 2 shows equivalent circuits for PIN diode switches in both the forward and reverse Mode s. The circuit only contains an inductor and a low-value resistor ($R_L$) while in the "ON" state. A capacitor ("C") is connected in parallel with an inductor and a high-value resistor ("$R_H$"). This study uses a Skyworks SMP1340-079LF PIN diode with L = 0.7 nH, $R_L$ = 0.85, and C = 0.21.pF.

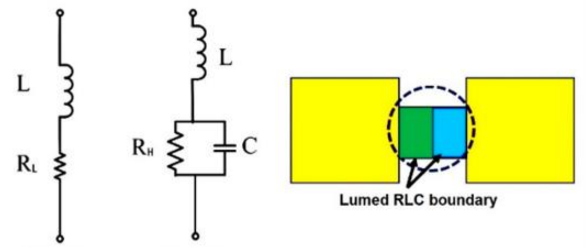



Fig. 2. A PIN diode's equivalent circuits and its CST model.

## III. RESULT AND DISCUSSION

The proposed structure has been created and assessed using CST Microwave Studio 2021. The radiating structure will be excited via a waveguide port of standard size. S-parameter, gain, and surface current plots are performance characteristics that may be obtained under standard boundary circumstances in the CST microwave studio.

### A. *Bandwidth and S-parameter*

The S-parameter for the recommended antenna in all Modes is shown in Fig. 3. The recommended antenna operates in the frequency ranges of 3.02 GHz with a bandwidth of 660 MHz (2.71–3.37 GHz) and with a 38.5 dB S-parameter at Mode 1 with all switches (D 1 and D2) in the off state. In Mode 2 (When D 1 is ON), the proposed antenna resonates with two bands., i.e., 2.34, 5.06 GHz, and with −36.74 dB, −22.68 dB S-parameters and bandwidth of 410 MHz (2.14–2.55 GHz) and 520 MHz (4.81–5.33 GHz), respectively. The same antenna in Mode 3 covers three different bands of 1.82, 4.2, and 6.44 GHz; when D 1 and D 2 are ON, an S-parameter is −28.37 dB,13.94 dB, and −35.76 dB with a bandwidth of 240 MHz (1.7–1.94 GHz) and 340 MHz (4.03–4.37 GHz), and 260 MHz (6.32–6.58 GHz) respectively at the operating frequencies.

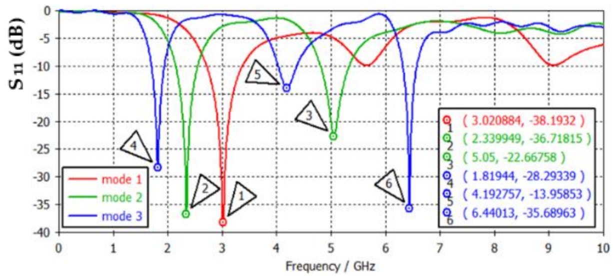



Fig. 3. S 11 for all antenna operating Mode s.

The antenna's VSWR, which measures ideal driving point impedance matching, is less than 1.5 for all resonant bands. Fig. 4 shows VSWR is below 2 across all usable frequency bands.

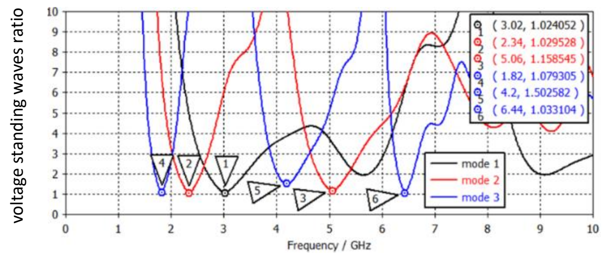
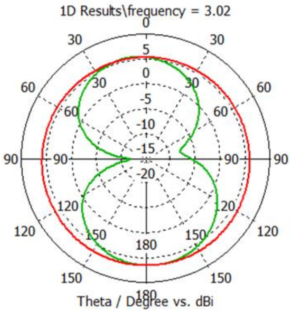


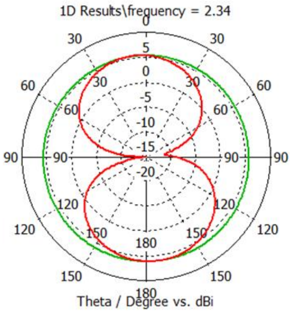

Fig. 4. VSWR of the suggested antenna in various Modes of operation.

### B. *Far Field Radiation Pattern*

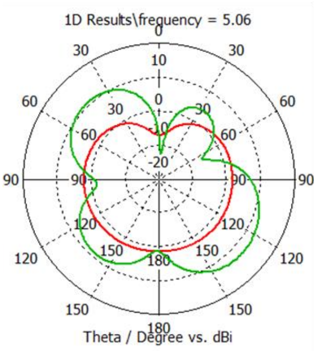
Fig. 5 displays the recommended antenna's predicted radiation pattern in the H and E planes at the operational frequency bands. Fig. 5(a) shows the radiation pattern of the antenna at 3.02 GHz, Fig. 5(b) shows the radiation pattern at 2.34 GHz, and Fig. 5(d) shows the pattern at 1.82 GHz show the figure-of-eight radiation pattern form in the E-plane. The antenna's radiation properties in the H-plane are omnidirectional for most frequency ranges. The e-plane is distorted in Fig. 5 (c, e, and f). With a gain of 1.43 dBi and a radiation efficiency of 79.23%, the recommended antenna runs on single bands at 3.02 GHz in Mode 1, as illustrated in Fig. 6(a). In Fig. 6(b) the illustration off dual-band 2.34 and 5.06 GHz at a gain of 1.04, 2.57 dBi, and 78.37% and 70.73% efficiency, correspondingly for Mode 2 operation. The recommended construction operated at 1.82, 4.2, and 6.44 GHz with peak gains of 1.12, 2.22, and 1.82 dBi and efficiency of 90.19%, 91.36%, and 98.19%, respectively, using Mode 3 as shown in Fig. 6(c). Fig. 6 displays gain and radiation efficiency charts at resonant frequencies to enhance comprehension of the antenna's radiation characteristics.



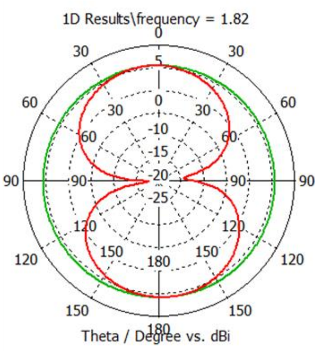

(a)



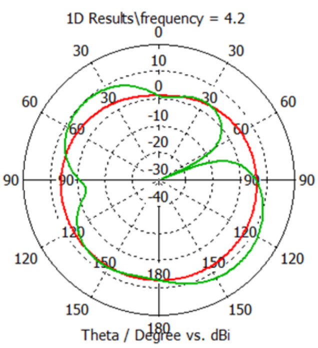

(b)



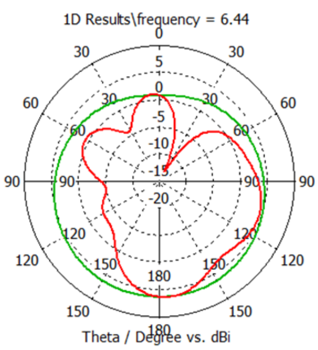

(c)




(d)

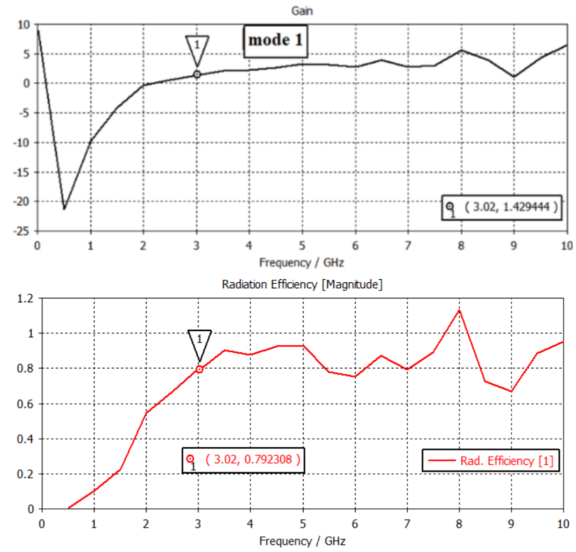



(e)

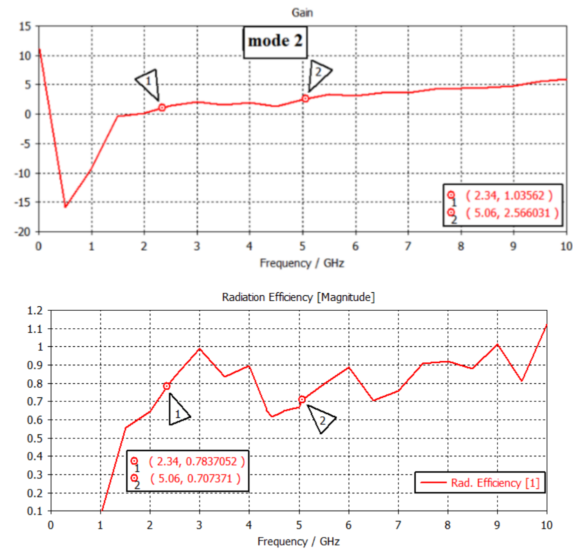



(f)

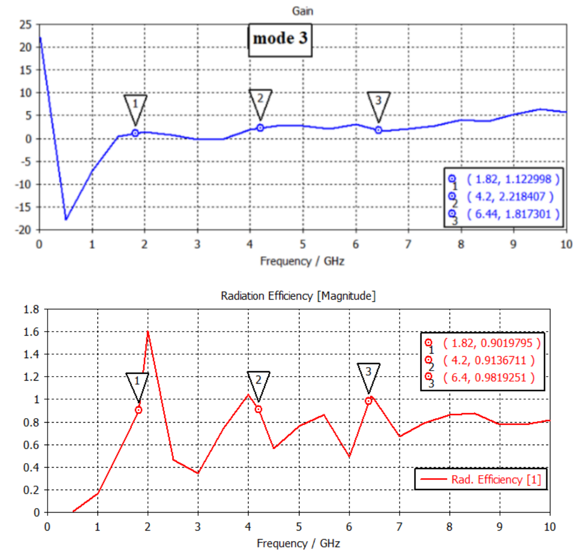
Fig. 5. Simulation demonstrates the recommended antenna's radiation pattern in different switching states and frequencies, including 3.02 GHz (Mode 1), 2.34 GHz (Mode 2), 5.06 GHz (Mode 2), 1.82 GHz (Mode 3), 4.2 GHz (Mode 3), and 6.44 GHz (Mode 3).




(a)




(b)




(c)

Fig. 6. Plots of the antenna's two-dimensional radiation efficiency and gain pattern at frequencies (a) Mode1 (13.02 GHz), (b) Mode 2 (22.34 GHz, 5.06 GHz), and (c) Mode 3 (31.82 GHz, 4.2 GHz, and 6.44 GHz).

TABLE III. THE SUGGESTED ANTENNA IS COMPARED TO PREVIOUSLY PUBLISHED STUDIES.

| **Previous Work** | **Frequency/GHz Antenna** | **Dimensions/mm$^2$** | **Gain** |
|---|---|---|---|
| [21] | 2, 3.4, 2.4, 3.1 | 37×35 | 1.98 |
| [22] | 2.1, 2.45, 3.2, 3.5 | 37×35 | 2.2 |
| [23] | 2.55, 3.5, 4.75 | 47×19 | 3 |
| [24] | 3.5,5.5 | 35×39 | 2.2 |
| [25] | 3.9, 4.9 | 62×40 | 3.5 |
| [26] | 3.5, 5.01, 3.2, 5.77 | 30×24.8 | 1.75 |
| This work | 3.02, 2.34, 5.06, 1.82, 4.2, 6.44 | 38×21 | 2.56 |

Compared to the antennas reported in [21–26], the proposed antenna takes up less space. Superior to [21, 22, 24–26] in terms of gain. The proposed antenna stands out because it can operate in six distinct frequency bands. In contrast, all other proposed antennas can only operate in two. Table III displays the results of this comparison.

## IV. CONCLUSION

There is a trend in scientific research to try to miniaturize antennas and work at a smaller frequency at the same time to benefit from this situation in the Internet of Things. Therefore, they created a combination of a RA and metamaterial to achieve this goal. The antenna efficiency and size are still noteworthy challenges in all antennas work in IoT applications. The suggested antenna works in less than 2 GHz range, with a Miniaturized size that supports long-distance communications. The suggested antenna has an overall size of (38×21×1.6) mm$^3$ and is intended for use at frequencies between 1.8 and 6.4 GHz. Two PIN diodes were inserted at various points along the antenna to resonate at 1.8, 2.33, 3.06, 4.19, 5.05, and 6.44 GHz with reflection coefficient values less than 10 dB. This resulted in reconfigurability behavior. The antenna's portable compact factor and flexibility in operating across three frequency Modes contribute to its impressive bandwidth, return loss, radiation efficiency, and gain stability.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Jamal Mohammed Rasool methodology, software, validation, investigation, resources, supervision; Ali Kadhum abd formal analysis, data curation, writing original draft preparation, original review, and editing. All authors have read and agreed to the published version of the manuscript.

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