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Survey on MIMO Dielectric Resonator Antenna for IOT Wireless Applications

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Abstract

The exponential growth of the Internet of Things (IoT) has driven the demand for compact, efficient, and high-performance antennas capable of supporting reliable wireless communication. Multiple-Input Multiple-Output (MIMO) antenna systems have become a key technology in addressing challenges such as signal fading, limited bandwidth, and high data requirements in IoT networks. Among various antenna structures, Dielectric Resonator Antennas (DRAs) offer significant advantages including high radiation efficiency, low loss, compact size, and wide bandwidth, making them ideal for IoT-enabled MIMO systems. This survey provides a comprehensive review of recent advancements in MIMO DRA design tailored for IoT applications. It discusses critical design parameters such as isolation improvement, feeding techniques, radiation pattern diversity, and mutual coupling reduction. Various approaches and innovations, including the use of electromagnetic bandgap structures and AI-assisted optimization, are analyzed. Performance metrics such as gain, bandwidth, envelope correlation coefficient (ECC), and diversity gain are also examined. The study concludes by identifying existing challenges and highlighting potential future research directions, such as reconfigurable DRA arrays and conformal designs for wearable IoT devices. This survey serves as a useful reference for researchers and engineers developing next-generation wireless systems integrating MIMO DRAs into IoT platforms.

Keywords: Dielectric Resonator Antenna, MIMO, IOT, Wireless Application

I. INTRODUCTION

The Internet of Things (IoT) has emerged as a transformative technology, enabling the interconnection of billions of devices across various domains such as healthcare, smart homes, industrial automation, agriculture, and transportation. These interconnected systems rely heavily on robust and energy-efficient wireless communication technologies to exchange information seamlessly and in real time. As IoT networks continue to grow in density and complexity, the need for compact, efficient, and high-performance antennas has become increasingly critical [1].

Multiple-Input Multiple-Output (MIMO) technology has proven to be a significant advancement in wireless communication, offering improvements in spectral efficiency, channel capacity, data rates, and link reliability. MIMO antennas leverage the principle of using multiple transmitting and receiving elements to exploit multipath propagation, thereby enhancing overall system performance without the need for additional bandwidth or transmission power. While MIMO is widely used in modern communication systems, integrating MIMO antennas into IoT devices presents considerable challenges, particularly in terms of miniaturization, mutual coupling, efficiency, and integration with compact hardware [2, 3].

Dielectric Resonator Antennas (DRAs) have gained increasing attention in recent years as a viable alternative to traditional metallic antennas, especially in high-frequency applications such as 5G, Wi-Fi 6, and IoT. DRAs utilize dielectric materials with high permittivity to support resonant modes that radiate efficiently into free space. Unlike conventional patch antennas, DRAs do not suffer from conductor losses and surface wave excitation, resulting in higher radiation efficiency and better performance in compact configurations. Furthermore, DRAs offer flexible design options, such as various geometrical shapes (cylindrical, rectangular, hemispherical), multiple excitation methods (probe, slot, microstrip line), and compatibility with multilayer and 3D structures [4].

In the context of MIMO systems, DRAs bring unique advantages. Their compact size and low-profile structure are well-suited for space-constrained IoT devices, while their wide impedance bandwidth and high isolation capabilities make them ideal candidates for multi-element MIMO arrays. However, the design of MIMO DRAs poses several challenges, such as maintaining low mutual coupling between antenna elements, ensuring pattern diversity, optimizing envelope correlation coefficient (ECC), and achieving uniform radiation characteristics across elements. Various techniques, including electromagnetic bandgap (EBG) structures, decoupling networks, parasitic elements, and polarization diversity, have been proposed in the literature to address these issues [5].

This survey aims to provide a detailed overview of the current state-of-the-art in MIMO DRA technology with specific emphasis on IoT wireless applications. It explores the design methodologies, feeding mechanisms, isolation techniques, performance parameters, and integration strategies for MIMO DRAs. Additionally, the review includes recent advancements such as the application of artificial intelligence (AI) and machine learning (ML) in the optimization and design of DRA arrays.

By analyzing and categorizing various MIMO DRA architectures reported in the literature, this study helps identify the most promising approaches and outlines the challenges that remain in the field. The objective is to provide researchers, antenna designers, and IoT system developers with a comprehensive reference that supports the development of compact, high-performance wireless systems for the next generation of IoT applications [6, 7].

II. LITERATURE REVIEW

Naresh Kumar et al. [1], for UWB X-band wireless applications, a reconfigurable 2x2 and 4x4 MIMO antenna is designed in this study. The suggested concept makes use of electromagnetic square patch radiation energy, a new ground structure, and a reconfiguration urable module that allows the operating mode to be set using a PIN diodes. The antenna can reject WLAN signals at 5 GHz and 7 GHz. DSS interference by the use of "Γ–T" shape type stubs. On the radiating patch, there are beds. The suggested layout has been configurable features with an RF PIN diode switch that is managed by integrated module. Evaluation of the performance of the suggested structure performance demonstrates a strong correlation between the simulated outcomes and actual results that have been measured in real-world situations.

J. D, K. Madhumitha et al. [2], in 5G wireless communication systems, MIMO antennas are a key technology for reaching high data concerns and enhanced network competence. The creation of small, effective antenna systems that can accommodate numerous antennas as a single system or module is necessary for the integration of MIMO technology in 5G systems. By providing spatial diversity and multiplexing, MIMO antennas can modify the wireless communication systems' competence, resilience, and dependability. MIMO systems contribute to improved performance in terms of link stability and data rate. The frequency spectrum range of 5 to 7 GHz, which is frequently used in a variety of wireless communication applications as well as other domains like Internet of Things (IoT) applications, is where the suggested 1 X 2 MIMO antenna design functions. The copper-based antenna materials are designed on a FR4 substrate with a thickness range of 1.6 mm and a dielectric constant of 4.4. The design of the emitting constituents allows for the creation of a small and effective antenna. The multiple antenna system's feeding network is essential and performs intricate tasks. Both antennas' radiating foundations receive the two signals that the feeding network evenly divides from the incoming signal. Additionally, it aids in combining the signals that are received by both antennas' radiating elements, which increases the received signal intensity overall.

P. Prakash et al. [3], MIMO is a sort of multiple output antenna (IoT) that can be used in 5G and IoT networks. Four coaxial cables—two in one plane and the other two in the other—power the antenna's four spatially orthogonal antenna elements. All of the antennas are constructed using grounded stubs and inverted L-monopoles. The resonance frequencies of L-monopoles can be adjusted to fit the needs of the application. Long grounded stubs can be used to create more resonant frequency modes. The adjustable 2-element folding meandered MIMO antenna can be used in the RFID bands (687 MHz-813 MHz) and the 2.4 GHz and 5.8 GHz LTE channels. The additional two-element tiny antennas support MIMO antennas in the 754 MHz to 971 MHz, 1.65 GHz to 1.83 GHz, 2GHz to 3.66 GHz, and 5.1GHz to 5.6 GHz bands. In the CR context, it serves as a ground plane for MIMO elements that perform spectrum sensing in the 0.668 GHz to 1.94 GHz and 3 GHz to 4.6 GHz frequency ranges. The antenna is made of inexpensive FR-4 and measures 65 x 120 x 1.56 mm. The radiation properties of the antenna in full-wave simulations are consistent with those predicted by the simulation. It was discovered that the 3D radiation pattern-based envelope correlation coefficient (ECC) of MIMO antennas was less than half of what was anticipated. IoT systems and modules may benefit from the proposed MIMO antenna's low profile, small size, light weight, and simplicity of integration with wireless communication devices.

H. Liu et al. [4], for portable applications, this paper proposes a small ultra-wideband (UWB) MIMO antenna with dual band-notched characteristics. The antenna has four feeding ports, each measuring 50 × 50 mm2, and is fed via a coplanar waveguide. Dual notches filtering off the 3.5 GHz WiMAX and 5.5 GHz WLAN bands can be accomplished by etching split-ring resonator slots on the radiation patches. Step-by-step instructions for the design procedure are provided, and the band-notched mechanism is examined using surface current distributions. Additionally, this article analyzes the cylindrical conformal antenna's band-notched features. According to the experimental results, the suggested antenna's low envelope correlation coefficient, steady gain, and good radiation properties make it suitable for widespread application in UWB communication systems. Research on band-notched conformal UWB MIMO antennas can also be guided by the concept presented in this article.

Gorai et al. [5], an ultrawideband (UWB) MIMO antenna with a low profile and a modified Koch fractal shape is introduced. The radiators have triangular loading and are tapered elliptically from the feed line. To increase impedance matching, a modified Koch fractal shape is implanted into the limits of the triangular-shaped loading. An electric inductive capacitive resonator at the rear of the substrate is used to incorporate a band suppression feature at 5.5 GHz. Ground plane shorting of a Maple leaf fractal structure results in improved port isolation of less than 20 dB. The envelope correlation factor of the suggested UWB MIMO antenna is less than 0.01 and its max realized gain is 4 dBi. The simulated and measured findings are very similar. Additionally, the suggested structure's equivalent circuit model is taken out and compared to the results of the em simulation, which show good agreement.

R.N. Tiwari et al. [6], the current effort presents a 2 x 2 MIMO configuration with dome-shaped monopole radiating elements fed by CPW. The antenna's dual-band response is achieved by embedding two comb-shaped slots in the ground plane. The 2.11–4.19 GHz (lower) and 4.98–6.81 GHz (upper) dual frequency bands that were measured adequately cover Bluetooth, Wi-Fi/WLAN, LTE, and Wi-MAX applications. To achieve strong isolation (>21 dB), a T-shaped stub is combined with the ground plane. The observed antenna gain ranges from 2.75 to 4.19 dBi, and in both resonating bands, its radiation efficiency is determined to be higher than 70%. The suggested antenna measures 20 × 34 × 1.6 mm^3 overall. The antenna is constructed, and the measured outcomes are compared to the CST Microwave Studio results. Ultimately, the antenna's diversity parameters are assessed, and the outcomes are adequate for MIMO applications.

N.O. Parchin et al. [7], reconfigurable antennas are the focus of several research investigations and are crucial components of intelligent and adaptable systems. They are well suited for use in wireless applications like fourth generation (4G) and fifth generation (5G) mobile terminals because of their advantages, which include multifunctional capabilities, reduced volume requirements, low front-end processing efforts without the need for a filtering element, good isolation, and sufficient out-of-band rejection. By modifying the current flow on the antenna construction, active materials like varactors, p-i-n (PIN) diodes, or microelectromechanical systems (MEMS) can be used to modify an antenna's properties. An antenna must have a sufficient number of active elements in order to be reconfigurable into a wide variety of states. However, using a lot of high-quality active components raises the cost and calls for intricate control circuitry and biasing networks. We examine a few recently suggested reconfigurable antenna designs that can be used in wireless communications, including 4G/5G mobile terminals, multiple-input multiple-output (MIMO), cognitive-ratio (CR), and ultra-wideband (UWB). The performance of a number of antenna examples with various reconfigurability functions is examined and contrasted.

Investigations are conducted into the basic characteristics and attributes of reconfigurable antennas with both single and multiple reconfigurability modes.

R. Mathur et al. [8], this paper presents a reconfigurable band notch small ultrawideband (UWB) MIMO antenna. The antenna's unique is dual-band notch approach, which prevents global interoperability for wireless local area network band interference or microwave access, is its primary feature. Two square monopoles separated by a grounded multi-branch T-shaped stub provide the UWB-MIMO property. PIN diodes incorporated in a parasitic resonant structure in the ground plane carry out the reconfigurable dual-band notch operation. The antenna is 40 x 20 mm2 and operates in the 3–11 GHz frequency range, with port isolation of at least 15 dB. The envelope correlation coefficient for the isotropic, indoor, and outdoor environments is calculated to guarantee the MIMO performance.

R. Gomez-Villanueva et al. [9], a four-port MIMO antenna array that is small and uniplanar is introduced. The antenna is built on a single layer of a laminate with a width of 0.8 mm and an εr of 4.5, covering a tiny area of 38.3 × 38.3 mm2. The average gain of the MIMO array is 4.1 dBi, its efficiency ranges from 72% to 97%, and its impedance bandwidth is 3-13.2 GHz. Polarization diversity served as this MIMO array's primary decoupling method. To lower the ECC to 0.02 or less in the operating bandwidth, a series of slits was also carved into the ground plane. One unique feature of the suggested array is that it is uniplanar, making it simple to install in mobile terminals where the antennas are printed on just one face of a partially non-flat dielectric surface.

III. FORMULATION OF DESIGNING METHOD

In the process of design we needs to calculate some parameters for subtract and the ground and which will be easily calculated by formulas discussed below:-

To calculate width of the dielectric subtract,

$$w = \frac{1}{f_r\sqrt{\mu 0\varepsilon 0}}\sqrt{\frac{2}{\varepsilon r+1}} \tag{1}$$

Where f_r is the resonance frequency, εrdielectric constant of the subtract & $\mu 0, \varepsilon 0$are the permeability and permittivity of free space respectively.

$$w = \frac{v0}{f_r}\sqrt{\frac{2}{\varepsilon r+1}} \tag{2}$$

Where $v0$ show the velocity of wave in free space. Now after calculating width of dielectric next is dielectric constant which we have to calculate and the formulas used to calculate dielectric constant is given by,

$$\varepsilon r = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2\sqrt{1+\frac{12h}{w}}} \tag{3}$$

Here we considers effective length instead of original length because the Microstrip antenna looks longer as only because of fringing effect and the effective length of the antenna is differ by ΔL from the physical length.

This extension in length is simply the ratio of width to the height and $\varepsilon reff$ which is given by below formula

$$\frac{\Delta Leff}{h} = 0.412\frac{(\varepsilon reff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)+(\frac{w}{h}+0.8)} \tag{4}$$

Now the original length is given by

$$L = \frac{1}{2fr\sqrt{\varepsilon reff\sqrt{\mu 0}}} - 2\,\Delta L \tag{5}$$

After calculating all these we have to calculate the dimension of the ground plane which will be varied for same antenna in some amount and this relation is given by

$$Lg \geq (\frac{\lambda eff}{4}) * 2 + L \tag{6}$$

$$Wg = \geq \left(\frac{\lambda eff}{4}\right) * 2 + W \tag{7}$$

By above flow chart it is very clear that the calculations of patch parameters like length, width and feeding point all are calculated with the help of MATLAB tool using special function with high accuracy, for this in very first step antenna working frequency is selected, now dielectric material chosen to work on given frequency.

Now optimum height of the substrate is inserted in the next step and the desired parameters are calculated. It gives us the flexibility to change our input frequency, height of subtract at run time and the time which is required for simulation is also very less.

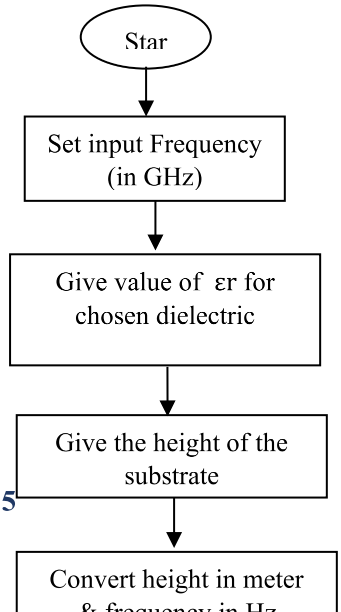

Figure 1: Flow Chart for Parameter Calculation

IV. PARAMETRIC OPTIMIZATION

The design parameters that govern the input impedance are substrate height, feed-point location and gap width.

a. Effect of Feed Point Location

For three different feed-point locations from the center of the patch, there is variation in the VSWR with frequency, shown in Fig. 2. With increase in frequency, the input impedance moves in a clockwise direction in the smith chart [7, 8]. As x moves from 1mm (feed-point is shifted to the edge), the input impedance loci shifts in the right direction on the smith chart implying that the impedance is increasing. A perfect match of 50 ohm feed-line is obtained for 4.75 mm along –x direction, which gives a bandwidth of 3.21 GHz for VSWR 2.

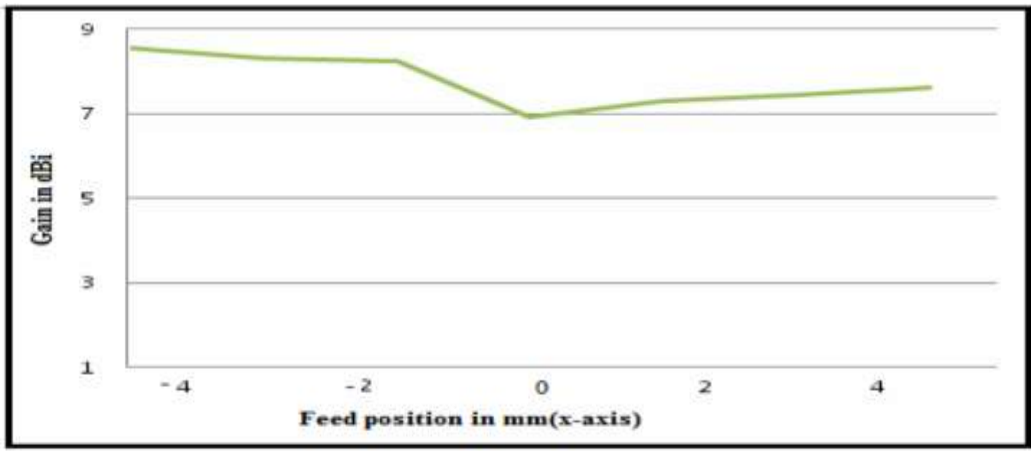

Figure 2: Gain variations of MIMO antenna

b. Effect of Gap Width

Gap width governs the interaction between the coupled patch and the main patch. Increase in the gap width decreases the size of the impedance loci, because the interaction between the resonators decreases. Also the impedance loci shift toward the left side of the smith chart is shown in Fig. 3(a) and (b). Further increase in the gap width decreases the size of the impedance loci and the loop disappears for larger gap width. In this case, the gap width is varied from 0.0073 to 0.033. The optimized value of 0.0073 gives good bandwidth thereby increasing the interaction between the co-patch and the main patch [9].

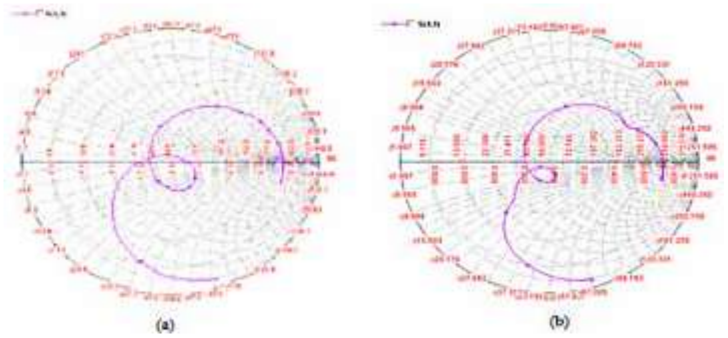

Figure 3: (a) Smith chart for optimized gap width (b) Smith chart for increased gap width

c. Effect of Height, h

With increase in height h, from 0.08Ʒ to 0.09Ʒ the fringe fields from the edges increase, which increases the extension length and hence the effective length, thereby decreasing the resonance frequency. The bandwidth of the antenna increases from 1.575 GHz to 3.21 GHz, for the optimized height 0.09Ʒ. The increase in the probe inductance of the feed moves the input impedance in clockwise, thereby introducing inductive shift [12].

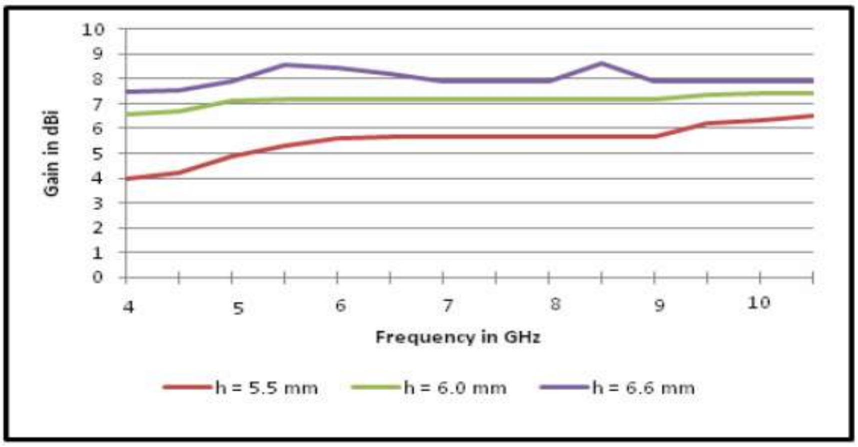

Figure 4: Gain variations of MIMO antenna

d. Effect of Width, W

Patch width affects the bandwidth to a larger extent [13]. A larger patch width increases the bandwidth, radiated power and the radiation efficiency. Patch width is chosen greater than the patch length, with good excitation. It is observed that the patch width various from 0.45Ʒ<W

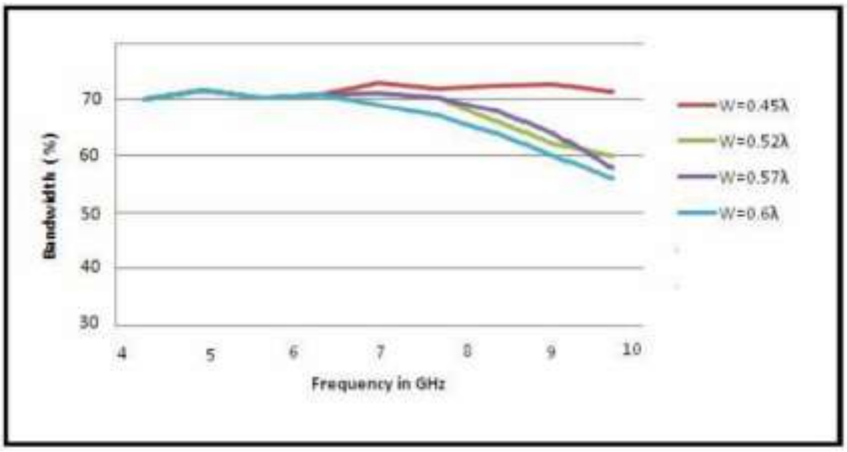

Figure 5: Bandwidth variations of MIMO antenna

V. TOOLS AND PARAMETERS

Tool: The Ansys HFSS software suite is used for the design and analysis of the antenna design. It is a full-wave electromagnetic test system dependent on FEM. It breaks down 3D and multilayer structures of broad shapes. It has been generally utilized in the structure of MICs, RFICs, fixed reception apparatuses, wire antennas, and other RF/remote receiving antennas. It tends to be utilized to compute and plot the S11 parameters, VSWR, current distributions, in addition to the radiation patterns. HFSS version 13.0 is utilized to get the design and analysis of the antennas.

Parameter:

Proposed antenna will simulate using HFSS software & corresponding graphs are obtained to analyze the performance in terms of output parameters, such as return loss, gain, radiation pattern and VSWR.

VI. CONCLUSION

The rapid evolution of IoT technology demands compact, efficient, and high-performance antenna solutions capable of supporting reliable wireless communication in a wide range of environments. MIMO antenna systems are essential in fulfilling these requirements by providing increased data rates, improved signal reliability, and enhanced spectral efficiency. Among the various antenna types explored for MIMO systems, Dielectric Resonator Antennas (DRAs) have proven to be highly effective due to their unique properties, including high radiation efficiency, low conductor losses, compact size, and wide operating bandwidth.

This survey has presented an in-depth review of the state-of-the-art MIMO DRA technologies suitable for IoT wireless applications. Various design strategies, performance metrics, isolation enhancement techniques, and real-world applications have been examined and compared. Key performance parameters such as ECC, diversity gain, gain, bandwidth, and mutual coupling have been analyzed to evaluate the suitability of different MIMO DRA configurations.

Despite the promising features, challenges remain in achieving optimal miniaturization, maintaining low mutual coupling, and integrating DRAs with compact IoT hardware platforms. The growing trend of incorporating AI and machine learning for intelligent antenna design and optimization opens new avenues for performance improvement.

In conclusion, MIMO DRAs represent a highly promising solution for future IoT-enabled wireless systems, especially in applications demanding compact, reliable, and high-speed communication modules. Further research focused on adaptive designs, reconfigurable structures, and smart optimization techniques will be crucial in addressing the remaining challenges and fully unlocking the potential of MIMO DRAs in the evolving IoT landscape.

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