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Pattern Reconfigurable Yagi-Uda Antenna

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Abstract

This study proposes a prototype of a reconfigurable Yagi-Uda Antenna that is capable of reconfiguration of the radiation pattern. The proposed flexible antenna will work as the director, and reflector can be switched in a Yagi-Uda set up antenna by using a radio frequency PIN diode. The radiating signals can be directed at desired signals away from undesirable signals that are impinging on the antenna in opposite directions. The antenna will function in the frequency of 5–6 GHz and will be focusing on increasing coverage, signal quality, and reduction of interference in changing wireless environments. The parameter specifications of the antenna performance and design were developed and tested empirically. The antenna's reconfigurable performance was validated through both simulated and experimental results, demonstrating its suitability for Wi-Fi, 5G, and other modern wireless communication technologies. This confirms its adaptability and effectiveness across various current wireless standards, making it a versatile solution for dynamic communication systems requiring flexible and efficient antenna configurations.

Keywords: Antenna, Yagi-Uda, pattern reconfigurable, radiation, detection, MIMO

INTRODUCTION

Modern communication systems have seen interest in reconfigurable antennas due to their ability to improve and adjust their performance. MIMO and reconfigurable antennas have encouraged engineers to research designs that can change their characteristics by modifying the usual structure. Pattern reconfigurable antennas are exceptional, as they can control their radiation pattern based on whatever changes in operations occur. The concept of the reconfigurable antenna was initially presented by Baik's patent, and it is achieved via electronic control of two pairs of RF PIN diodes [1]. The steering of the antenna allows it to select the desired facility. To prevent interference with other signals, the radio signals stay on their own track. For proper planning of wireless communication networks, Kittiyanpunya and Krairiksh's research have come up with a new Yagi-Uda antenna design. This antenna can change its beam pattern to four different configurations. It uses SPDT RF switches and PIN diodes to control the beam direction on the fly. The antenna also includes an electromagnetic band gap (EBG) structure.

This addition makes it work well when mounted on the roof of moving vehicle. Enhancing signal quality and dependability for TV viewing in vehicles or other mobile environments is the goal of design [2]. In order to address this issue, Chen *et al.* presented a pattern-reconfigurable antenna that can generate five different radiation beams in the elevation plane [3]. By combining reflective metal components beneath a central radiating dipole with dynamically controlled parasitic striplines arranged around it, the beam may be steered. This arrangement provides accurate and adaptable beam

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control by allowing the main beam of the antenna to be directed successively from left end-fire through left-tilted, boresight, and right-tilted positions, all the way to right end-fire direction. Based on how they work, reconfigurable antennas can be broadly divided into three types: those that change their radiation pattern, those that modify polarization, and those that change their resonant frequency [4–8]. A truncated microstrip patch antenna with a U-shaped slot incorporated and managed by a PIN diode is used by Chung *et al.* to achieve frequency and polarization adjustments [4]. According to the study by Santamaria *et al.*, the Internet of Things (IoT) facilitates smooth communication amongst a wide range of low-power wireless devices [5]. Smart objects are constantly collecting data from their surroundings and detecting changes. The same ground plane supports all four of the antenna's wire patches. This component offers waveform bandwidth in the 2.25 to 2.54 GHz frequency range and can change its end-fire radiation states in 5 µs.

The results show that the antenna's maximum gain at 2.44 GHz is 3.9 dBi, and its front-to-back ratio is higher than 6.5 dB. One SP4T switch, which is low-power and low-loss, is used to direct radiation patterns on the radar beam. Reconfigurable antennas have gained popularity as wireless communication technologies advance quickly. Because it provides systems that use multiple frequencies, different polarizations, and different forms of radiation, attention is necessary. The advantage of having several antennas is diversity. Functionalities could be beneficial in a variety of computer systems. Additionally, they can reduce the impact of multipath effects. Additionally, the reconfigurable antenna can be made to function better even when noise interferes. Since it directs the primary water to a new location, it is advantageous to change the direction of its radiation that does not interact with objects [6]. A simple Yagi-Uda antenna, supported by a dielectric substrate and a limited ground plane, is used to build the antennas described in other studies [7, 8]. Furthermore, the effects of the bias lines are unknown, and these antennas use metal pads rather than RF switching circuits. In this study, we successfully design a pattern reconfigurable Yagi-Uda antenna without a ground plane by moving the minimum and maximum levels of the radiation pattern to opposite side orientations using an RF PIN diode.

ANTENNA DESIGN

Antenna Structure

Solid and side views of the reconfigurable antenna construction created are shown in Figure 1(a) and (b). This antenna is designed for pattern-switching capability and is built on an RT/Duroid 5870 substrate.

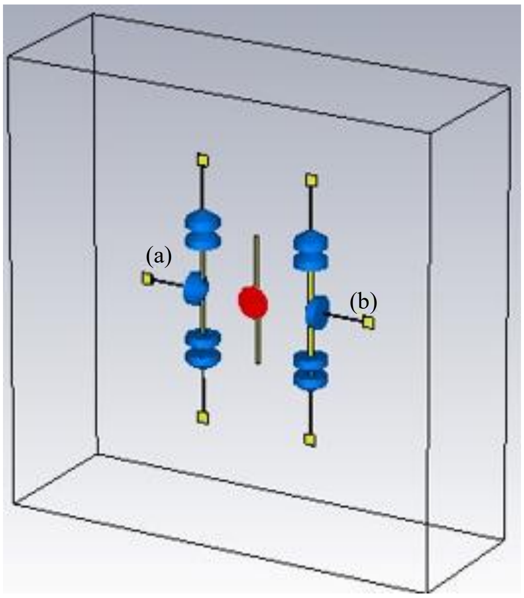

Figure 1. Antenna Shows: (a) s3-d view (b) side view from CST software.

The free-space wavelength (λ_0) at the center frequency range of 5–6 GHz was used in this design to excite a balanced mode, as illustrated in Figure 1(b), even though a conventional arrangement is not used. The manufactured antenna's physical dimensions are 50 mm (lt)×50 mm (lt)×0.8 mm. Figure 2 depicts a schematic of the proposed reconfigurable antenna's layout. With λg being the guided wavelength at 6 GHz, the computed distance between the driven element and reflector (or director) is 9.84 mm, or 0.125λg. The width (w) of the driver and reflector (director) is always 0.82 mm. As illustrated in Figure 2, a microstrip extension with a length (l_3=2.89 mm) is added to one leg of the PIN diode to allow switching from reflector to director [9]. The RF choke inductors electrically isolate the bias line to the reflector (or director). To evaluate operational capabilities, the PIN diodes are activated with a 5 Ω resistance while the analogue ON state maintained a capacitance of .035 pF to keep the diode in the OFF state. The length of the forward director (l_2) is 18.77 mm, or 0.239λ, and each half of the dipole element is 11.72 mm (l_1). For the RF PIN diode, a tiny soldering gap of 0.55 mm is utilized. Once the PIN diodes are turned on (ON state), the total length of the reflector is at 25.68 mm.

Pattern Reconfiguration Mechanism

The efficiency and operation of an antenna mostly depend on how the antenna pattern is arranged. It forms one of the key concepts that influence the way antennas work. In the design, dynamic switching between the director and reflector modes is achieved with PIN diodes. Proper separation of voltage between the biasing network and RF circuit, is supported using RF choke inductors [10]. They remain stable so that radio signals do not reach the bias lines and allow DC biasing to control the PIN diodes. With a bias of 5 Ω across the PIN diode, the current begins to flow in the right direction to activate the radiation. In case the diodes need to stay off, a capacitor of 0.035 pF is used which blocks the direct current without much effect on the radio part. A resistor of 5 Ω is linked to the RLC circuit on the PIN diodes positioned on one side of the reflectors. A capacitive load is applied to the reflector elements facing the area you wish to block radiation from. As a result, this setting enables precision in directing the main beam to chosen points and controlling unwanted signals.

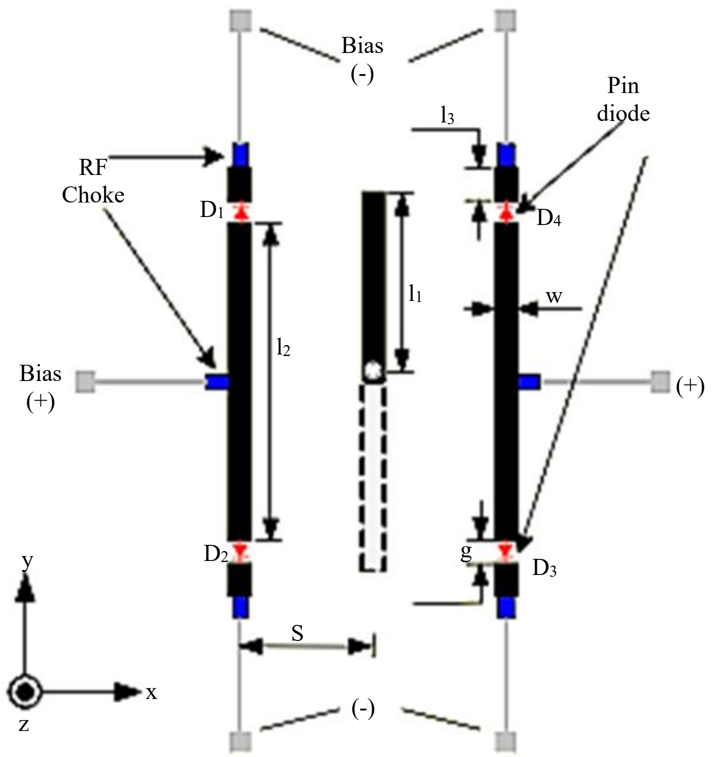

Figure 2. Schematic of the proposed antenna using the PIN diode.

As shown in Figure 2, D1, D2, D3, and D4 are four PIN diodes that enable the reconfigurability of the antenna. Firstly, if D1 and D2 are given a resistance of 5 Ω, the radiation pattern is reconfigured toward the right side of the antenna, which can be referred to as the **+x plane**. Similarly, if D3 and D4 are given a resistance of 5 Ω, the pattern is reconfigured toward the **–x plane**. The configuration can be adjusted accordingly to achieve the desired radiation direction.

EXPERIMENTAL RESULTS

The proposed reconfigurable Yagi-Uda antenna's simulated and measured return loss characteristics are shown in Figure 3, particularly when diodes D1 (or D4) and D2 (or D3) are in the ON-state and the other diodes are switched OFF. A 10 dB impedance bandwidth of 1.7 GHz, spanning the frequency range of 5.1 to 6.8 GHz, is shown by the experimental data. This amounts to roughly 28.33% at a center frequency of 6 GHz. Figure 4 illustrates the excellent correlation between the simulated data and the measured return loss. A Vector Network Analyzer (VNA) was used for the practical measurements, and CST Studio Suite, which uses the finite element method, was used for the antenna simulations and performance optimizations.

When D1 and D2 are turned on and D3 and D4 are turned off, the measured and simulated radiation patterns are shown in the x-y plane (E-plane) and x-z plane (H-plane) in Figure 3(a and b). The front-to-back (F/B) ratio of the measured E-plane pattern is around 10 dB, and it is significantly impacted by the interaction between the reflector and the driven dipole. The second observation is that the observed and simulated backlobes exhibit some backlobe radiation type disagreement; however, this could be attributed to bias lines and suboptimal RF choke inductor performance.

The primary radiation will not be significantly impacted by the electrically open bias lines directed towards the directors. The observed performance was comparable to the simulated peak gain of 15.0 dBi, with the measured gain at the center frequency of 5.78 GHz being 14.0 dBi. Figure 5 shows the measured E-plane patterns for each pair of RF PIN diodes upon switching. The radiation pattern associated with D1 and D2 being in the ON-state (Figure 5) is compatible with the co-polarized E-plane radiation pattern seen in Figure 6(a). Additionally, it is evident from Figure 5 that the main lobe and back lobe of the radiation pattern flip places in the opposite directions.

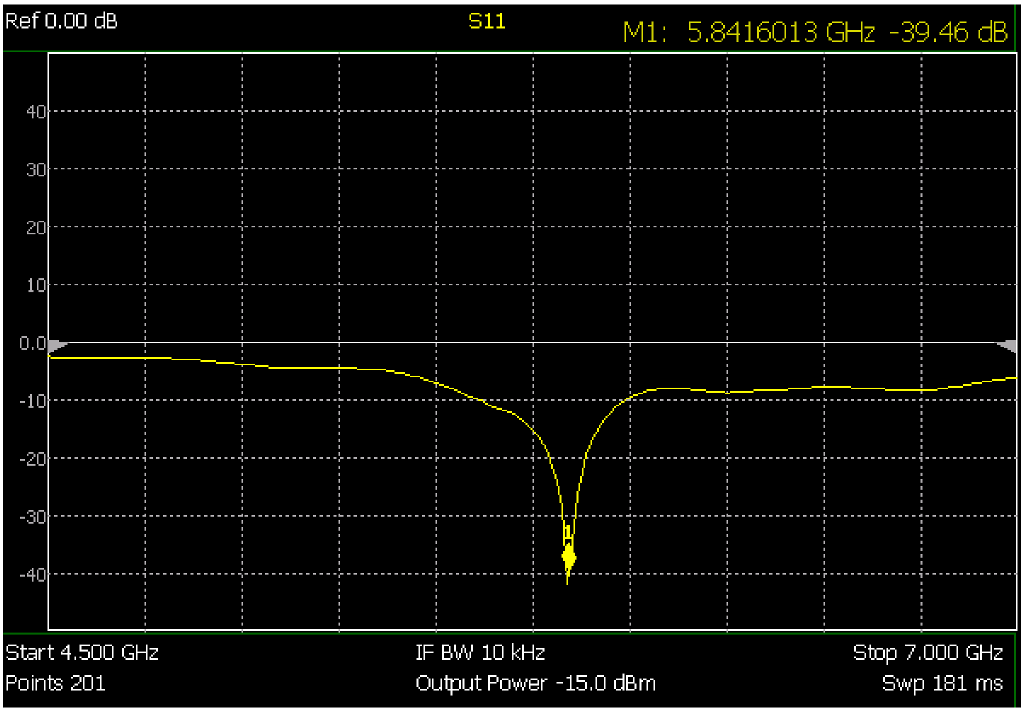

Figure 3. Simulated and tested resonating frequency of Antenna.

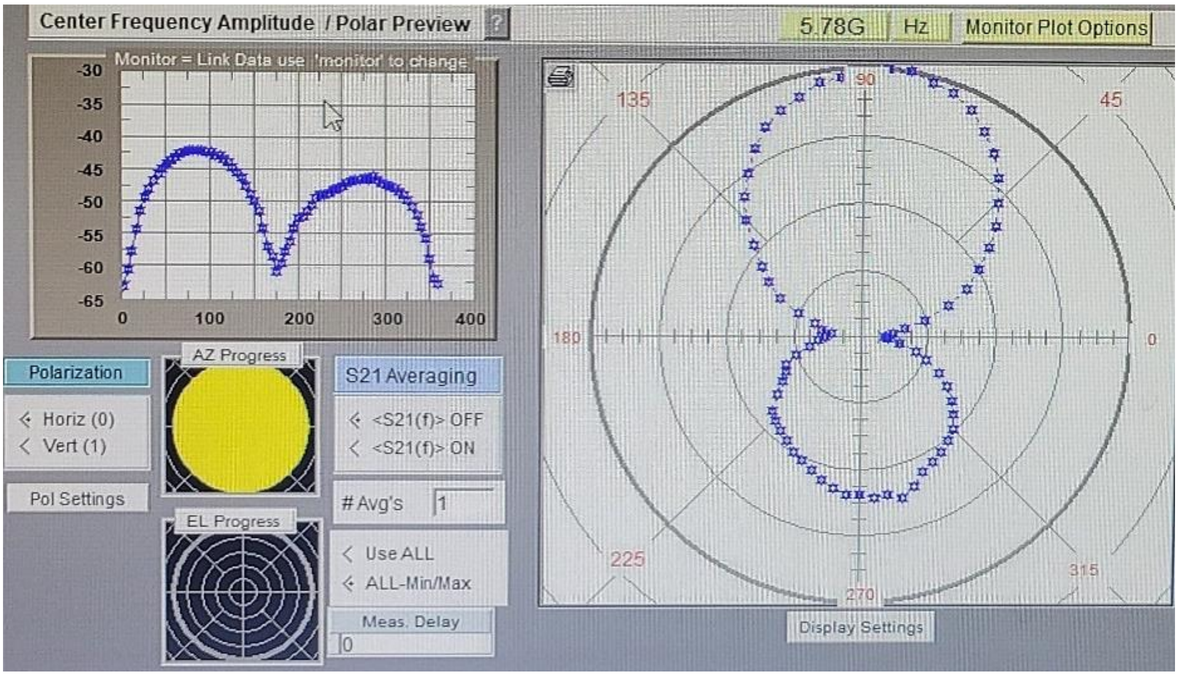

Figure 4. Radiation pattern of antenna when D1 and D2 are turned on. Pattern shifted along X-plane.

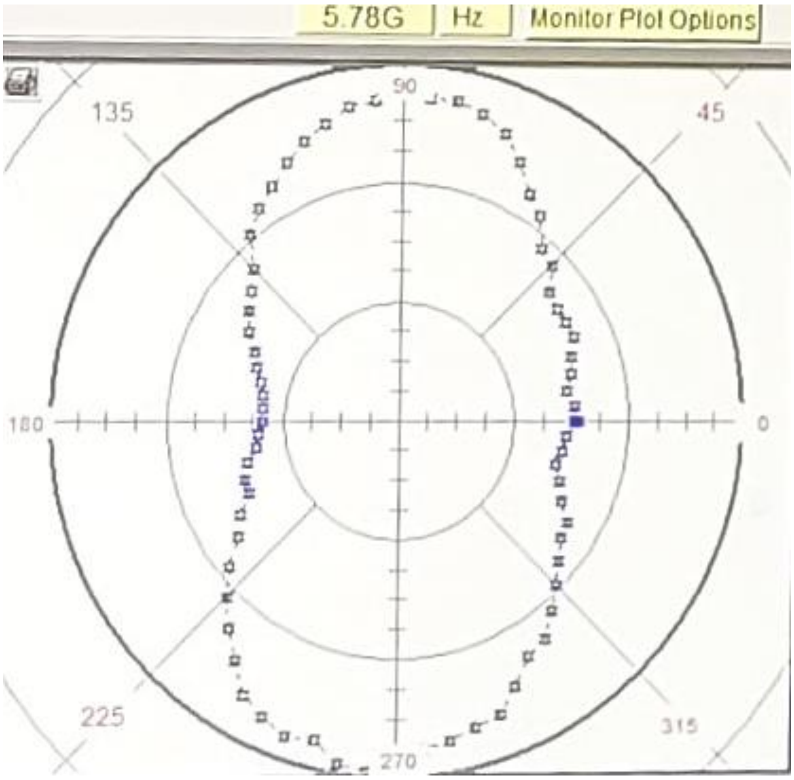

Figure 5. Radiation patterns in each state keeping all Pin diodes ON.

CONCLUSION

In this study, a pattern reconfigurable Yagi-Uda antenna in the 5–6 GHz frequency range has been designed and implemented. Dynamic control of the radiation pattern is realized in the antenna by electronically switching RF PIN diodes, which interchange the roles of reflector and director elements. This allows real-time steering of the radiation pattern to receive desired signals while rejecting interference, rendering major enhancement in coverage and signal dependability in dynamic wireless scenarios. The proposed structure is small-sized, economical, and ideal for contemporary wireless applications like Wi-Fi, 5G, and IoT networks. Even if shown in the 5–6 GHz frequency range, the design can be scale-shifted to other frequencies by using frequency scaling methods, ensuring its flexibility and suitability for incorporation into future communication networks.

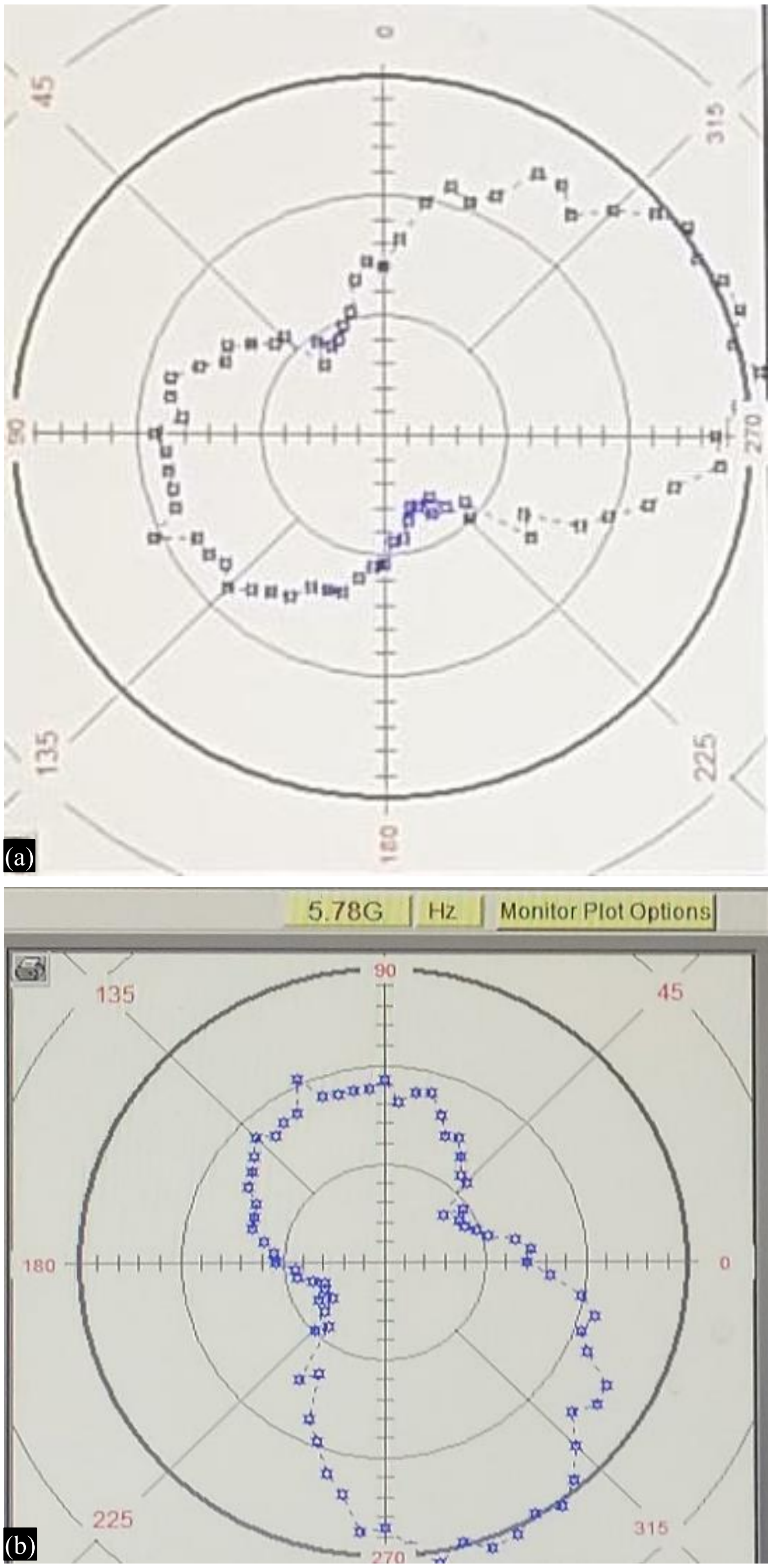

Figure 6. Simulated and measured radiation patterns: (a) E-plane and (b) H-plane.

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