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Enhancement Of Wider Impedance Bandwidth Monopole Cpw-Fed Pentagonal Patch Antenna With Slits For SRR Applications

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***Abstract*— This paper presents the design of a monopole CPW-fed pentagonal patch antenna with slits for Short Range Radar (SRR) applications. The proposed antenna is implemented on an FR4 substrate with dimensions of 28 × 23 × 1.6 mm³ and utilizes a Co-planar Waveguide (CPW) feeding technique. The antenna is optimized through a stepwise geometric evolution process using slot-loading technique which resonates at 9.73 GHz with reflection coefficients of –38.05 dB. It operates over a frequency band of 8.85–11.69 GHz producing a bandwidth of 2.84 GHz. The observed peak gain is 3.6 dBi. This paper presents the analysis of S11 parameters, far-field radiation patterns, 3D gain characteristics, and surface current distributions at the resonant frequency. The structure was optimized for stable reflection coefficient, omnidirectional radiation, and compatibility with compact sensing systems.**

Keywords*— *Pentagonal patch antenna, Short Range Radar applications, Co-planar Waveguide, Slot-loading technique, S11 parameters, Gain characteristics, Radiation patterns, Surface current distributions.

I. INTRODUCTION

Short-Range Radar (SRR) systems have started to be very important modern sensing systems because of their ability to function properly and accurately. SRR is also preferred more than other systems like optical and infrared sensors due to its ability to function properly and accurately. SRR is applicable in many tasks that involve obstacle detection and tracking in real time, navigation and support for other systems, and monitoring in short distances. The most important and critical RF and Radar components are their antennas because they determine almost everything in a radar system such as the resolution, the accuracy of the detection, and the entire effectiveness of the radar system.

However, meeting the requirements for SRR antennas are challenging and undergo a huge balancing act. SRR systems were designed to be small and compact which means the antennas are also required to be low profile, lightweight, and mechanically stable. Not to mention, they still have to perform extremely well at electromagnetic radiation. Additionally, they also must exhibit wide impedance bandwidth, strong radiation patterns, and reliable sensing for various operational conditions.

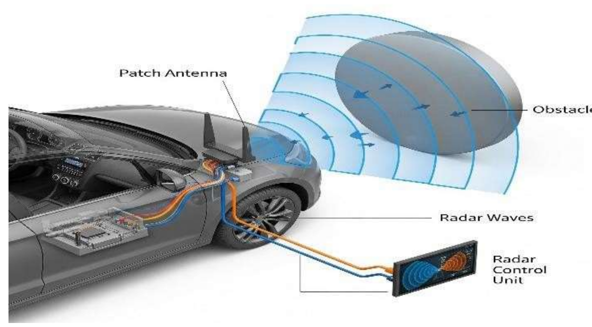

Figure 1 Short Range Radar

Wireless communication is growing fast, and antennas play a big role in making these systems work well. Monopole patch antennas fed by coplanar waveguide (CPW) are popular because they're small, easy to make, and work well over a wide range of frequencies The Coplanar Waveguide (CPW), while maintaining all these benefits, allows substrate losses to be minimized. Thus, CPWs aid in ease of integration with the other electronic components of a system.

It has been shown that such antennas can have their performance enhanced using geometric modifications such as slot loading, adding symmetric parasitic features, and using polygonal shapes for the radiating elements. In essence these modifications elongate the available current-carrying paths, improve the available impedance, and yield a better overall radiation pattern. Short-Range Radar operates in the X-band (9–12 GHz) range. The design proposes to add multiple slits to control resonance and extend usable bandwidth while keeping the overall size small.

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This work focuses on optimizing such antennas to achieve stable impedance and suitable radiation patterns for short range radar applications. The proposed design aims to meet the demands of modern radar systems requiring reliable, wideband operation.

Numerous researchers proposed various antennas. An example is Manal K. Fattoum et al. who proposed the design of a compact broadband antenna that accommodates the long-term evolution (LTE) bands. A wide band of operation is achieved using a slot-loading technique [1]. Sumon Modak et al. proposed a conformal, ultra-miniaturized, circuit integrated ultra-wide band (UWB) coplanar-waveguide (CPW) antenna system intended for use in on-body applications [2]. With better impedance matching and broadband characteristics, Haiwen Liu et al. proposed for WiMAX and X-band a coplanar waveguide fishtail-shaped antenna [3]. For WLAN/WiMAX applications, Hong Chen et al. proposed a novel coplanar waveguide fed triband planar monopole antenna [4]. With a U-shaped monopole and coplanar waveguide feed, Qing-Xin Chu et al. introduced a triangular monopole to create dual-wideband operating frequencies [5]. Mohamed El Hammoumi et al. proposed a novel wideband circularly polarized CPW-fed printed monopole antenna for CubeSat applications that maintains a wide impedance bandwidth and a broad 3-dB axial ratio bandwidth [6]. Lin Peng and others proposed a special type of ultra-wideband notched-band antenna designed with two mushroom-type EBG structures on the CPW feeding lines [7]. Anil Kr Gautam and others proposed an antenna designed using a technique aimed at reducing the height of a monopole antenna by incorporating an inverted L-strip element on the conventional monopole patch antenna [8]. Seyed Ramin Emadian and others have developed a small-sized coplanar waveguide fed rectangular slot antenna with dual band notched characteristics applicable to the ultra-wideband range [9]. Xin Sun and others presented a new design of a CPW fed slot antenna which is significantly miniaturized and allows quad-band operation through the incorporation of three L-shape slots along with a rectangular slot on the substrate [10]. Shayan Hakimi and others have proposed a new design of a coplanar waveguide fed transparent antenna for ultra-wideband applications with improved bandwidth [11]. Farooq Faisal and others designed two compact and flexible antennas of the Flower shape coplanar waveguide fed for high data wireless applications. The Flower shaped radiators of both antennas are designed by creating round slots in a simple circular shape [12].

A super wideband antenna for wireless sensor networks has been presented by Rezaul Azim et al. which consists of a modified bowtie shaped vertical patch and two asymmetrical ground planes. M. Naser-Moghadasi et al. have designed a compact dual-band coplanar waveguide antenna which consists of a rectangular patch and upper and lower ground structure that pertains to GSM and Wi-Fi/WLAN [14]. The study by Amit Birwal \& Koohestani et al. includes the first coplanar waveguide antenna that is bi-directional coplanar waveguide-fed antenna with circular polarization. [15]. Koohestani et al. have designed a compact cp fed antenna for polarization diversity in ultra wide band applications with good port isolation [16]. Javad Pourahmadazar et al. have designed a novel antenna which is circularly polarized and consists of a square ground plane with two uneven inverted-L shaped strips [17].

Farah Raad Kareem et al. have designed a triple-band all-textile monopole antenna with a coplanar waveguide that is fed and has improved gain for the wearable Internet of Medical Things to support wireless wearable sensors [18].

II. Proposed Methodology

The design of the proposed CPW-fed pentagonal monopole antenna was done following specific steps as shown in the figure above.

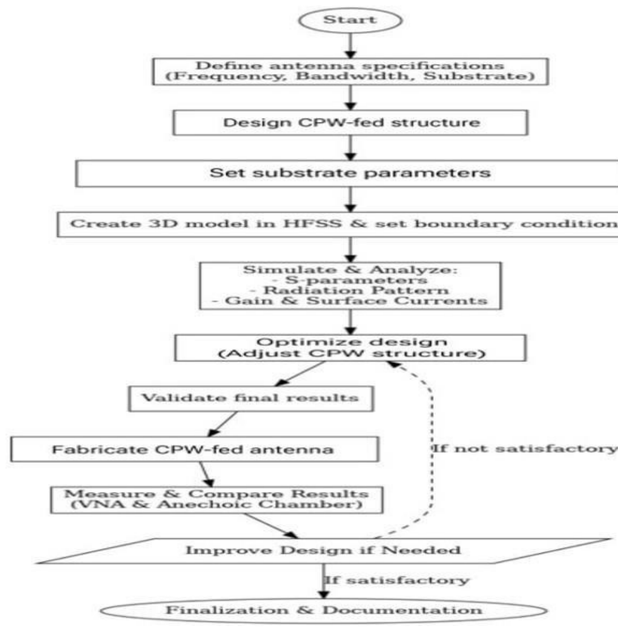

Figure 2 Block Diagram of Methodology

- Determining Antenna Specifications:

The first step is identifying key specifications of the antenna such as the operational frequency range and bandwidth as well as the appropriate substrate material. These specifications become the building blocks of the design.

- Constructing the CPW-Fed Structure:

With the specifications defined, the next step is to prepare the design of the first Coplanar Waveguide (CPW) feeding structure. This stage is concerned with the determination of the feeding size, spacing to the ground plane, and the shape of the radiating element.

- Assigning Substrate Parameters:

The substrate parameters such as the dielectric constant, thickness, and the loss tangent are defined. These parameters will define the antenna's impedance, frequency, and efficiency.

- Designing the 3D HFSS Model:

The HFSS environment is used to construct a complete 3D model of the antenna. The model is then set up with boundary conditions, excitation ports, and materials in preparation for a simulation.

- Simulating and Assessing:

S-parameters, radiation patterns, the gain of the antenna, and the current surface flow to the antenna are measured. The aim of this simulation is to assess the antenna's electromagnetic practicality. These measurements will depict the antenna's behavior with current electromagnetic fields.

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- Improving the Design:

Geometric changes are required when the antenna fails to satisfy the specifications. This leads to iterating on the model which is a key part of the design as the whole design is created around a set of specifications.

- Result:

In the obtained optimized design, the final simulated results must first be checked for consistency and reliability before proceeding to the fabrication phase of the design.

II. DESIGN PARAMETERS

The designed antenna is constructed on an FR4 epoxy substrate that possesses a relative permittivity =4.4, loss tangent =0.02, and thickness h. A coplanar waveguide feed method is utilized to excite the radiating element because it is easy, has minimal radiation loss, and is simple to integrate.

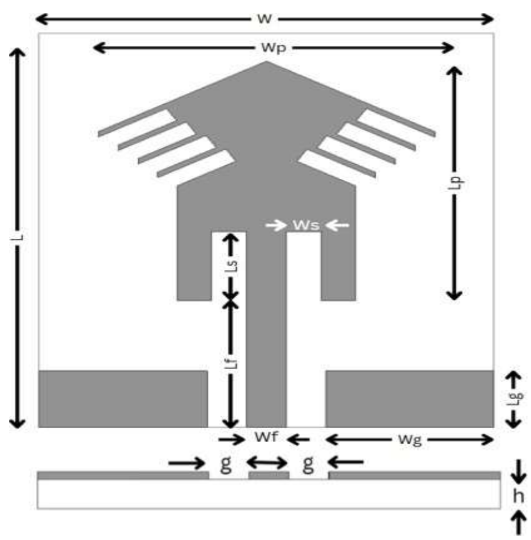

Figure 3 Antenna Geometry

The radiating patch is made up of a tapered arrow shaped geometry as shown in Figure 1 integrated with stepped edges and symmetrical parasitic arms. These parasitic branches increase surface current distribution and play an important role in enhancing impedance matching and radiation stability. The size of the antenna is L and W, which gives the structure a compact size for contemporary embedded applications. CPW feedline width is Wf and has a gap of g from the ground planes. The ground planes on either side are width of Wg and length of Lg. The center radiating patch is Lp long and Wp wide. Slits of sizes Ls and Ws are added to enhance resonance properties.

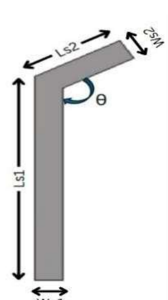

Figure 4 Slit Geometry

Slot loading technique is used by subtracting reverse L-shaped slits with widths Ws1, Ws2 and lengths Ls1, Ls2 is connected at an angle of θ = 30.5 degree from the patch as shown in Figure 2. The simulations were performed in ANSYS HFSS with wave port excitation. optimal values of parameters are presented in given Table 1.

Parameter	Value (in mm)	Parameter	Value (in mm)
L	28	Lg	4
W	23	Wg	8.5
Lp	17	Ls1	16.612
Wp	17	Ws1	1
Ls	4.9	Ls2	4
Ws	1.77	Ws2	1
Lf	9	g	2
Wf	2	h	1.6

Table 1 Parameter values

III. RESULTS AND IMPLEMENTATION

The performance of the proposed CPW-fed pentagonal monopole antenna with slits was evaluated through High Frequency Structure Simulator (HFSS). Key antenna parameters such as return loss, gain, bandwidth, radiation pattern, and surface current distribution were analyzed were analyzed at the resonant frequency of 9.73 GHz. The results presented below confirm the effectiveness of the design in meeting the requirements for short range radar (SRR) applications.

A. Reflection Coefficient:

In the simulation, the proposed antenna resonated at frequency of 9.73 GHz with the reflection coefficient of –38.05 dB. Also, it has a wider bandwidth of 2.84 GHz (8.85– 11.69 GHz) and is depicted in Figure 5. It has a fractional bandwidth of 27.65 percentage.

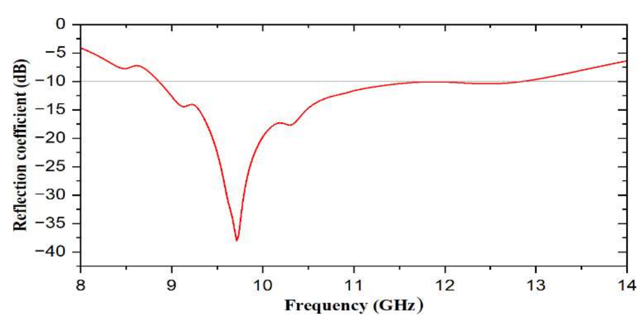

Figure 5 S11 Parameter (dB)

Figure 5 represents the simulation and measurement results of reflection coefficients.

B. Radiation Pattern:

The simulated radiation pattern of the suggested antenna configuration at 9.73 GHz in both the E-plane (Φ = 0°) and H-plane (Φ = 90°). The antenna exhibits a directional radiation pattern with high gain and main lobes that are symmetrical. The E-plane pattern (red line) has a smooth direction profile, whereas the H-plane pattern (green line) shows an analogous direction trend with slight oscillations. This radiation pattern validates the antenna's performance for usage in applications

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that demand stable and directional radiation characteristics at X-band frequencies.

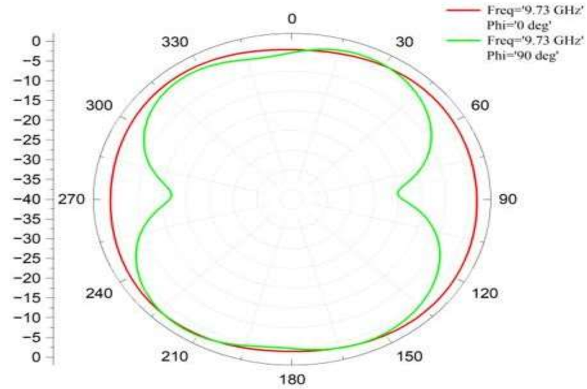

Figure 6 Radiation Pattern

Figure 6 represents the simulation and measurement results of radiation pattern.

C. Gain Plot:

Gain performance of the designed Pentagonal microstrip patch antenna was comprehensively studied with the help of ANSYS HFSS. The simulated three-dimensional gain plot of the proposed antenna at the operating frequency of 9.73 GHz. The maximum gain attained is approximately 3.60 dBi as indicated.

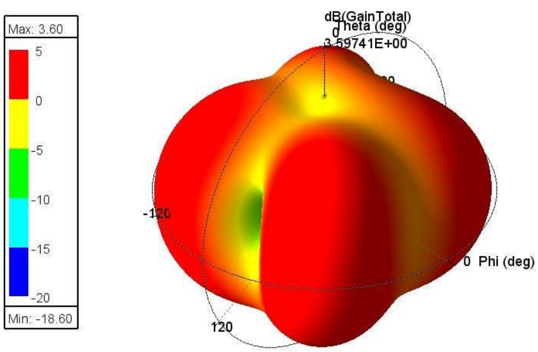

Figure 7 Gain Plot (dBi)

Figure 7 represents the simulation and measurement results of Gain Plot.

D. Surface Current Distribution:

Surface current in antennas signifies the flow of electric current along the surface of an antenna element, particularly when the dimensions E-Plane, H-Plane closely match the wavelength of the electromagnetic wave they transmit or receive. From Figure 8, the maximum number of current excitations is 131.173 A/m at 9.73 GHz frequency.

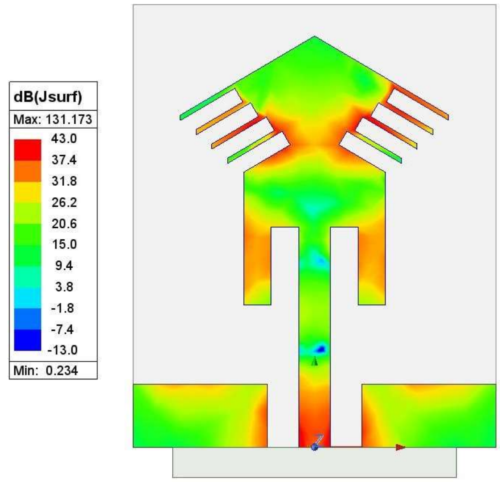

Figure 8 Surface Current Distribution

Figure 8 represents the surface current distributions at the operating frequency 9.73 GHz .

E. Fabrication Result:

The fabricated prototype uses a FR4 substrate with adhesive copper tape forming the radiating elements, and an SMA connector is attached for measurement. Its compact size, demonstrated by comparison with a Scale, confirms suitability for Radar and Sensing applications.

Figure 8 Fabricated Antenna

IV. CONCLUSION

This paper discusses a slotted monopole CPW-fed pentagonal patch antenna designed for Short Range Radar (SRR) applications. The Proposed antenna operates at 9.73 GHz with a return loss of -38.05 dB. A bandwidth of 2.84 GHz (8.85-11.69 GHz) was recorded. A wide fractional bandwidth of 27.65 percent is achieved. This antenna offers a 3.6 d Bi gain at the relevant frequency. The far-field E-plane and H-plane characteristics at the resonant frequencies were also studied. A wideband agreement was found for the simulated and measured results.

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