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A Pentagonal Slit Bow-Tie Patch Antenna with a Novelty Design for MANPADS Guiding Simulator for Defense

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Abstract—A unique bow-tie shaped pentagonal slit microstrip patch antenna has been particularly developed, manufactured, and tested for defense applications such as gunner training systems. The substrate is made of 3.2 mm thick FR4 material with a dielectric constant of 4.3. With a conductivity of 5.96×10^7 Siemens/m copper is used as a pentagonal bow-tie patch. During the training period of MANPADS, previously wired system is used, and it is replaced by a completely wireless system with a specially designed antenna along with an ultrasonic sensor and processor unit. The innovation of antenna is pentagonal slit created on patch, and it increases fringing effects. It attains 6.523 GHz with a return loss of −22.5 dB, maximum gain of 5.84 dB, and better VSWR of 1.16. CST Microwave Studio 2016 simulates the proposed antenna characteristics such as gain, return loss, radiation pattern, and VSWR.

1. INTRODUCTION

MANPADSs (Man-Portable Air Defense systems) are surface-to-air weapon systems where a person or a small team can aim at the aircraft. MANPADSs are handling defensive systems [1].

These weapons systems are also referred to as anti-aircraft missiles that are fired by the shoulder. These weapons usually make the last layer of aerial threats protection. MANPADS operators are deployed close to the defense system, and they have little response time to attack aircraft. In many dangerous cases like an airfield under attack, the situation gets more complicated. To handle these scenarios takes great skill and the ability to take tactical decisions rapidly.

The gunners are allowed to shoot during live drills through live training opportunities. For stinger gunners and squads, the army has an important training void [2, 3, 15]. The simulation facility does not exist (or is not available), or it is unattainable for working out when training is needed, and manual practice drills on physical training ranges serve for much of the training [4]. During this training period, a vehicle can be used as the target. At present, a wired communication system is used to analyze the direction of the vehicle, and it also covers more than 50 to 75 m. The gunners need to change the mode before they start firing it probably focusing on the direction of a target (moving vehicle) through the wired system. This wired system is mainly used to analyze the performance of gunners during the training period. In this paper, the wired system is replaced by a completely wireless system with a specially designed bow-tie shaped pentagonal slot microstrip patch antenna along with an ultrasonic sensor and processor unit.

A bow-tie antenna is composed of a two-wire triangle or a bow-tie-shaped base, fed at a distance from the triangle [5]. In that, it produces frequency, as needed, independent features, greater bandwidth, and high radiation [17–20]. The pentagonal normal patch that gives dual bandwidths is customized to irregular shapes with equal areas to achieve improved characteristics in terms of bandwidth and supply the gain that varies between −3 dB and 3 dB. This gain is enhanced by building slots [21–24] within the

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irregular pentagonal patch to be within the range between −0.95 dBi and 4.4 dBi [6]. In the previous article [7], the pentagon-shaped antenna obtains better performance than other shaped antennas. A implantable hexagon shape bow-tie patch is used for bio-medical application at 2.43 GHz with a return loss of −29 dB [8]. The different configurations of patches are analyzed [9] in which the pentagon patch with inner pentagon had better performance than other patches. The innovation of antenna is a pentagonal slit created on pentagon patch, and it increases fringing effects. The proposed antenna is resonated at a particular frequency of 6.523 GHz to avoid data theft in defense training field. Compared with previous antennas, it obtains better return loss, good VSWR, high frequency, high gain, more directivity, and better radiation pattern.

Since this antenna is specially designed for defense application and to avoid data theft, it resonates at 6.523 GHz. The frequency of 6.5 GHz is also used for wireless sensor applications [13]. In this paper, an ultrasonic sensor is used to analyze the gunner's performance.

In this paper, the pentagon-shaped bow-tie copper patch is placed on an FR4 substrate with $\varepsilon_r = 4.3$. Inside the copper patch, a pentagon-formed slot can be generated with different substrates to increase the resonant frequency with a better return loss. It attains 6.523 GHz with a return loss of −22.5 dB. This proposed antenna is used to analyze the gunner's performance in field-level training systems for the gunners. The FR4 substrate standard thickness is 1.6 mm. If the thickness is doubled, it increases bandwidth and gain [14]. When the thickness of substrate of antenna is changed, it changes the system performance.

2. ANTENNA DESIGN AND SIMULATION

2.1. Design Structure and Equation Of Proposed Antenna

The pentagon patch is derived from a circular patch. The connection between the circular patch (r_{cir}) and pentagonal one (r_{pen}), where the pentagon patch is inscribed, to achieve equivalent areas is given by the equation [10]:

$$r_{pen}^2 = \frac{\pi r_{cir}^2}{2.37} \tag{1}$$

$$\text{Pentagon Side} = 2r \sin \frac{\pi}{n} \tag{2}$$

Radius is related to wavelength by

$$r_{pen} = \frac{\lambda}{\pi} \tag{3}$$

The frequency is related by the equation

$$\lambda = \frac{v}{f_{res}\sqrt{\varepsilon_{rel}}} \tag{4}$$

$$W_s = \frac{v}{2f_{res}}\sqrt{\frac{2}{\varepsilon_{rel}+1}} \tag{5}$$

$$L_s = \bar{L}_{eff} - 2\nabla Ls \tag{6}$$

$$\bar{L}_{eff} = \frac{v}{2f_{res}\sqrt{\bar{\varepsilon}_{reff}}} \tag{7}$$

$$\nabla Ls = h_{sub} \times 0.412 \frac{\bar{\varepsilon}_{reff} + 0.3\left(\frac{w_s}{h_s} + 0.264\right)}{\bar{\varepsilon}_{reff} - 0.258\left(\frac{w_s}{h_s} + 0.8\right)} \tag{8}$$

$$\bar{\varepsilon}_{reff} = \frac{\varepsilon_{rel}+1}{2} + \frac{\varepsilon_{rel}-1}{2}\left(1 + 2\frac{h_{sub}}{w_s}\right)^{-\frac{1}{2}} \tag{9}$$

where

r_{pen} — Pentagon radius

r_{cir} — Circle radius
f_{res} — Resonant Frequency
ε_{rel} — Substrate dielectric constant
L_{pat} — Patch length
h_{sub} — Height of the substrate
$\overline{L}_{eff}$ — Patch length effect
$\overline{\varepsilon}_{reff}$ — Effective dielectric constant

The bow-tie shaped pentagonal slot microstrip patch antenna is shown in Figure 1, and dimensions of the proposed antenna structure are given in Table 1.

Table 1. Dimensions and parameters of proposed antenna design structure.

Parameters	**Dimensions**
Dielectric substrate(FR4) length, width, and thickness	$L_s \sim W_S \sim T_s$ 31 mm∼46 mm∼3.2 mm
Dielectric constant (FR4 Substrate)	$\varepsilon_r = 4.3$
Microstrip feedline length width and thickness	L_f∼W_f∼T_f 15.5 mm∼1.2 mm∼0.0365 mm
Pentagon patch side Outer and Inner	$L_p = 10.58$ mm (outer patch length) $L_{p1} = 4.7$ mm (inner patch length)
Patch (copper) Thickness	W_{pat}∼0.0365 mm
Ground (copper) thickness	0.0365 mm
r_{cir}	9 mm
r_{pen}	107.37 mm

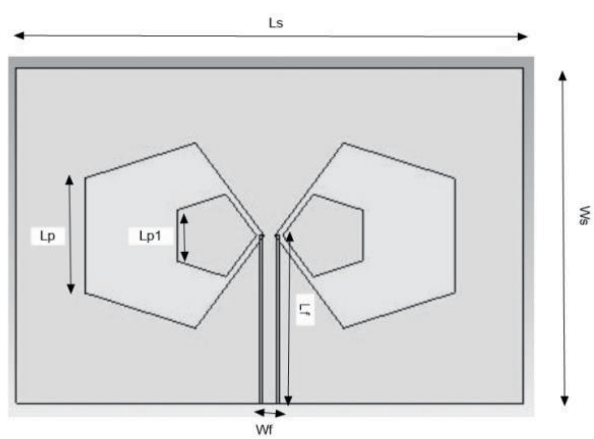


Figure 1. Design structure of proposed bow-tie pentagonal patch antenna.

2.2. Simulation Results on CST Software

2.2.1. Return Loss

The proposed antenna is simulated with CST software and resonates at a frequency of 6.523 GHz with a minimal S_{11} return loss of −22.5 dB. The S_{11} vs frequency plot of the proposed antenna is shown in

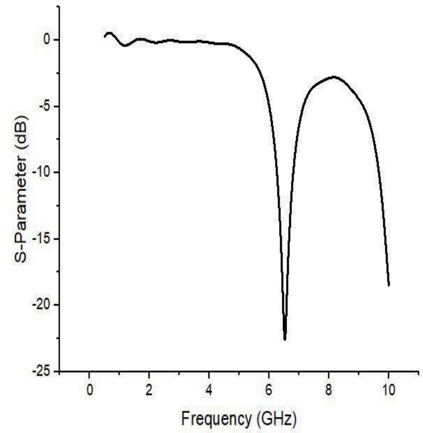


Figure 2. Return loss vs frequency.

Figure 2. Parasitic passband exists at 10 GHz and does not affect the use of antenna. To avoid data theft in defence, the antenna is used for training field at specific frequency at 6.523 GHz. It is reduced by filter which is in PIC microcontroller.

This graph demonstrates the simulation result about −22.5 dB at 6.523 GHz which is less, and the designed antenna is used for defense purpose. The proposed antenna shows a less return loss of −22.5 dB at 6.523 GHz. It is enough to use for the MANPADS simulator of training.

2.2.2. VSWR (Voltage Standing Wave Ratio)

Figure 3 illustrates that the VSWR value for 6.523 GHz is 1.16.

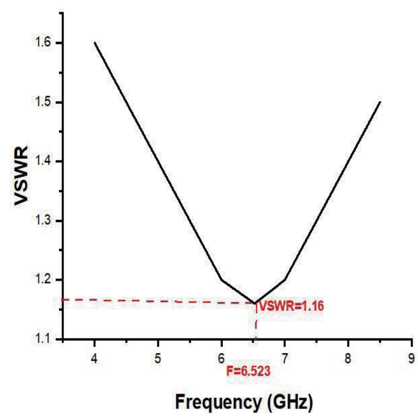


Figure 3. VSWR plot.

2.2.3. Gain

The simulation gain of the designed antenna is shown in Figure 4, and also the value of gain is obtained as 5.84 dB at 6.523 GHz.

2.2.4. Radiation Pattern

The 3D radiation pattern of the proposed antenna is shown in Figure 5. Figures 6 and 7 demonstrate the suggested antenna's E and H far field patterns at 6.523 GHz. The maximum gain 5.84 dB is obtained on the E-plane and H-plane. A figure-of-eight pattern is formed, and it has a sharp directional shaped pattern at particularly 6.523 GHz.

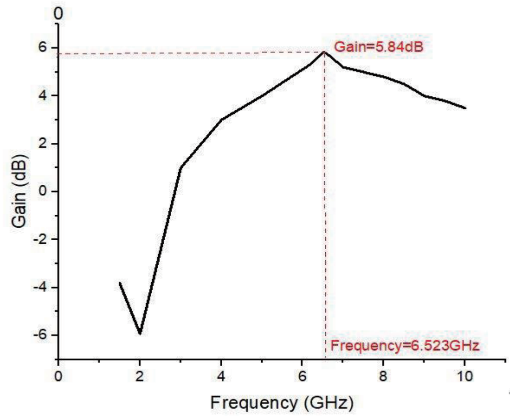


Figure 4. Gain vs frequency.

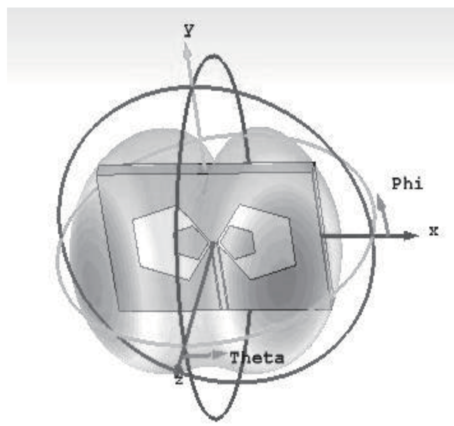


Figure 5. 3D radiation pattern of the designed antenna.

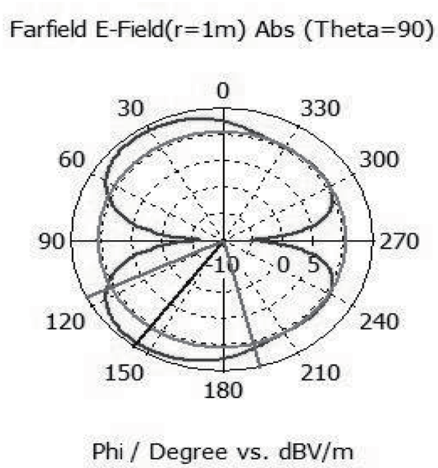


Figure 6. *E*-far field pattern of the designed antenna.

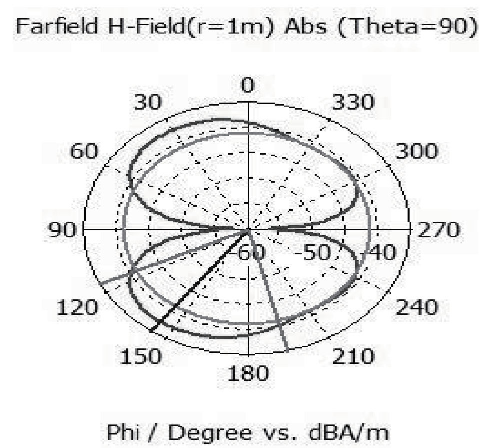


Figure 7. *H*-far field pattern of the proposed antenna.

2.2.5. Current Distribution

Figure 8 illustrates an EM characteristics modeled and current antenna distribution at 6.523 GHz.

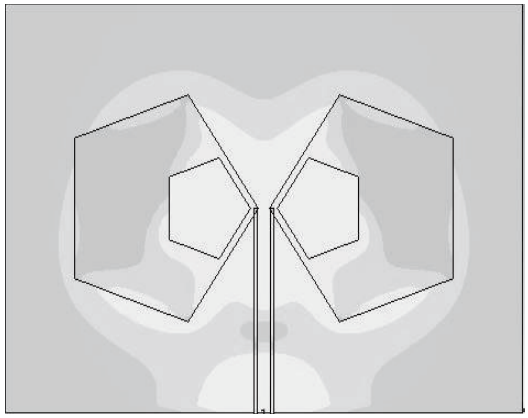


Figure 8. Current distribution of the proposed antenna.

3. HARDWARE SYSTEM DESIGN

3.1. Block Diagram of Proposed Wireless Communication System

In the existing system, the gunner training system consists of a liquid-filled tube that is used to activate the Control Panel. It almost has 60 to 110 meters of a wired connection between the gun device and the control panel [11, 12].

This tube is placed exactly along the line of sight of gunners. Their performance is analyzed by changing their mode before they start firing it to probably focus on the direction of the target and to identify the direction of the target (moving vehicle). There are two modes viz.

(i) Mode A (Front mode)-before a line of the sight — The vehicle moves towards the tube.

(ii) Mode B (Back mode)-after line of the sight — The vehicle moves away from the tube.

The tube and gun device are connected to the control panel. The control panel consists of PIC controller 877A and panel display.

During the training period, when the target vehicle touches the tube, signal will be immediately passed to the control panel and the gunner's starting time(S) activated. When the gunman changes the mode, again the signal will be passed, and mode time(M) is activated. The time difference between M-S is calculated which is the gunner's performance time.

The proposed wireless communication system is shown as a block diagram in Figure 9. In this system, the built antenna is used for transmission and reception.

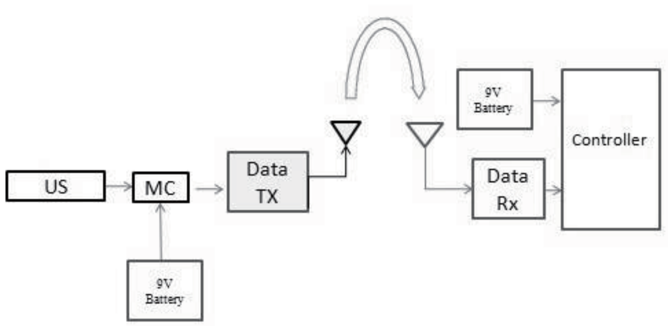


Figure 9. Block diagram of wireless communication.

In this paper, Liquid-filled tube which is connected to the control panel is completely replaced by wireless technology with a specially designed bow-tie antenna.

The main aim of designing the antenna is to make the system in wireless and to avoid data theft. In practice, the tube may be damaged earlier due to vehicle target crosses it and wired one.

The cross-over module is a combination circuit of microcontroller (PIC877A) and ultrasonic sensors along with the wireless module (ESP8266EX) [16]. A 12 volt, 7 Ah battery is used as a source to enable the cross-over module.

Here everything is fixed with a special object like a tripod stand, or any equivalent is used to find the interrupt like vehicle crossing the particular area. It will send a signal to the control panel in wireless mode. During the training period, the target vehicle when crossing the ultrasonic sensor immediately the antenna sends a signal, and it will be passed to the control panel and the gunner's starting time(S) activated. When the gunman changes the mode, again the signal will be passed and mode time(M) activated. The time difference between M-S is calculated which is the gunner's performance time.

4. EXPERIMENTAL RESULTS

Figure 10 shows the fabricated proposed pentagonal bow-tie patch antenna.

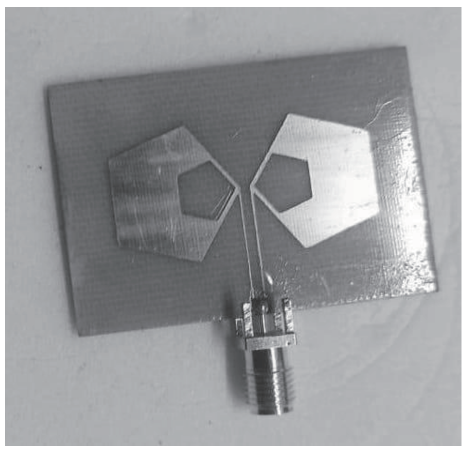


Figure 10. Fabricated bow-tie pentagonal patch antenna.

The fabricated antenna is used as a transmitter as shown in Figure 11, and it will send a signal to the control panel in wireless mode when the target vehicle crosses the ultrasonic sensor immediately.

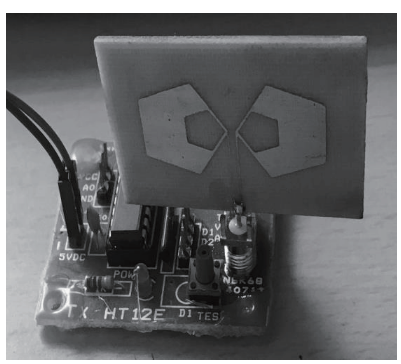


Figure 11. Transmitter section.

Figure 12 shows the receiver section which receives the signal and displays the gunner performance which is correct or wrong.

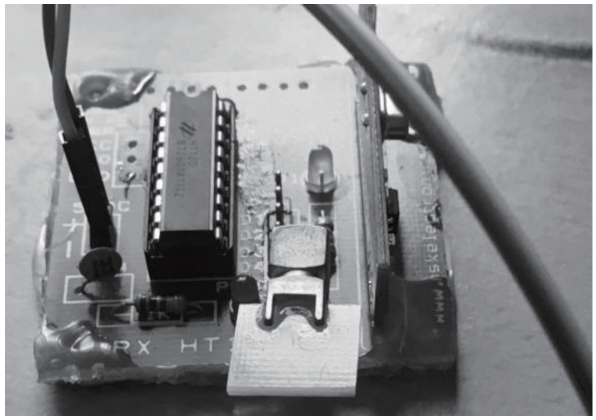
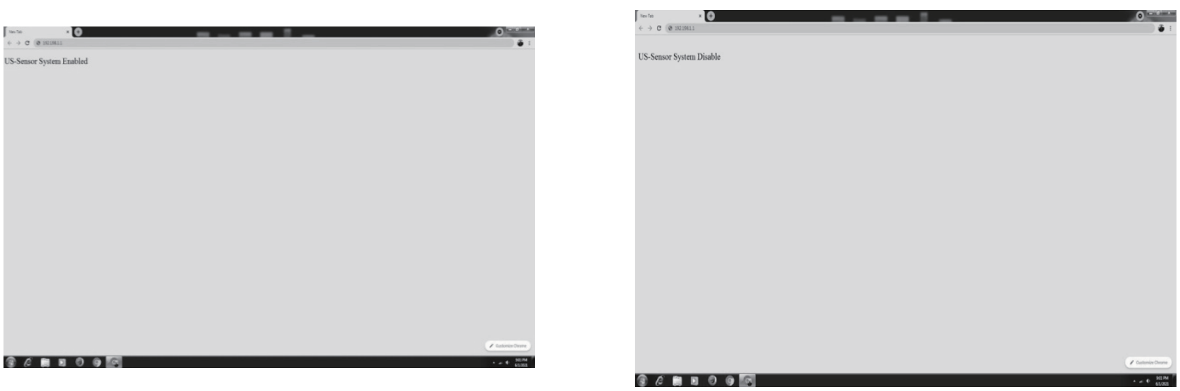


Figure 12. Receiver section.

Figures 13(a) & (b) show the output section which displays that the US sensor is enabled or displayed with the aid of embedded C platform. Then the control panel analyzes the gunner who is going to change the mode in a correct way.



(a) (b)

Figure 13. (a) US system enable. (b) US system disable.

Table 2 explains that the mode of operation is A when the sensor is activated. Then the displayed performance of the gunner is in the right position. When the sensor is not activated, the mode of operation is B which is set by default, and it is also considered as the right condition for gunner performance. The gunner is in mode B not trying to change mode A when the status of the sensor is activated. Then the gunner performance is considered wrong. The gunner is in mode A not trying to change mode B, when the status of the sensor is not activated. Then the gunner performance is considered wrong.

Table 2. Display of control panel.

Sl.No	Status Of Sensor	Mode Of Operation	Display Performance
1	Active	Mode A	Right
2	Inactive	Mode B	Right
3	Active	Mode B	Wrong
4	Inactive	Mode A	Wrong

5. CONCLUSIONS

In this paper, a unique bow-tie shaped Pentagonal slit microstrip patch antenna is suggested and experimentally demonstrated for military applications such as gunner training systems. CST Microwave Studio 2016 is used for simulation, and the antenna settings are examined. As a result, a low return loss, VSWR with superior impedance matching, and high gain are produced. The performance of the shooter is experimentally evaluated using the suggested antenna indicated in Table 2. Finally, the proposed bow-tie shaped antenna is preferable for determining the gunner's performance throughout the training time.

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