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Miniaturized Single Feed Multi-band Microstrip Patch Antenna

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Abstract: *In recent years, the demand for compact and multi-functional antennas has increased due to the development of wireless communication systems. In this paper, a miniaturized multi-band single feed patch antenna is proposed, for designing multiband antenna first we need to design single band antenna then multi band, which operates in the frequency range of 2.4 GHz to 8 GHz. A single slot is inserted in the patch of the proposed antenna to achieve multi-band operation. The antenna is designed and simulated using the software ADS simulation Studio. The simulation results show that the proposed antenna has a compact size with Patch width, w 19.83mm, patch Length, L 23.71mm. With input impedance of 144 Ω and achieves good performance in terms of return loss, radiation patterns, and gain at different frequency bands.*

Keywords: Antenna

I. INTRODUCTION

With the increasing demand for wireless communication systems, the development of miniaturized and multi-functional antennas has become a topic of great interest. A patch antenna is one of the most popular types of antennas due to its simple structure, low cost, and ease of fabrication. However, traditional patch antennas have limited bandwidth and can only operate at a single frequency. In order to overcome this limitation, several techniques have been proposed to achieve multi-band operation of patch antennas, such as inserting slots in the patch or using different feeding techniques. In this paper, a miniaturized multi-band single feed patch antenna with a single slot in the patch is proposed.

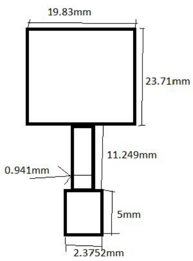
Patch antennas are determined to be an acceptable alternative and a potential contender to be employed in different wireless communication applications [1]. Ordinary half-wavelength patch antennas are surprisingly large, though, for some devices that need to be miniaturized. In order to fulfil the specific requirement, a size reduction is necessary. Several techniques for size reduction have been reported and investigated, such as using metamaterial structures [2], loading shorting walls [3], or loading capacitors and inductors [4], [5].

On the other hand, antennas with diverse working frequencies are crucial for wireless communication and radar systems' capacity to adapt to various conditions. Significantly In the literature, a variety of multi-band antennas have been introduced. Different methodologies are employed to realize the multi-band function such as exploiting the fundamental and higher modes of the antenna [6], employing a defected ground plane structure [7], or using split-ring resonators (SRR) [8]. The majority of older multi-band miniature antennas have unstable emission patterns and make it challenging to implement additional frequency bands.[6] [9] For instance, obtaining dual-band functioning after adjusting the angle of an arc-shaped tuning stub integrated with the antenna's feeding structure is relatively challenging. Another Disadvantages of previous approaches lies in the complexity of their design [10] [11].

II. DESIGN OF MINIATURIZED SINGLE FEED SINGLE BAND PATCH ANTENNA.

2.1 Geometric Specification

The geometry of the single-band miniaturized antenna is shown in Figure 1. It can be observed that the radiating patch on the top layer is designed with one edge intentionally shortened to minimize the electrical size of the antenna. The current flows from the top layer to the ground plane in a single path at resonant frequencies. Figure 2 shows that, in order to simplify fabrication and achieve a compact design, a short 50-ohm feed line is embedded on the ground plane.



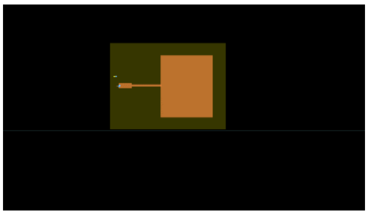


Fig. 1. Geometry of miniaturized single band antenna. Fig. 2. Structure of simulated design of single band patch antenna.

The proposed antenna is designed on a substrate with a relative permittivity of 4.4. The structural parameters of the single-band miniaturized antenna can be seen in the above geometry. The size of the patch is L = 23.71mm in length and W = 19.83mm in width. The size of the λ/4 transformation is L = 11.249mm in length and 0.941mm in width. The 50 Ohm feedline is sized at L = 5mm in length and 2.3762mm in width. This antenna is placed on a ground plane with dimensions of W = 44.3mm in width and H = 33mm in height

2.2 Parametric Studies

The simulation results were obtained using ADS Software. For this design, FR4 was used as the substrate in our communication. It has a relative permittivity of 4.4, a thickness of 2mm, and a loss tangent of 0.002. In this design, tuning was performed.

In Figure 3, we can observe a parametric study of antenna parameters with respect to frequency. The image below contains four figures, the first of which displays the relationship between gain and frequency. From this figure, we can deduce that the maximum gain of 9.256 dB is achieved at a frequency of 7.083 GHz.

The second figure demonstrates the relationship between efficiency and frequency. We can observe that the single band miniaturized patch antenna exhibits maximum efficiency of 93.093% at a frequency of 3 GHz in the simulated results.

2.3 Parametric Graph

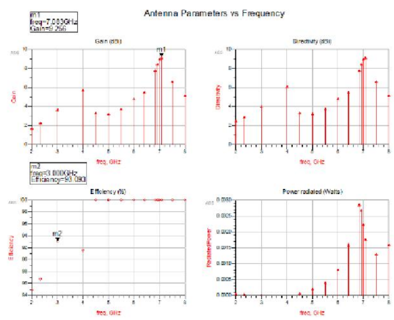


Fig.3 Parameter of Single band Antenna Results

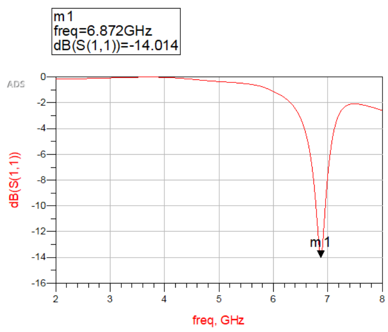


Fig.4 Result

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The above figure shows the gain vs frequency graph in this the proposed antenna is tunned at 6.872Ghz frequency, with gain of –14.014dB. Which is successfully tunned the antenna.

III. DESIGN OF MINIATURIZED SINGLE FEED MULTI BAND PATCH ANTENNA

In this section, the patch dimensions are set to a length L=23.71mm and a width W=19.83mm. To achieve a λ/4 transformation, the length and width of the patch are adjusted to L=11.249mm and W=0.941mm, respectively, while the feedline dimensions are set to L=5mm and W=2.3752mm. To convert this antenna from a single-band to a multiband antenna, a slot must be inserted. The slot is etched in a rectangular structure in the patch of the antenna, with dimensions of L=19.144mm and W=0.8mm. The ground plane for this antenna has a width of W=44.3mm and a length of L=33mm. The substrate used for this multiband microstrip patch antenna is FR4, with a permittivity of 4.4 and a substrate height of 1.9mm.

3.1 Simulated Design

The Structure of the multiband antenna shown in fig:5

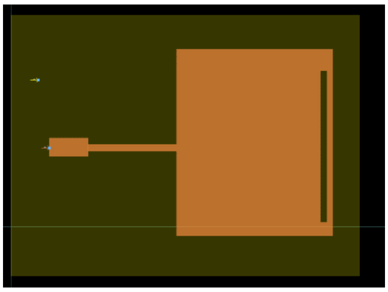

Fig:5 Simulated Multiband antenna

3.2 Simulation and Measured Results

We designed a multi-band Microstrip patch antenna using ADS software and subsequently simulated it in the same software. The simulated S11 results are presented in Figure 6.

From the simulated |S11| results, we can observe three bands that exhibit good performance in terms of return loss, radiation pattern, and gain at different frequencies. The first dip in the graph occurs at a frequency of 4.22GHz with an (S11) gain of -14.062dB, which is labeled as m1. The second dip appears at a frequency of 5.77GHz with an (S11) gain of -12.428dB, labeled as m2 on the graph. The third dip is observed at a frequency of 6.211GHz, with a gain of -22.842, which exhibits a larger bandwidth than the other two bands and is marked as m3 on the graph.

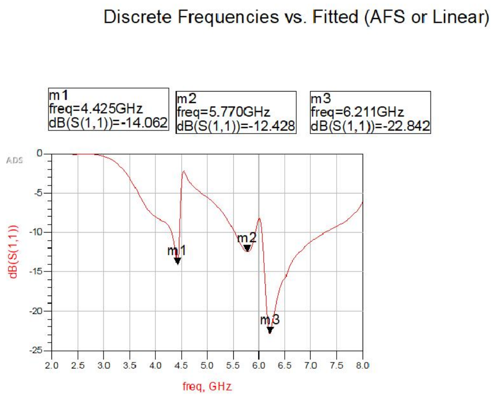

Fig:6 Results of Multi-band antenna

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3.3 Equations

There are some Mathematical calculations for designing the patch of the Antenna.

1. Width of the patch Antenna:

$$w = 1 \div 2fr\sqrt{\mu 0 \epsilon 0} * \frac{\sqrt{2}}{\epsilon r} + 1$$

2. Length of the patch antenna

$$L = \frac{1}{2fr\sqrt{\epsilon reff}\sqrt{\mu\varepsilon}} - 2\Delta L$$

Here yo = L/2

Input impedance = 144Ohm.

Parametric Study of Multi-band antenna.

The parameter of the multiband antenna is shown in fig:7

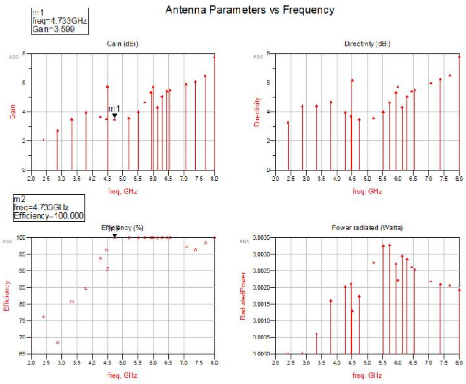

Fig:7 Antenna parameter vs frequency for multiband antenna

In the above figure there are four graphs shown which share information as First Demonstrate "Frequency vs Gain", the second shows "Frequency vs Efficiency" the third shows "Directivity vs frequency" and the fourth "Frequency vs Power radiated (watt)".

IV. FABRICATION OF MULTIBAND MICROSTRIP PATCH ANTENNA.

The fabrication process of an antenna involves several steps, starting with the selection of a substrate made of a dielectric material like FR4. The substrate is then cut into the desired shape using a CNC or laser cutter based on the antenna design calculations. Next, the conductive layer made of materials like copper or aluminium is prepared, followed by etching using an etching tray containing FeCl solution. After etching, a connector is connected to the antenna and must touch the feedline of the antenna. Finally, the antenna is tested using a Vector Network Analyzer (VNA) to measure its performance characteristics such as return loss, radiation pattern, and gain.

4.1 Why FR4 as Substrate.

- High dielectric constant: FR4 has a high dielectric constant, which means it can store a large amount of electrical energy. This property is beneficial in antenna design because it helps to increase the radiation efficiency of the antenna.
- Low loss tangent: FR4 has a low loss tangent, which means it has low electrical losses. This property is beneficial for antennas because it helps to minimize signal attenuation, which can improve the overall performance of the antenna.
- High mechanical strength: FR4 is a relatively strong and durable material, which makes it suitable for use in harsh environments. This property is particularly important for outdoor antennas, which are exposed to the elements and can be subject to physical stress.

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- Easy to work with: FR4 is a relatively easy material to work with, which means it can be easily cut, drilled, and shaped into the desired form for antenna fabrication. This makes it a popular choice for both hobbyists and professionals alike

4.2 Final View of Fabricated Antenna

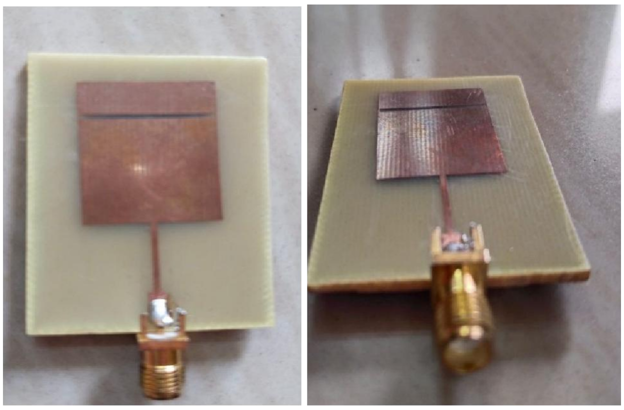


fig:8 Top view Bottom view

4.3 Vector Network Analyzer

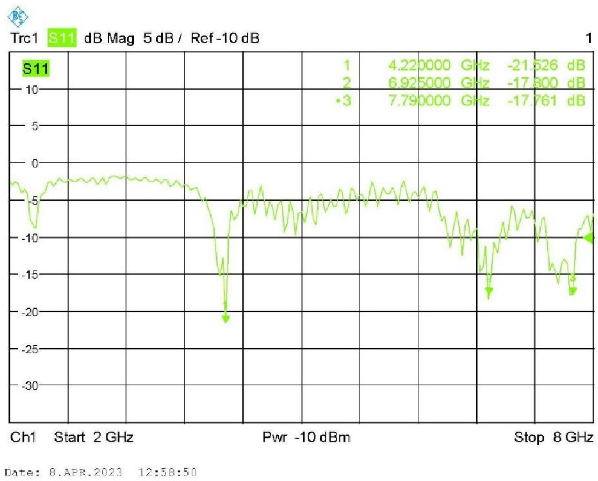
VNA stands for Vector Network Analyzer. It is an electronic test instrument that measures the performance of high-frequency components and networks, such as antennas, filters, amplifiers, and transmission lines.

A VNA operates by injecting a high-frequency signal into the device under test (DUT) and measuring the reflected and transmitted signals. It then analyzes these signals to determine the device's characteristics, such as its frequency response, gain, impedance, and phase shift.

VNAs are used extensively in the design, testing, and production of radio-frequency (RF) and microwave devices. They are also used in fields such as telecommunications, aerospace, and defense, where high-frequency components play a crucial role.

4.4 Fabricated Results on VNA

After the antenna is fabricated, it is tested using a VNA, which is an instrument used for testing electronic devices. To test the proposed antenna, we set the frequency range on the VNA to 2 GHz to 8 GHz, and the results are displayed on the screen. The results are saved in both .jpg and .csv format for each frequency within the set range. The output results of the fabricated antenna are shown in Figure 10.



The figure above shows three dips in frequency with good bandwidth and low return loss. The first dip is at 4.22 GHz with a return loss of -21.526 dB, the second dip is at 6.925 GHz with a return loss of -17.800 dB, and the third dip is at 7.7900 GHz with a return loss of -17.800 dB and good bandwidth. From the fabricated output graph, we can observe that there is very little difference between the simulated and fabricated results, indicating that our proposed antenna design is good and is in working condition.

4.5 Comparative analysis of Fabricated design with simulated design

Comparative analysis of Fabricated design with simulated design in term of bandwidth, return loss and efficiency is given in Table1

References	Simulated Design	Fabricated Design
Antenna Thickness	1.9 mm	1.9mm
Operating Frequency	2 to 8 GHz	2 to 8 Ghz
Feeding Technique	Microstrip feed line	Microstrip feed line
Return loss for 1st bandwidth	-14.062dB	-21.526dB
Return loss for 2nd bandwidth	-12.428dB	-17.400dB
Return loss for 3rd bandwidth	-22.826dB	-17.721dB

Table: 1 Comparative Analysis

V. CONCLUSION

This communication presents the conception and creation of miniaturized single-feed multi-band patch antennas. The miniaturization of the antenna is achieved by shorting one edge of the patch, while multi-band functionality is achieved through etching rectangular slot in patch of the antenna. The simulation and measurement results are compared and analyzed. The antennas produced have a low profile and a small radiating patch area and exhibit multi-band behavior with wide tuning and symmetrical directional radiation patterns that remain consistent across all resonance frequencies. As such, these antennas are recommended for wireless applications, particularly point-to-point communications.

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