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# Design a Circularly Polarized Micro Strip Patch Antenna

Yogeshwaran.A*,Akash Menon.N**,Manimaran.M***,Tamizharasan.S****,Varadharajan.K*****

*Assistant Professor, Electronics & Communication Engineering, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur, Tamil Nadu.

Email: yogeshwaranaphd@gmail.com

**,***,****,*****UG - Electronics & Communication Engineering, DhanalakshmiSrinivasan Engineering College(Autonomous), Perambalur, Tamil Nadu.

Email: n.akashmenon514@gmail.com, manimaranms781@gmail.com.

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## Abstract

A hybrid patch antenna featuring a reduced slot-loaded ground plane and a broadband "HEART" form is suggested in this article. A standard circular patch can be effectively upgraded to a "heart" shape by positioning two circular radiating pieces at key locations on the patch.Additionally, four rectangular inverted 'L' slots in the reduced ground plane enhance impedance matching across a wide frequency range. Two precisely positioned rectangular holes on the decreased ground plane allow for proper impedance matching over a variety of frequencies. These methods work together to introduce high-gain, low-profile, and broadband antenna designs. The electrical and physical dimensions of the proposed antenna are 0.266λ × 0.241λ × 0.0108λ and 29 mm × 32 mm × 1.6 mm, respectively. The wavelength of the minimum operational frequency is indicated by the symbol λ. With an impedance bandwidth of 5 GHz from (5 GHz to 17 GHz), the suggested antenna resonantly functions at 5 GHz, 10.7 GHz, 11.4 GHz, 14.1 GHz, 14.6 GHz, 15.3 GHz, 16.1 GHz, and 16.9 GHz frequencies. 100% fractional bandwidth, 3.6dBi peak gain, and stable enough E and H field patterns are attained at 5.5 GHz and 6.9 GHz. On the other hand, the design and simulation of the displayed antenna are done using HFSS software. The recommended antenna is designed using the low-cost FR-4 substrate (1.6 mm in height, 0.02 loss tangent, 4.4 dielectric constant).

After that, it is investigated with a standard microwave measurement device. A wide range of frequency bands could find application for the proposed antenna, including WiMAX (3.4–3.6 GHz and 5.5 GHz), from 3.3 GHz to 4.2 GHz n77 frequency band, from 3.3 GHz to 3.8 GHz n78 frequency band, from 4.4 GHz to 5 GHz n79 frequency band, and from 5.08 GHz to 5.73 GHz Wireless local area network frequency band. It also covers the 5G-V2X band (3.3-5GHz) and LTE 46 band (5.15-5.925GHz), object placement, high-bandwidth communications, and short-range remote sensing.

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## I. INTRODUCTION

Modern wireless communication requires a single patch antenna with broadband characteristics and different resonant frequencies in order to accommodate multiple applications. Because conventional regular-shaped patch antennas are limited to a single resonant frequency, scientists have been looking into different ways to suit the demands of the market. The study of hybrid-shaped patches with changed ground planes is one such method. These patches combine typical regular patterns, such as square, circular, elliptical, rectangular, and so on, to generate hybrid-shaped radiating patch elements. One such method is the analysis of hybrid-shaped patches with altered ground planes. In [10], a hybrid patch with two resonant frequencies and ultra wideband and characteristics is produced by overlapping one rectangle and two ellipses. In [12], a "bloom" structured patch covering the frequency range of 1.6 GHz to 2.45 GHz is produced by combining four circles. The floral structured patch in [21] is designed to achieve multiband activity with two resonant frequencies. To give a broad impedance bandwidth, a sigmoid inverted structured hybrid patch with circular polarization is constructed in [20]. In [2], many slots are filled to provide a dumbbell-shaped patch, and one rectangle and two octagons are coupled to offer a high impedance bandwidth. Moreover, [4] describes a "dumbbell"-shaped antenna that quadruples the gain and bandwidth of the proposed antenna by combining two circle and one rectangle radiating elements. In order to achieve an ultra-wide band antenna, [5] provides a "skirt" built patch antenna. A hybrid patch antenna with a rhombus construction is studied in [15] to achieve variable polarization. A hybrid patch structure is created by packing conventional circular and rectangular patches with slots of various shapes. Changing the ground plane also produces a range of resonance frequencies [3,6,7,8,9,11,14,16,8,19]. In this proposed effort, a hybrid micro strip patch antenna (32 mm × 29 mm × 1.6 mm) shaped like a "HEART" and intended for broadband (4.8 GHz to 16.8 GHz) would be configured and printed. Subsequently, it is validated using structural and analogous circuit modeling and examined through a conventional microwave measurement apparatus. The radiating planes, which were formed by three circular radiating elements, resembled a heart. Two slots are loaded onto the narrowed ground plane to improve the impedance mismatch. The proposed shape reduces the reflection loss over a wide area by utilizing three intersecting circles to build a hybrid structure free of sharp discontinuities. Because of the ground plane's slots, the surface current route has been extended, resulting in a lower resonance frequency. The suggested antenna has a high bandwidth of 100% and a peak gain of 3.6dBi at 5.5 GHz and 6.9 GHz. The antenna also displays four resonance frequencies: 4.8 GHz, 10.9 GHz, 11.4 GHz, 14.1 GHz, 15.2 GHz, and 16.8 GHz. Numerous frequency ranges, such as 3.4–3.6 GHz and 5.5 GHz for WiMAX, 3.3–4.2 GHz for n77, 3.3–3.8 GHz for n78, 4.4–5 GHz for n79, and 5.08 GHz to 5.73 GHz for Wireless local area network frequency band, indicate potential applications for the proposed antenna. LTE 46 band (5.15–5.925GHz), 5G-V2X band (3.3-5GHz), high-bandwidth communications, VSAT, and short-range remote sensing are also supported by it.

## II. PROPOSED ANTENNA STRUCTURE

Radiating element structure and ground plane structure are given in Fig. 1(a), 1(b) respectively. Radiating patch consists of three circular patches among which two circles are identical and they are placed in a way that the composite radiating structure looks like a "HEART". Two rectangular slots are loaded in the reduced width ground plane to get broadband characteristics. Suggested antenna structure is printed using FR-4 material having dielectric constant 4.4, loss tangent 0.02 and thickness 1.6 mm. Figure 2(a) displays internal patch geometry and Fig. 2(b) shows the fabricated model of the designed antenna. All optimized parameter values of suggested antenna are tabulated in Table 1.

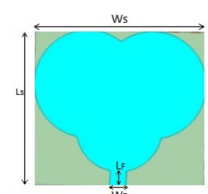
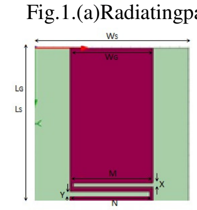



Fig.1.(a)Radiatingpatch




(b) Ground plane

Table 1. Suggested antenna specifications
(all dimensions are in mm)

| Parameter | value | Parameter | value | Parameter | Value |
|---|---|---|---|---|---|
| $W_S$ | 32 | $L_F$ | 3 | N,M | 16.5 |
| $L_S$ | 29 | $W_G$ | 17 | A | 8 |
| $W_F$ | 3 | $L_G$ | 29 | h(antenna) | 1.6 |
| X | 0.8 | Y | 1.1 | B | 10 |

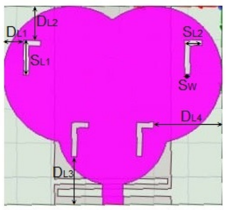



Fig. 2. Radiating patchwith inverter L slot

Table 2. Suggested antenna specifications
(all dimensions are in mm)

| Parameter | value | Parameter | value |
|---|---|---|---|
| $D_{L1}$ | 3 | $S_W$ | 0.8 |
| $D_{L2}$ | 5 | $D_{L3}$ | 7 |
| $S_{L1}$ | 5 | $D_{L4}$ | 10 |
| $S_{L2}$ | 2.5 | | |

## III.DESIGN STEPS OF ANTENNA

The suggested antenna is developed using HFSS software. FR-4 base material measuring 32 mm by 29 mm by 1.6 mm (length by width by height) is first taken using the entire ground plane. Equation 1-2 [14] is used to build the reference circular patch, which has a radius of 8 mm and is displayed in step 1 of Figure 3.Figure 4 shows that the step 1 reference antenna resonates at 8.27 GHz rather than 5 GHz because of an impedance mismatch.

$$a = \frac{F}{\left(1+\frac{2h}{\pi\epsilon_r F}\right)\left(\ln\left(\frac{\pi F}{2h}\right)+1.7726\right)^{\frac{1}{2}}} \qquad (1)$$

$$F = \frac{8.791\times10^9}{f_r\sqrt{\epsilon_r}} \qquad (2)$$

Where □= substrate material height,$\epsilon\epsilon_{rr}$= dielectric constant, = circle radius and$ff_{rr}$= resonant frequency

The antenna ground plane width is decreased in the second stage, and two optimally sized slots (MHX, NHY) are loaded at the ideal location. Better impedance matching throughout three distinct frequency bands (2.1 GHz -2.36 GHz, 5.1 GHz 5.4 GHz, and 6.1 GHz -7 GHz) is achieved as a result of slot loading in reduced ground plane, as illustrated in fig. 4.Three close frequency bands—2.58 GHz–3.8 GHz, 4.49 GHz–4.7 GHz, and 5.4 GHz–7.4 GHz—are obtained in step three by shortening the feed line. A second circular radiator (10 mm in radius) added to the reference patch at the optimal location combines two frequency bands (4.49 GHz – 4.7 GHz and 5.4 GHz – 7.4 GHz bands) and creates two additional bands (2.43 GHz – 3.91 GHz and 4.6 GHz – 7.8 GHz). As demonstrated in step 5, a final circular radiator with the same radius is added symmetrically. The merger of the aforementioned two frequency bands to provide broadband characteristics from 2.48 GHz to 7.55 GHz is made easier by the staggering effect.

## IV. Multiband Micro strip Patch Antenna

The structure in the image is a Multiband Micro strip Patch Antenna , which falls under the category of directional antennas. These antennas are commonly used in wireless communication systems to improve signal reception and transmission in specific directions.

Fig. 10.9 Fabrication for proposed patch antenna.

***A.Anechoic Chamber Setup:***

The image captures an anechoic chamber, a specialized room used for testing antennas and electronic systems. The purpose of this chamber is to create an environment with minimal external noise and reflections, allowing precise measurements. The walls of the chamber are covered in radio-frequency absorber material, which absorbs electromagnetic waves and prevents reflections. The dim lighting emphasizes the texture of the absorber material on the walls.

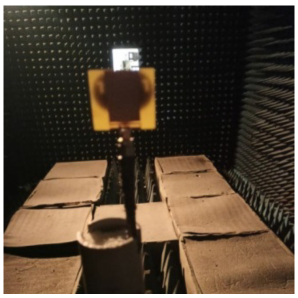


Fig. 10.11 Anechoic Chamber for proposed patch antenna.

***B.Graph Description:***

The image displays a screenshot of an antenna graph shown on a software interface. The graph represents the S11 Log Mag (reflection coefficient or return loss) in the frequency domain. Key features of the graph include markers, frequency values, and dB levels.

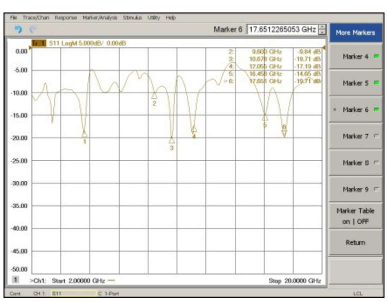


Fig. 10.1 FABRICATION GRAPHfor proposed patch antenna.

The, formula to measure the gain is

$G_{AUT} = (P_{R2} / P_{R3}). G_{REF}$

$\mathbf{G}_{AUT}$ = gain of the antenna under test

$P_{R2}$ = power received by the reference antenna

$P_{R3}$ = power received by the antenna under test

$G_{REF}$ = gain of the reference antenna

- You may use this formula for gain calculation, you can find $P_{R2}$ and $P_{R3}$ from data sheet (.xls) {Radiation and Gain (power)}. First convert dBm into dB (as dBm-30=dB) and as per your respective frequency in data sheet choose the reference gain ($G_{REF}$) value from figure 1 or 2. You will find gain in dBi.
- You can also refer some books for another formulas for Gain Calculation.
- Distance b/w Transmitter and Receiver = 1.5 Meter
- Transmitted power = 13~15 dBM
- Amkom Horn Antenna: 1 GHz to 18 GHz Broad Frequency Range, Impedance: 50 ohm
- VNA Details: Agilent N5247A: A.09.90.02
- TRL technique is used to calibrate the VNA with 3.5 SMA calibration kit.
- To learn more about Anechoic Chamber, you may visit to:
  https://anechoicchamber.ku.edu/specifications

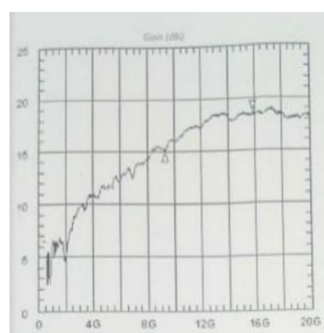


Figure 1: Gain of Reference Antenna ($G_{REF}$)

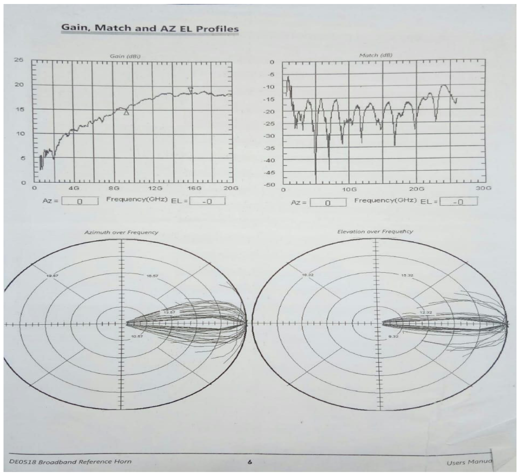
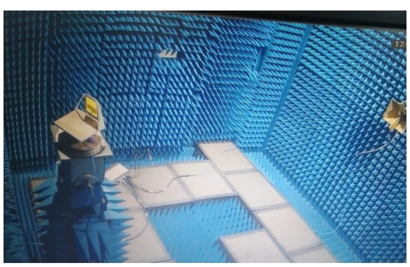



Figure 2: Clear Photograph for Gain of Reference Antenna ($G_{REF}$)

**(a)**



**(b)**

Figure 3: Anechoic Chamber Photographs (a) Outside (b) Inside

## V.PARAMETRIC STUDIES

The Fig.5. $S_{11}$ known as an S-parameter plot, specifically S(1,1), which is to analyze the performance of circuits and devices at various frequencies. Here's a breakdown of the key elements in the image: S-Parameter Plot 4: This designates that it is the fourth S-parameter plot, either for the fourth port in a multi-port device or maybe in a series of plots. The S-parameter being plotted is dB(S(1,1)). The reflection coefficient at port 1 is denoted by S(1,1). Decibels (dB), a logarithmic unit of measurement used to express ratios, are used to present it. Freq (GHz): Plotting the S-parameter over this frequency range, expressed in gigahertz (GHz), is done. First, sweep: This is perhaps a reference to a frequency sweep, which is a test kind in which the input signal's frequency is varied (or "swept") throughout a range of frequencies. Red Line: The S-parameter value (in dB) at each sweep frequency is shown by the red line on the plot. The line's peaks and troughs represent frequencies where the performance of the circuit or device varies noticeably.

This image is frequently used to depict a circuit's or device's activity at different frequencies, which is crucial for developing systems for telecommunications, radar, and many other uses. ANSYS HFSS is a popular programme for these kind of high-frequency electromagnetic field simulations.The Voltage Standing Wave Ratio (VSWR) plot is shown in the graph you submitted. The efficiency of radio frequency power transmission from its source into a load, such as an antenna from a power amplifier, is measured by the voltage spike-to-signal ratio (VSWR).

There are two lines on your graph: a black line and a red line. The frequency in GHz is represented by the x-axis, and the VSWR is represented by the y-axis. The highest and minimum voltage points are indicated by the red line, which peaks at roughly 6 GHz and troughs at roughly 12 GHz, respectively. Across the frequency range, the black line appears to be somewhat flat and remains around 40 VSWR, indicating a constant voltage ratio.The ratio of the greatest to minimum voltage in a standing wave pattern across the course of a transmission line construction is known as the voltage-standby-wave ratio, or VSWR. It is utilized in numerous wireless communication domains, such as amplifier and antenna design.Note that efficient power transfer usually requires a reduced VSWR, meaning that more power is sent to the antenna and less is reflected back to the source. Thus, the frequencies at which the system operates most efficiently are those at which the VSWR is lower.

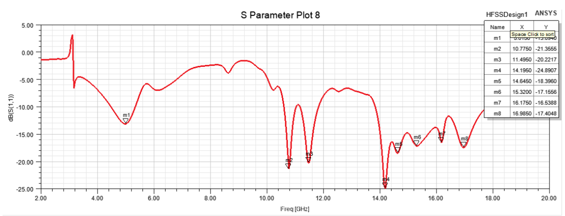



Fig.5. $S_{11}$ for variation

This Fig.6.VSWR represents the VSWR of a certain circuit.The x-axis displays the frequency in GHz .The y-axis represents the VSWR.
There are two lines on the graph:

The red line indicates the VSWR curve. This graph shows how the VSWR fluctuates with frequency. The black line is the sweep curve. This graph illustrates the range of frequencies over which the measurement was made. The impedance mismatch between the source (the test apparatus) and the load (the item being tested) is measured by VSWR.A high VSWR denotes a high level of reflected power, which means that the load is reflecting back a significant amount of the power that was sent from the source. This is typically not what you want because it might result in inefficiencies and possibly harm the source. On the other hand, a low VSWR denotes a low level of reflected power, which usually means that the load is absorbing the majority of the power, which is the desired result.You can determine any frequencies at which the circuit's performance might be subpar and learn how well the circuit works at various frequencies by examining this graph.

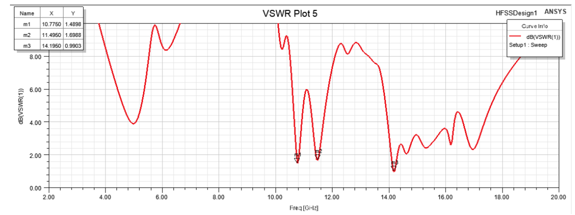



Fig.6. VSWR for variation

**A.Radiation Pattern**

***1).Explore:***The **radiation pattern** (also known as the **antenna pattern** or **far-field pattern**) describes the **directional dependence** of the strength of radio waves emitted from an antenna or any other source. It represents how the electromagnetic field strength varies with the **angle** around the antenna in **three-dimensional space**.

***2).Representation****:* Imagine a three-dimensional graph where the **radial distance** from the origin in any direction corresponds to the **strength of radiation** emitted in that direction. The radiation pattern can be visualized as a plot showing the field strength at a constant large radius (an **amplitude pattern**), the power per unit solid angle (the **power pattern**), or the **directive gain** of the antenna. Typically, this plot is represented as a **polar diagram**.

***3).Reciprocity****:* A fundamental property of antennas is that the **receiving pattern** (sensitivity as a function of direction) when used for receiving is **identical** to the **far-field radiation pattern** when used for transmitting. This reciprocity theorem of electromagnetics allows us to view the antenna as either transmitting or receiving, whichever is more convenient. Note that this applies only to **passive antenna elements**; active antennas with amplifiers or other components are no longer reciprocal devices.

This is fig 7 show simulation result of radiation pattern

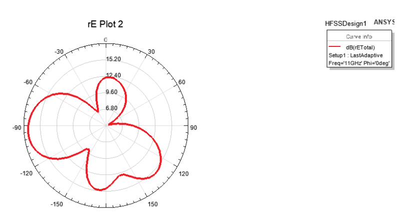



Fig.7.RADIATION PATTERNfor variation

The **Fig.8.** GAIN you've shared is a **gain plot**. It's a 3D representation of a sphere with a red and green gradient, labeled "Gain Plot 2" in the top right corner. The plot has a color scale on the left side, ranging from -233 to 23. The plot has three axes, labeled "Phi (deg)", "Theta (deg)", and "Gain (dB)".In the context of antennas, gain refers to the peak value of the gain in the direction of the antenna's main lobe. A plot of the gain as a function of direction is called the antenna pattern or radiation pattern. In the context of control system engineering, a gain plot is part of a Bode plot, which maps the frequency response of the system through two graphs – the Bode magnitude plot (expressing the magnitude in decibels) and the Bode phase plot (expressing the phase shift in degrees).The gain plot shows two important frequencies, f1 and f2. f1 is the lower break frequency while f2 is the upper break frequency. The gain at the break frequencies is 3 dB less than the midband gain. These frequencies are also known as the half-power points, or corner frequencies.

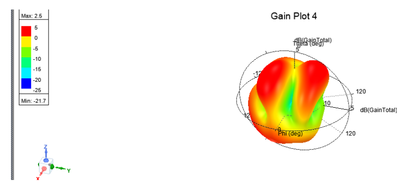



**Fig.8.** GAIN for variation

Table 3. Comparison with the cited literature

| Ref. No. | Physical Size | Electrical Size | BW (GHz) | VSWR | FBW (%) | Peak Gain (dBi) | Resonant frequency(GHz), Return Loss(dB) |
|---|---|---|---|---|---|---|---|
| [1] | 35 × 35 $mm^2$ | 0.36λ × 0.36λ | 3.1-10.6 | Not reported | 109 | 3.5 | 4 (-32 ), 6.7 ( -44 ) |
| [9] | 30 × 30 $mm^2$ | 0.31λ × 0.31λ | 3.1-10.6 | Less than 2 | 109 | 6.1 | 3.4(<-20) , 5 ( <-20 ), 6.5 ( <-20 ), 7.7 ( <-20 ), 9.3 ( <-20 ) |
| [10] | 20 × 16 $mm^2$ | 0.4λ × 0.32λ | 6-13.7 | <= 2 | 78.2 | 5 | 3.7 (-22 ), 4.27(-27 ) , 5.1(-26 ) |
| [20] | 44 × 44 $mm^2$ | 0.54λ × 0.54λ | 3.69-6.53 | Not reported | 55.6 | 2.9 | 5.6 (-22 ) |
| [21] | 21 × 21 $mm^2$ | 0.30λ × 0.30λ | 4.3-9.1 | Not reported. | 71.64 | 5 | 4.2 (-26 ) ,8.4 (-18 ) |
| **This work** | **29 × 32 $mm^2$** | **0.266λ × 0.241λ** | **5 - 17** | **In between 1 and 2** | **100** | **3.3** | **5 (- 13 ), 10.7 (-21.3 ), 11.4 (- 20.2 ) , 14.1 (-24.8 ) , 14.6 (-18.3) , 15.3 (-17.1), 16.1(-16.5), 16.9(-17.4)** |

Table 3 compares the proposed work with equivalent cited work in terms of physical size, electrical size, bandwidth, VSWR, fractional bandwidth, peak gain, and resonant frequencies with related return loss. It is evident that the antenna bandwidth in references [1] and [9] is slightly higher than the suggested one. However, the proposed antenna's dimensions are slightly small in relation to other relevant publications.

## CONCLUSION

An impedance bandwidth of 5 GHz (from 5 GHz to 17 GHz) and 100% fractional bandwidth are proposed for this broadband "HEART" shaped hybrid patch antenna. It is resonating at frequencies of 5 GHz, 10.7 GHz, 11.4 GHz, 14.1 GHz, 14.6GHz, 15.3GHz, 16.1GHz and 16.9 GHz. Average efficiency of over 65% and average gain of over 2.5dBi are achieved over the whole band of interest. Furthermore, in both the E and H fields, a steady radiation pattern with strong isolation between the cross- and co-polarization components is generated.The physical dimensions of the antenna under display are 29 mm × 32 mm × 1.6 mm, while its electrical dimensions are 0.266λ × 0.241λ × 0.0108λ. The suggested antenna is printed on a cheap 1.6 mm thick FR-4 base material with a dielectric constant of 4.4. The suggested antenna is appropriate for a variety of wireless applications, such as VSAT, sub-6GHz 5G, WiMAX, WLAN, short-range remote sensing, high data rate communications, and object location, due to its four resonant frequencies and broadband features.

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