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Design of a Heart-Shaped Microstrip Antenna for SART-Based Emergency Sea Rescue Applications

V. Sivasankara Rao [1] , U. Nandini[2], T. Purna Ganesh[3], V. Saideswara Rao[4]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[1]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[2]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[3]

UG Student, Department of ECE, R.V.R & J.C College of Engineering, Chowdavaram, India[4]

ABSTRACT: In this project it is proposed to presents the design and analysis of a heart-shaped micro strip patch antenna specifically developed for Search and Rescue Transponder (SART) applications in the X-band frequency range. The antenna is intended to provide a compact, lightweight, and cost-effective solution for reliable emergency communication in maritime environments such as locating ships or individuals in distress during sea accidents or harsh weather conditions. This antenna is proposed to design with an FR-4 substrate, which ensures affordability and structural reliability. The unique heart-shaped patch antenna geometry enhances radiation efficiency and directivity, ensuring strong and focused signal transmission for effective detection of emergency signals during rescue operations. The proposed antenna is designed and simulated using ANSYS HFSS software, which provides accurate electromagnetic field analysis and helps optimize parameters such as return loss, VSWR, radiation pattern, and gain. Design optimizations such as inset feed configuration and ground plane slotting were employed to achieve improved bandwidth, impedance matching, and minimal signal reflection, which are critical for maintaining reliable communication in challenging sea environments. The proposed antenna demonstrates superior performance compared to conventional patch antennas, making it an ideal device for critical maritime rescue and communication systems, where reliability and efficiency are essential for life-saving operations.

KEYWORDS: Heart-Shaped Microstrip Antenna, Search and Rescue Transponder (SART), X-Band Antenna, FR-4 Substrate, Inset Feed.

I. INTRODUCTION

Antennas play a crucial role in modern wireless communication systems by enabling efficient transmission and reception of electromagnetic signals. With the rapid evolution of technologies such as satellite communication, radar systems, Wi-Fi, and mobile networks, there is a growing demand for antennas that are not only compact and lightweight but also capable of supporting multiple frequency bands. Among the various antenna types, microstrip patch antennas have emerged as a preferred choice due to their low profile, ease of fabrication, low cost, and compatibility with integrated microwave circuits.A particularly critical application of antennas is in maritime emergency systems, especially in Search and Rescue Transponder (SART) devices. SART systems are life-saving technologies used to locate distressed ships or individuals at sea by transmitting signals in the X-band frequency range. These signals are detected by nearby radar systems, enabling rapid identification and rescue operations. However, SART devices must operate reliably under extreme environmental conditions such as high humidity, sea turbulence, and electromagnetic interference. Therefore, antennas designed for such applications must exhibit high gain, stable radiation patterns, and excellent impedance matching to ensure dependable long-range communication.

A Search and Rescue Transponder (SART) is an essential maritime safety device used to locate vessels or individuals in distress during emergency situations at sea. It operates in the X-band frequency range and is designed to interact with radar systems of nearby ships and rescue aircraft. When a radar signal is transmitted from a search unit, the SART detects the incoming signal and automatically responds by transmitting a sequence of pulses. These response signals are received by the radar system and displayed as a series of dots or arcs, indicating the location of the distressed target. As the distance between the SART and the radar decreases, the displayed signals become clearer, enabling precise localization. This mechanism allows rescuers to quickly identify and reach the affected area even under challenging

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environmental conditions such as low visibility, rough seas, and electromagnetic interference. Due to its reliable detection capability and real-time response, SART plays a critical role in maritime search and rescue operations.

Conventional microstrip patch antennas typically operate at a single frequency band, which limits their effectiveness in modern multi-functional communication systems. To overcome this limitation, multiband antenna designs have been introduced, allowing a single antenna structure to operate at multiple resonant frequencies. This capability is highly advantageous in systems like SART and advanced wireless platforms, where efficient spectrum utilization and consistent performance are essential. In this work, a **heart-shaped triple-band microstrip patch antenna** is proposed and analyzed. The unique heart-shaped geometry enhances electromagnetic behavior by improving radiation characteristics such as directivity and beamwidth, which are critical for maritime detection and communication. At the same time, the triple-band operation enables the antenna to function across multiple frequency ranges within the microwave region, thereby increasing its versatility and application scope.

The antenna is designed and simulated using Ansys HFSS ensuring accurate analysis of its performance. Key parameters including return loss (S11), Voltage Standing Wave Ratio (VSWR), gain, bandwidth, radiation pattern, and efficiency are thoroughly evaluated. The results indicate excellent impedance matching with low return loss values, reduced signal reflection, and stable radiation characteristics suitable for long-distance communication.Furthermore, the proposed design demonstrates improved bandwidth and multiband capability compared to conventional single-band antennas. The integration of a heart-shaped structure with triple-band functionality provides a significant enhancement in antenna performance while maintaining compactness. This makes the antenna highly suitable for critical applications such as SART systems, as well as for modern wireless, radar, and satellite communication systems.

In conclusion, this work presents an innovative approach to antenna design by combining unconventional geometry with multiband operation. The proposed antenna not only meets the stringent requirements of maritime rescue communication but also opens new possibilities for the development of high-performance, compact antennas for next-generation wireless applications.

II. LITERATURE REVIEW

A rectangular microstrip patch antenna designed for X-band applications is presented in [1]. Due to its simple geometry and ease of fabrication, it is one of the most commonly used antenna structures in wireless and radar systems. The antenna provides stable radiation characteristics and reliable impedance matching, making it suitable for general communication purposes. It can also be adapted for applications such as Search and Rescue Transponder (SART) systems, where consistent signal transmission is required for detecting distress signals.

Key Observations:

- Simple and easy-to-design structure
- Low cost and easy fabrication
- Stable radiation performance

Main Limitation: limited directivity

However, despite these advantages, the antenna has certain limitations when used in critical applications like SART. The major drawback is its limited directivity, which reduces its effectiveness in long-distance detection scenarios. In maritime rescue operations, antennas must focus energy in a particular direction to ensure accurate and reliable signal detection. Additionally, the antenna suffers from narrow bandwidth and single-band operation, making it less suitable for modern multiband communication systems.

In [2], a circular ring microstrip patch antenna is proposed to enhance bandwidth and suppress unwanted harmonic components. The design improves spectral efficiency and is suitable for applications such as RF energy harvesting and wireless power transfer. this approach also contributes to improved impedance matching and stable performance across the desired frequency range.

Key Observations:

- Improved bandwidth performance
- Suppression of harmonics and spurious signals
- Better spectral efficiency

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➢ **Main Limitation:** The structure is comparatively complex, which increases fabrication difficulty and design effort.
A defected ground structure (DGS)-based antenna is discussed in [3] for achieving size reduction and bandwidth enhancement. By modifying the ground plane, the antenna achieves compactness while maintaining acceptable performance.

Key Observations:
- Significant size reduction
- Improved bandwidth
- Suitable for compact wireless devices

➢ **Main Limitation:** The introduction of defected ground structures leads to back radiation, which can degrade radiation efficiency.
An E-shaped broadband microstrip patch antenna is proposed in [4], which achieves wideband performance by generating multiple resonances. This makes it suitable for advanced communication systems requiring operation over a wide frequency range.

Key Observations:
- Wideband performance
- Multiple resonant frequencies
- Suitable for broadband applications

➢ **Main Limitation:** Maintaining proper impedance matching across the entire bandwidth is challenging, increasing design complexity.

III. PROPOSED ANTENNA DESIGN

This work proposes a novel heart-shaped triple-band microstrip patch antenna specifically designed to enhance the performance of Search and Rescue Transponder (SART) systems and modern wireless communication applications. The primary objective is to overcome the limitations of conventional antenna designs, such as low directivity, narrow bandwidth, and poor performance in harsh maritime environments. proposed antenna utilizes a heart-shaped patch geometry, which provides improved radiation characteristics compared to traditional shapes such as rectangular and circular patches. This unique structure enhances directivity and beamwidth, enabling better signal focusing and wider coverage, which are essential for long-distance detection in maritime rescue operations.

To further improve performance, an inset feed technique is employed. This feeding method ensures proper impedance matching between the antenna and the transmission line, thereby reducing signal reflection and minimizing power loss. As a result, the antenna achieves higher efficiency and more reliable signal transmission. The antenna is designed to operate in a triple-band configuration, allowing it to support multiple frequency bands within the microwave region. This multiband capability increases the versatility of the antenna, making it suitable not only for SART applications but also for radar, satellite, and other wireless communication systems.

An FR-4 substrate is used in the design due to its cost-effectiveness, mechanical strength, and ability to withstand environmental conditions such as humidity and temperature variations. This makes the antenna highly reliable for real-world maritime applications where durability is crucial. The proposed heart-shaped triple-band microstrip patch antenna offers a significant improvement over conventional designs by combining compact size, multiband capability, and enhanced radiation characteristics. This makes it highly suitable for critical applications such as SART systems, where reliable and efficient communication is essential for saving lives.

IV. ANTENNA DESIGN PARAMETERS

The proposed antenna is a compact heart-shaped microstrip patch antenna designed using an inset feed technique on an FR-4 substrate. The antenna is modeled and simulated using Ansys HFSS to achieve optimized performance in the X-band region. The substrate material selected is FR-4, having a dielectric constant of 4.4, thickness of 1.6 mm, and a loss tangent of 0.02, which provides a suitable balance between cost, mechanical strength, and radiation efficiency. The overall dimensions of the substrate are maintained at 30 mm × 30 mm, and the ground plane is taken to be the same size to ensure proper radiation and minimize edge effects. The radiating patch is designed in a heart-shaped geometry using copper with a thickness of 0.035 mm. The shape is formed by combining two circular sections with equal radii

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(R_1 and R_2), separated by a distance of 8 mm and connected through a narrow neck region of width 3 mm. The total patch dimensions are approximately 18 mm in height and 14 mm in width. This unique geometry improves current distribution and enhances radiation characteristics, which is beneficial for applications requiring better directivity and coverage.

An inset-fed microstrip line is used to excite the antenna, ensuring proper impedance matching with a standard 50 Ω transmission line. The feed line has a width of 3 mm and a length of 12 mm, while the inset depth is optimized to 4 mm with a small gap of 1 mm. This configuration reduces reflection losses and improves power transfer efficiency. The antenna is designed to operate in the X-band frequency range of 9.2–9.5 GHz and achieves triple-band operation, making it suitable for applications such as Search and Rescue Transponder (SART) systems, radar, and modern wireless communication. The combination of optimized dimensions, heart-shaped geometry, and inset feed technique results in improved gain, enhanced directivity, and stable performance under varying conditions.

Antenna Parameter Abbreviations Ls – Substrate Length Ws – Substrate Width R_1 – Left Circle Radius R_2 – Right Circle Radius D – Distance Between Circles Wn – Neck Width (middle connection) Lp – Patch Length (Height) Wp – Patch Width Wf – Feed Line Width Lf – Feed Line Length h – Substrate Thickness εr – Dielectric Constant

V. ANTENNA DESIGN STEPS

Design Steps:

1. **Start:** The design process begins with defining the primary objective of developing a compact and efficient microstrip patch antenna suitable for X-band applications. At this stage, the key requirements such as operating frequency, bandwidth, gain, and radiation characteristics are clearly identified. The intended application, particularly for maritime communication and SART systems, is also considered. Design constraints including size, cost, and fabrication feasibility are analyzed carefully. The need for improved directivity and multiband operation is emphasized. This step provides a clear direction for the design process. Establishing these requirements ensures a structured and efficient workflow. It forms the foundation for all subsequent design stages.

2. **Substrate Selection:** In this step, a suitable substrate material is selected based on its electrical and mechanical properties. The dielectric constant (εr) is chosen to control antenna size and performance. The substrate thickness (h) is selected to balance bandwidth and radiation efficiency. The overall dimensions (Ls and Ws) are defined to support proper radiation and minimize edge effects. Material characteristics such as loss tangent and thermal stability are also considered. FR-4 is selected due to its cost-effectiveness and durability. The substrate plays a crucial role in determining resonant frequency. Proper selection ensures stable performance in practical conditions.the substrate selection influences impedance matching and overall antenna efficiency, making it a critical factor in achieving optimal performance. A well-chosen substrate also helps in reducing signal losses and ensures consistent operation across the desired frequency range.

3. **Left Circular Section (R_1):** The geometry design begins by creating the left circular section of the patch. A radius (R_1) is defined based on the required operating frequency. This section forms one half of the radiating structure. It contributes to the distribution of surface currents across the antenna. The size and placement of this circle directly influence the resonant behavior. It also impacts impedance matching and radiation efficiency. Accurate modeling of this section is essential. This step initiates the formation of the antenna geometry.Proper alignment of the left circular section with the overall geometry ensures symmetry in the antenna structure. Any variation in the radius can lead to shifts in the resonant frequency and radiation pattern. This section also plays a key role in determining the bandwidth characteristics of the antenna.

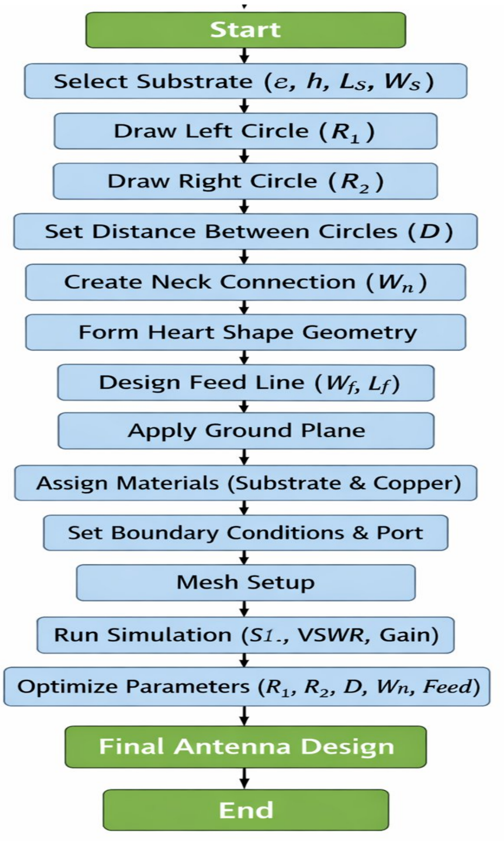

Fig 1. design flow

4. **Right Circular Section (R_2):** The right circular section is then created using radius (R_2). This section complements the left circle to form the complete radiating patch. Symmetry between both circles ensures balanced current flow. The interaction between the two sections affects coupling and frequency response. Proper positioning is required for effective operation. This step helps in defining the core structure of the antenna. It also contributes to overall radiation performance. Precision in geometry improves simulation accuracy.

5. **Distance Between Circles (D):** The spacing between the two circular sections is defined in this stage. The distance (D) plays a significant role in controlling electromagnetic coupling. It influences the resonant frequencies and bandwidth of the antenna. Proper spacing ensures efficient current transfer between the sections. If not optimized, it may lead to poor performance. This parameter is often tuned during simulation. It also affects impedance characteristics. Careful adjustment helps achieve desired results.

6. **Neck Connection (W_n):** A narrow connection is introduced between the two circles to form a continuous structure. The width (W_n) of this region determines the current flow between both sections. This connection is responsible for shaping the antenna into a heart-like geometry. It enhances structural continuity and stability. The neck region also impacts radiation characteristics and impedance.

7. **Heart-Shaped Geometry Formation:** After connecting the circles, the geometry is refined to obtain the final heart shape. Edges are adjusted to ensure smooth transitions. The final shape provides improved electromagnetic characteristics. It enhances radiation pattern and beamwidth. The geometry also supports better current distribution. This unique design differentiates it from conventional antennas. It contributes to multiband operation capability. Finalizing the geometry is crucial for achieving desired performance.

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8. **Feed Line Design (Wf, Lf):** A microstrip feed line is designed to excite the antenna effectively. The width (Wf) is selected to achieve proper impedance matching. The length (Lf) ensures correct positioning and connection to the patch. An inset feed technique is used to minimize reflection losses. Proper feed placement improves power transfer efficiency. It also reduces return loss. Incorrect design can degrade performance. Optimization of feed parameters is essential.

9. **Ground Plane:** A ground plane is added beneath the substrate to complete the antenna structure. It serves as a reference for electromagnetic waves. The ground plane directs radiation efficiently. It also improves antenna stability and performance. The size is typically equal to the substrate. Proper grounding reduces unwanted losses. It plays a key role in impedance behavior. This step is essential for practical antenna operation.

10. **Material Assignment:** Materials are assigned to different parts of the antenna model. The substrate is defined using FR-4 properties. Copper is assigned to the patch and ground due to high conductivity. Material selection affects losses and efficiency. Accurate assignment ensures realistic simulation. It also influences thermal stability. Proper materials improve durability. This step is necessary for accurate modeling.

11. **Boundary Conditions and Port Setup:** Boundary conditions are defined to simulate free-space radiation. Radiation boundaries are applied around the antenna. A wave port or lumped port is assigned for excitation. This enables signal transmission and reception. Proper setup avoids simulation errors. It ensures accurate electromagnetic behavior. Incorrect configuration may lead to invalid results. This step is critical for reliable simulation.

12. **Mesh Setup:** The antenna structure is divided into smaller elements using meshing. This allows numerical analysis of electromagnetic fields. Mesh density is adjusted based on geometry complexity. Fine mesh improves accuracy but increases computation time. Coarse mesh reduces accuracy but speeds up simulation. A balanced mesh is selected. Proper meshing ensures reliable results. This step is essential for precise analysis.

13. **Simulation (S11, VSWR, Gain):** The antenna is simulated using Ansys HFSS. Key performance parameters such as return loss (S11), VSWR, and gain are obtained. Radiation patterns are also analyzed. These results indicate overall antenna performance. Simulation helps identify design issues. It provides insight into frequency behavior. Accurate results are necessary before fabrication. This step validates the design.

14. **Parameter Optimization (R_1, R_2, D, W_n, Feed):** Design parameters are adjusted iteratively to improve performance. Radii, spacing, and feed dimensions are modified. The goal is to achieve better impedance matching and higher gain. Multiple simulations are performed during this stage. Optimization improves bandwidth and radiation characteristics. It ensures efficient antenna operation.It refines the overall design.

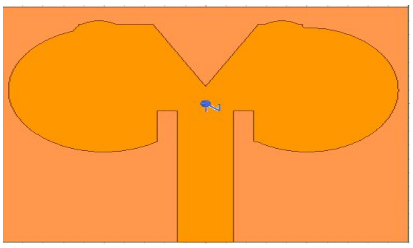

Fig 2. Heart shape Antenna

15. **Final Antenna Design:** After optimization, the final antenna structure is obtained. The design meets all required specifications. It provides stable radiation and good impedance matching. The antenna is ready for validation and comparison. Final results confirm its effectiveness. This stage ensures readiness for practical use. The design is suitable for real-world applications. It represents the completed optimized model. The design process concludes with a validated antenna model. This marks the completion of the design cycle.

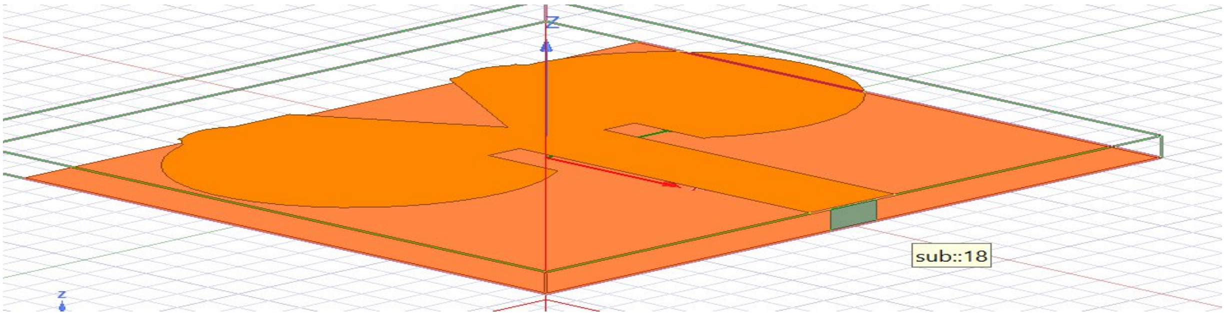

Fig 3. Heart shape Antenna with inset feed

VI. RESULTS AND ANALYSIS

Results of Proposed Antenna:-

S11 (Return Loss):-

- **S11 (Return Loss)** S11, also known as the return loss, represents the amount of power reflected back from the antenna due to impedance mismatch. It is expressed in decibels (dB) and indicates how efficiently the antenna radiates the input signal. When a signal is applied to the antenna, a portion is radiated while some may be reflected back toward the source. A lower (more negative) S11 value indicates better impedance matching and efficient radiation. Typically, an S11 value below −10 dB is considered acceptable, as it implies that most of the input power is transmitted.

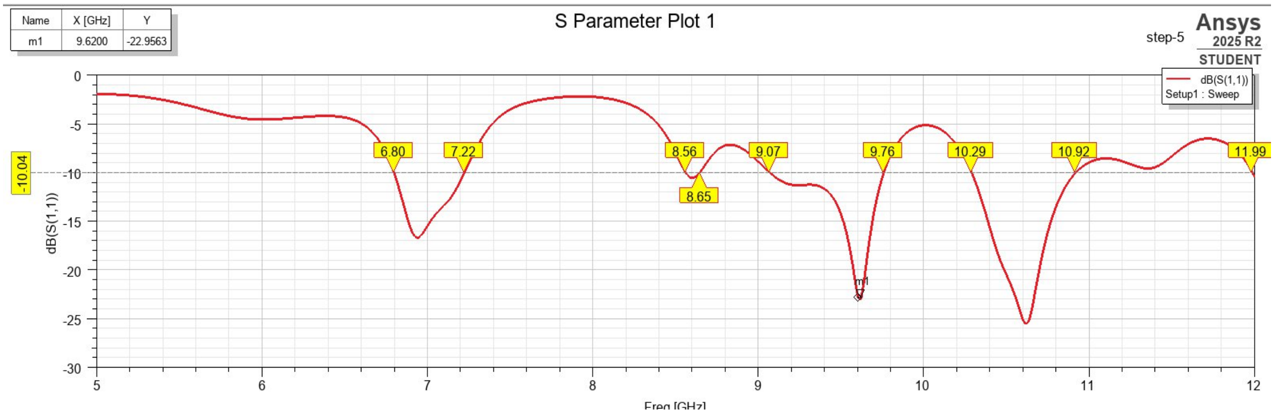

Fig 4. Simulated S11 (Return Loss) Characteristics Showing Multiband Behavior of the Proposed Antenna

- The simulated S11 plot of the proposed antenna clearly shows multiple resonant dips, confirming its triple-band behavior. The antenna exhibits resonances at approximately 6.9 GHz (−16 dB), 8.65 GHz (−10 dB), 9.62 GHz (−22.95 dB), 10.5 GHz (≈ −25 dB), and 10.9 GHz (≈ −10 dB). Among these, the resonances at 6.9 GHz, 9.62 GHz, and 10.5 GHz show strong S11 values well below −10 dB, which can be considered as the dominant bands, confirming the triple-band nature of the antenna.
- A particularly important observation is the resonance at 9.62 GHz, where the S11 value reaches approximately −22.95 dB, indicating excellent impedance matching and minimal reflection. Another strong resonance is observed around 10.5 GHz, where the S11 value is even lower (around −25 dB), representing peak antenna performance. These frequencies lie within or very close to the X-band region (9.2–9.5 GHz and nearby range).
- Since Search and Rescue Transponder (SART) systems operate in the X-band, the deep S11 dip at 9.62 GHz clearly confirms that the proposed antenna is highly suitable for SART applications. The strong matching in this region ensures efficient signal transmission and reliable detection, which is critical for maritime rescue operations.
- Overall, the S11 results demonstrate that the antenna achieves triple-band operation with strong resonances and excellent impedance matching in the X-band region, making it an effective and reliable candidate for SART and modern wireless communication systems.

VSWR (Voltage Standing Wave Ratio):-

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- VSWR (Voltage Standing Wave Ratio) is an important parameter used to evaluate the impedance matching of an antenna. It represents the ratio of maximum to minimum voltage along the transmission line. A lower VSWR value indicates better impedance matching and efficient power transfer between the transmission line and the antenna. Ideally, a VSWR value of 1 indicates perfect matching, while values less than 2 are generally considered acceptable for practical antenna operation.

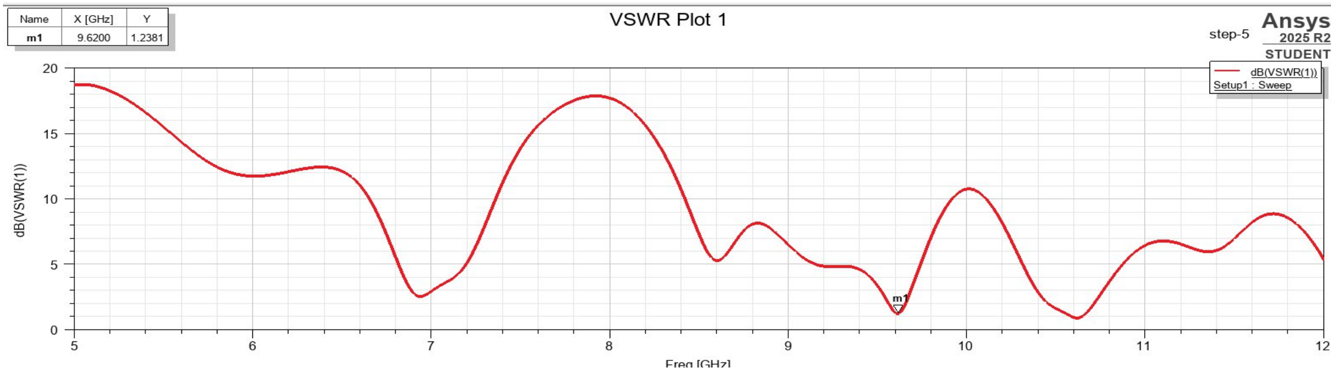

Fig 5. Simulated VSWR Plot

- The simulated VSWR plot of the proposed antenna shows multiple dips across the frequency range, confirming its **multiband behavior**. The antenna exhibits VSWR values less than 2 at several frequencies, indicating good impedance matching at those points. From the graph, a VSWR value of approximately **1.23 is observed at 9.62 GHz**, which is very close to the ideal value, indicating excellent matching and minimal reflection.
- Additionally, low VSWR values are also observed around **6.9 GHz** and **10.5 GHz**, corresponding to the resonant frequencies identified in the S11 plot. These frequencies represent the dominant operating bands of the antenna, confirming its **triple-band characteristics**. The consistency between S11 dips and VSWR minima further validates the antenna performance.
- A key observation is that the **VSWR is minimum in the X-band region**, particularly near **9.62 GHz**, which aligns with the operating range of **Search and Rescue Transponder (SART) systems**. This indicates that the antenna can efficiently transmit and receive signals in this critical frequency range with minimal losses.
- Overall, the VSWR results demonstrate that the proposed antenna achieves **good impedance matching, triple-band operation, and excellent performance in the X-band region**, making it highly suitable for **SART and wireless communication applications**.

Gain Radiation Characteristics:-

- The gain characteristics of the proposed heart-shaped microstrip patch antenna are analyzed using both 2D polar plots and 3D radiation patterns, which provide a comprehensive understanding of the antenna's radiation behavior.
- The 2D gain plot represents the radiation pattern in two principal planes (Φ = 0° and Φ = 90°). From this plot, it is observed that the antenna exhibits a directional radiation pattern, where the radiated power is concentrated in specific directions. The maximum gain in the 2D plot is approximately around 2 to 2.5 dB, indicating moderate radiation strength in the main lobe direction. The presence of side lobes and nulls (around −2 to −3 dB) indicates variations in radiation intensity at different angles. However, the dominant main lobe ensures effective signal transmission in the desired direction.

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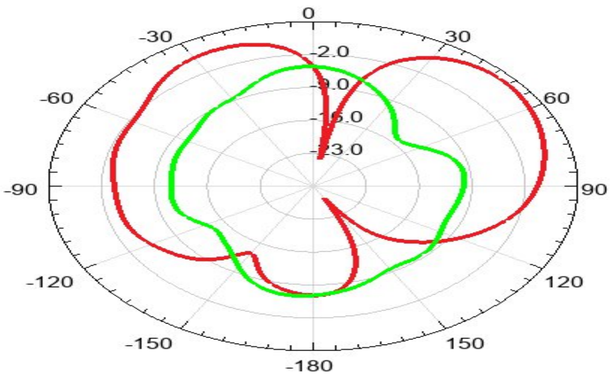

Fig 6. 2D polar plot

- The 2D gain plot represents the radiation pattern in two principal planes (Φ = 0° and Φ = 90°). From this plot, it is observed that the antenna exhibits a directional radiation pattern, where the radiated power is concentrated in specific directions. The maximum gain in the 2D plot is approximately around 2 to 2.5 dB, indicating moderate radiation strength in the main lobe direction. The presence of side lobes and nulls (around −2 to −3 dB) indicates variations in radiation intensity at different angles. However, the dominant main lobe ensures effective signal transmission in the desired direction.

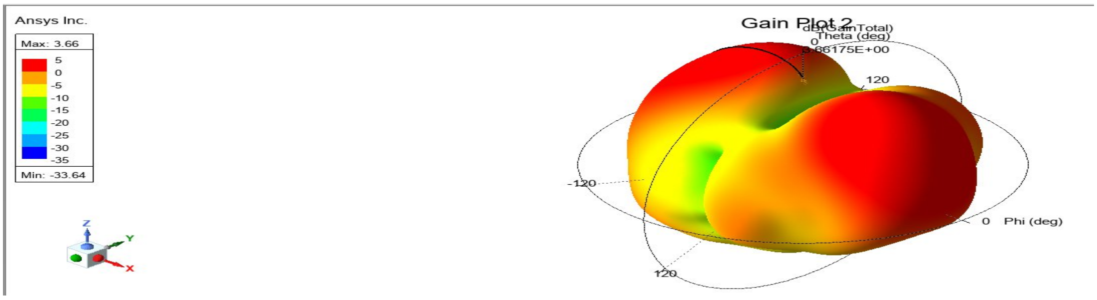

Fig 7. 3D gain plot

- The **3D gain plot** provides a complete spatial view of radiation. From this plot, the **maximum gain is observed to be approximately 3.66 dB**, which is higher than the 2D representation, indicating improved overall radiation performance. The **minimum gain reaches around −33.64 dB**, representing null regions where radiation is minimal. The color distribution clearly shows that **maximum radiation occurs in the red regions**, while **blue regions indicate very low radiation**. The antenna exhibits a **well-defined directional pattern with a strong main lobe and suppressed back radiation**, which is desirable for efficient communication.
- Combining both results, it is evident that the antenna provides **moderate to good gain with directional characteristics**. The gain is stable around the **X-band frequency region (~9.62 GHz)**, which is critical for radar-based systems.
- Since **Search and Rescue Transponder (SART) systems operate in the X-band**, the observed gain performance ensures **reliable signal transmission and detection over long distances**. The directional radiation further improves the efficiency by focusing energy toward the receiver.

VII. COMPARISON OF PROPOSED ANTENNA WITH EXISTING WORK

Parameter	Reference Paper [5]	Proposed Work
Resonant Frequency(GHz)	9.35	Multiband (6.9, 8.65, 9.62, 10.5 GHz)
S11 (dB)	-42 dB	-22.95 dB at 9.62 GHz

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VSWR	1.25	1.23 at 9.62 GHz
Gain	2.3 dB	3.66 dB
Bandwidth	Wideband (around X-band)	Multiple bands (Triple-band behavior)
Application	SART	SART + Multiple Applications

Table.1 Comparison of Reference vs This work

From the comparison, it is observed that the reference antenna is optimized for SART applications with excellent return loss performance. However, it operates as a single-band antenna centered around the X-band frequency.In contrast, the proposed antenna exhibits **multiband (triple-band) behavior**, operating at multiple frequencies including **9.62 GHz**, which lies in the X-band region suitable for SART. Although the S11 value is slightly higher than the reference, it is still well within acceptable limits. Additionally, the proposed antenna achieves a **higher gain (3.66 dB)** compared to the reference antenna.

Therefore, the proposed design provides a **better balance between performance and versatility**, supporting both **SART and multiple wireless applications**.

VIII. CONCLUSION

In this work, a **heart-shaped triple-band microstrip patch antenna** has been successfully designed and analyzed using Ansys HFSS. The proposed antenna demonstrates **multiband behavior**, with resonant frequencies at **6.9 GHz, 8.65 GHz, 9.62 GHz, and 10.5 GHz**, confirming its versatility for multiple applications.The antenna achieves good impedance matching with an **S11 value of −22.95 dB at 9.62 GHz** and a **VSWR of 1.23**, indicating efficient power transmission. A **maximum gain of 3.66 dB** is obtained, which ensures effective radiation and reliable communication. The radiation patterns show **directional characteristics**, suitable for focused signal transmission.
A key highlight of this work is its strong performance in the **X-band region**, particularly around **9.62 GHz**, which makes it highly suitable for **Search and Rescue Transponder (SART) applications**. In addition, the triple-band nature of the antenna enables it to support **radar, satellite, and wireless communication systems**, making it more flexible than conventional single-band designOverall, the proposed antenna provides a **good balance between performance, compact size, and multiband capability**, making it an effective solution for both **SART and modern wireless communication applications**.

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| Mobile No: +91-6381907438 | Whatsapp: +91-6381907438 | ijmrset@gmail.com |

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