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Design of Hexagonal Ring Slotted Microstrip Antenna for ISM Band Applications

[1] G. Vasu Deva Naidu, [1]B. Salviyah, [1]A. Rajesh, [2]A. Sudhakar
[1]UG Students, [2]Associate Professor
[1,2] Department of Electronics and communication,
[1,2] GMR Institute of Technology, Rajam, India

Abstract : This study presents the design, modeling, and analysis of a hexagonal ring slotted microstrip antenna suited for 470 MHz center frequency Applications for the Industrial, Scientific, and Medical (ISM) band. The antenna's operating frequency of 470 MHz is specifically intended for it. The FR-4 substrate has a relative permittivity of 4.4 and a thickness of 1.6 mm, is used in its construction. The antenna's physical dimensions are 124 × 124 × 1.6 mm^3, and it functions at the previously indicated frequency in the ISM range. Software for electromagnetic modelling is used to analyse and design the antenna in order to evaluate various performance measures, such as the S11 parameter, radiation pattern, and voltage standing wave ratio (VSWR). The results indicate that the proposed hexagonal ring slotted microstrip antenna is suitable for 470 MHz ISM band applications due to its good performance characteristics, including reduced VSWR, preferred radiation patterns, and acceptable S11 parameter values.

***IndexTerms* – Slotted Microstrip antenna; Substrate; ISM band; VSWR; Relative permittivity.**

1. INTRODUCTION

The unlicensed nature of the Industry, Science, and Medicine (ISM) band and its versatility in applications have drawn a lot of interest in the world of wireless communication. Within this range, 470 MHz is a frequently used frequency that offers many of options for communication systems, remote sensing, and telemetry. It's an interesting task and an exciting potential to design and optimize antennas for 470 MHz ISM band applications. For modern wireless systems used in industrial automation, smart agriculture, and environmental monitoring, the ISM band at 470 MHz in the electromagnetic spectrum is essential because it allows long-distance communication with less interference. Performance factors including gain, bandwidth, and radiation pattern must be taken into account while building antennas optimized for this frequency. Microstrip antennas compact size, low profile, and ease of fabrication have made them a popular option for ISM band applications. They can be used in many different applications because of their planar architecture, which makes it simple to integrate them with contemporary electrical systems and equipment. Microstrip antennas provide the adaptability needed to fulfill stringent weight and size restrictions while meeting the performance standards needed for 470 MHz ISM band communication. Microstrip antennas can have their attributes tailored to individual requirements by adding slots, which increases design flexibility. Through the facilitation of radiation pattern control, bandwidth augmentation, and impedance matching, slotting techniques enhance overall antenna performance. For ISM band applications at 470 MHz, the best antenna performance in terms of efficiency and directivity can be obtained by efficiently using slots. When creating a slotted microstrip antenna that operates in the 470 MHz ISM band, considerations such as impedance matching, bandwidth optimization, and radiation efficiency must be made. Overcoming these obstacles will open up a lot of possibilities for improvements in antenna design, choice of material, and manufacturing techniques. This project aims to design, develop, and improve a slotted microstrip antenna especially for 470 MHz ISM band applications. By improving wireless communication performance in a variety of ISM band applications, the suggested antenna design may contribute to the advancement of wireless technology. Antennas that are small, effective, and suited to particular frequency bands are becoming more and more in demand in the world of contemporary wireless communication systems. Because of their affordability and adaptability, unlicensed frequency Applications in the fields of Industry, Science, and Medicine (ISM) employ bands. which have seen a sharp rise in demand. For wireless communication applications, the 470 MHz ISM band is quite appealing. Because of their low profile, simplicity in construction, and compatibility with integrated circuit technology, microstrip antennas have become a popular option for ISM band applications. Slotted microstrip antennas are a popular variant of microstrip antennas because of their better performance attributes, which include less surface wave excitation, increased impedance bandwidth, and radiation pattern control. For 470 MHz ISM band applications, designing a slotted microstrip antenna necessitates carefully taking into account factors including feed mechanism, substrate material choice, slot dimensions, and antenna geometry. To sum up, the creation of a slotted microstrip antenna for application in the 470 MHz ISM band is a noteworthy study endeavor with important ramifications for wireless networks. Engineers can design high-performing antennas that satisfy the strict specifications of contemporary wireless applications by utilizing cutting-edge slotting techniques and the built-in benefits of microstrip antennas. The design of a small, An analysis of a multi-band microstrip patch antenna is provided.+ . In a typical microstrip patch arrangement, the antenna contains two semicircular and the edges have two ring slots. The antenna is created to be mounted on a substrate with a relative permittivity of 2.94, TD/Duroid 6002. It measures 24.25 by 31.43 by 3.5 mm. The best frequencies for WLAN, mobile broadband (MBB) at 3.6 KHz, and WiMAX technology, which works at 3.17–3.26 GHz, are 465 MHz (3.55.2.63 GHz) and 80 MHz (3.55.2.63 GHz), respectively. At the chosen center frequencies, the antenna and 2:1 VSWR come into contact. At 4.82 GHz, the recommended antenna may produce a maximum gain of 7.15dB. The antenna's bandwidth is sufficient for wireless communication applications. Its efficiency is rather good [1]. Building ultra-high frequency (UHF) television (TV) antennas for commercial usage has gotten increasingly difficult because these antennas are usually very huge and don't always follow aesthetic guidelines. A transparent liquid multiple-antenna array (470–770 MHz; 48.5%) is presented in this study for usage in ultra-high definition television (UHD TV) applications. The necessity for several transparent antennas stems from the fact that a single transparent antenna typically performs poorly, given the low conductivity of transparent conductors. Two outstanding optically transparent (>90%) saltwater antenna elements make up this array of numerous antennas. Three distinct operating modes are selected for the antenna elements in order to optimize their omnidirectional properties and gain [2]. This letter proposes a planar feeding structure four-leaf clover slot element antenna for dual-polarization applications. A four-element array is constructed and measured using the suggested antenna. Because the array's feeding network and radiators are located on the same substrate, manufacturing is simple and reasonably priced. The two polarizations have respective bandwidths of 465 MHz and 275 MHz. There is a front-to-back ratio and over 25 dB of isolation between the two ports [3]. This letter proposes a planar feeding structure four-leaf clover slot element antenna for dual-polarization applications. A four-element array is constructed and measured using the suggested antenna. Because the array's feeding network and radiators are located on the same substrate, manufacturing is simple and reasonably priced. The two polarizations have respective bandwidths of 465 MHz and 275 MHz. There is a front-to-back ratio and over 25 dB of isolation between the two ports [4]. This work proposes a reconfigurable planar antenna supported by a truncated ground plane, printed for hexa-band frequencies using a FR 4 substrate that is 1.6 mm thicker. Modelling and simulations are done in CST MWS [5] to operate an antenna in 300–500 MHz range. Flexible magnetic composite quarter-wavelength microstrip patch antenna served as the reference system [6] to suggests a new application for a microstrip circular patch antenna with three rings on the patch. This antenna is designed to take use of the white space TV band, which is currently available because TV transmission has moved to other bands. The antenna operates across the entire TV band with a bandwidth of 11 MHz. Creation of three circular rings on the patch and conversion of infinite ground plane to a finite one, the bandwidth is further expanded. This work proposes a new application for a three-ringed microstrip circular patch antenna. The white space TV band is now available for use because TV transmission has moved to other bands, and this antenna is designed to take use of it. With a bandwidth of 11 MHz, the antenna operates throughout the entire TV spectrum. Three circular rings are etched onto the patch to further boost the bandwidth, and the infinite ground plane is converted to a finite one. The proposed antenna has a gain of 1.3 dBi and a radiation efficiency of 92% at the white space TV band frequency [7]. Passive radar uses electromagnetic radiation from sources like FM radios and mobile phone base stations to detect objects. A microstrip antenna receives the reflected signals, processes them, and displays the results on a monitor. The goal of this research is to build a passive radar directed microstrip antenna. The antenna is inexpensive, lightweight, and simple to put together. The CST Studio Suite software is used to complete the simulation and design. If the results satisfy the specifications, the antenna is constructed and measured. The resulting antenna has a range bandwidth of 470MHz–780MHz, a directional pattern, a gain of 6dBi, and an ultrahigh frequency [8]. The design and analysis of a dual band operating microstrip line-fed patch antenna and a rectangular radiating patch with narrow slots are presented in this paper. One phase in the design process that aids in determining the intended resonance frequencies is a parametric analysis. A reasonably cost FR4 substrate with partial ground plane and vertical thin slits on the radiating element is used to construct the antenna prototype. The experiment's results indicate that the centre resonant frequencies are 460 MHz and 4.5 GHz, respectively. The antenna's average gain for the lower band is 6.6 dBi with an efficiency of 85%, while for the higher band, it is 9.7 dBi with an efficiency of 88%. [9]. One of the most popular types of wireless communication antennas is the microstrip patch antenna. Its low cost, simple production, and restricted bandwidth are some of its most noteworthy characteristics. The design of a microstrip patch antenna for use in UWB applications that operates in the frequency range of 3.1 GHz to 10.6 GHz is covered in this paper. The selected substrate material is FR4, The dielectric constant is 4.4 and the substrate thickness is 1.59 mm. The microstrip antenna developed in this study has a hexagon-shaped radiating patch. [10-11]. The rapid expansion of wireless communication calls for ever-more intricate and precise antenna designs. As a result, improved output performance from the antenna designs is required [12]. The slotted microstrip patch antenna design for ISM (Industrial, Scientific, and Medical) band applications at 470MHz is presented in this work.

2. METHODOLOGY

This study's comprehensive design approach makes use of electromagnetic simulation, prototype construction, and performance validation.

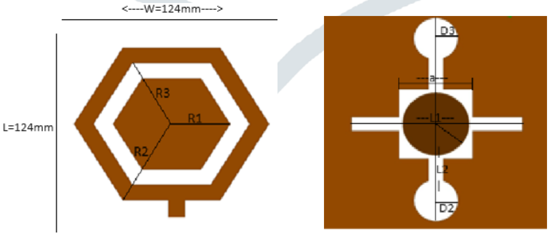


fig. 2.1. Design of microstrip antenna

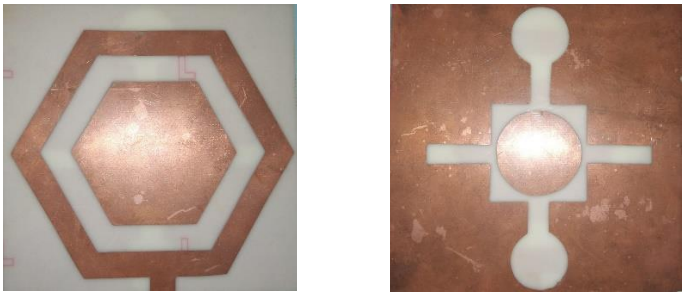
Antenna features can be modeled and examined with the aid of advanced modeling tools, enabling gradual changes to meet the necessary performance targets. Applications operating in the 470MHz ISM band employ a hexagonal microstrip patch antenna. It uses a specific FR-4 substrate with a thickness of 1.6 mm and a dielectric constant of 4.4. A 34 mm-radius hexagonal patch with 46 and 57 mm outer main radii, respectively, is part of the antenna's design.

TABLE 1: DESIGNED ANTENNA VALUES AND SPECIFICATIONS:

S.NO	PARAMETERS	VALUE
1	Substrate	FR4 epoxy
2	Dielectric constant	4.4
3	Dimensions	124 × 124 × 1.6 mm^3
4	Height of the substrate	1.6 mm
5	L	124 mm
6	W	124 mm
7	L1,L2	93 mm
8	A	40 mm
9	R1	34 mm
10	R2	46 mm
11	R3	57 mm
12	D1	17 mm
13	D2,D3	12 mm

Each of these components is placed on the dielectric substrate. Two rectangular, orthogonal slots, each measuring 93 mm in width and length, are present in the ground plane of the patch. Moreover, a 40 mm-square slit is placed beneath the patch's center on each side. There are circular features on the ground side. These are circles with a radius of 12 mm that are positioned at the corners of the rectangular slots. A round element with a diameter of 17 mm is also included. When integrated with the antenna system, these ground plane slots work as a load, deliberately increasing the antenna's performance by bringing the input impedance closer to the characteristic impedance. Iteration and improvement are required continuously to achieve the desired performance within the specified frequency range. This method of implementation integrates modeling, optimization, validation, and possibly experimental testing, as will be seen below,

Requirements gathering: The first step in the process is to define the specific requirements for the antenna, including the desired frequency range, VSWR, radiation pattern, and other relevant parameters.
Geometry creation: Once the requirements are defined, the next step is to design the layout of the slotted microstrip antenna, including the dimensions of the substrate, slots, and feed mechanism. This design should be based on the previously established requirements.
Material selection: An appropriate dielectric material must be chosen for the substrate, taking into consideration the desired electrical properties such as the dielectric constant.
Simulation setup: To accurately analyze the antenna's performance, a simulation setup is necessary. This involves defining the working frequency, setting up the analysis settings (such as the frequency sweep range), determining meshing parameters, establishing boundary conditions, and selecting excitation sources.
Excitation: A suitable excitation, such as a voltage source or a wave port, must be applied to the antenna structure. It is important to ensure that the excitation is properly placed and aligned with the antenna structure.
Meshing: A mesh must be generated for the antenna structure. The mesh settings should be adjusted to achieve both accuracy and efficiency. It is often necessary to have a fine mesh around slots and edges to obtain accurate results.
Simulation and analysis: To evaluate the performance of the antenna, electromagnetic simulations are performed. Important factors are assessed, including efficiency, VSWR, radiation pattern, return loss, and impedance matching.
Optimization: If necessary, optimizations can be performed to improve the antenna's performance. This may involve adjusting slot dimensions, substrate properties, or other relevant parameters.
Iterative refinement: Based on the simulation results, the design can be iteratively refined to enhance the antenna's performance. Adjustments to geometrical parameters or material properties may be made as needed to meet performance goals.
Results analysis: The simulation results are carefully analyzed to ensure that the antenna meets the desired specifications. Adjustments can be made based on the obtained results.
Fabrication and testing: Experimental testing is performed to validate the simulated results and ensure that the antenna performs as expected in real-world conditions.



(2.2a) Front perspective (2.2b) Rear view

fig. 2.2. Hardware Model about the Suggested Antenna

The width (W) of the antenna can be mathematically represented as per the following basic formulas:

$$W = \frac{c}{2f_0}\sqrt{\frac{2}{2\varepsilon_r+1}} \qquad \text{Eq.1}$$

To calculate the effective dielectric constant, use the formula below (ε_{reff}):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2 \times \sqrt{(12 \times \frac{h}{w})}} \qquad \text{Eq.2}$$

Determining the microstrip antenna's length extension is the next computational step. Performing this computation is crucial in order to get the intended gain and bandwidth. It is also utilized to determine the antenna's resonance frequency. The length extension ΔL) is computed in this way:

$$\Delta L = 0.412h \times \left[\frac{(\varepsilon_{reff} + 0.3) \times (\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258) \times (\frac{W}{h} + 0.8)}\right] \qquad \text{Eq.3}$$

The length (L) and effective length (L_{eff}) calculations are as follows:

$$L_{eff} = \frac{c}{2 \times f_r \times \sqrt{\varepsilon_{reff}}} \qquad \text{Eq.4}$$

Next, the length of the antenna is calculated using the formula below:

$$L = L_{eff} - 2\Delta L \qquad \text{Eq.5}$$

3. RESULTS AND DISCUSSION

The design of microstrip patch antennas is presented in this study using a comprehensive approach that emphasises the integration of modelling, fabrication, and prototype testing. Critical design parameters encompass the selection of dielectric material (FR4 epoxy), substrate height (1.6 mm), and patch dimensions (124 mm × 124mm).

(a) Return loss(S_{11}):

One of the most important metrics for assessing how well a slotted microstrip antenna reduces signal reflections is return loss. It is generally expressed in decibels (dB) and provides information on how well the antenna impedance matches the transmission line and surrounding environment. In the case of a slotted microstrip atenna, a lower return loss value is desirable since it indicates a better impedance match and fewer signal reflections. An antenna with more efficiency is indicated by a bigger negative return loss value, which is commonly expressed in dB. The performance of the slotted microstrip antenna in the 470 MHz ISM band demonstrates a very favorable return loss of -22.3dB. The extremely low return loss value suggests that the perfect impedance match between the transmission line and the antenna results in very few signal reflections.

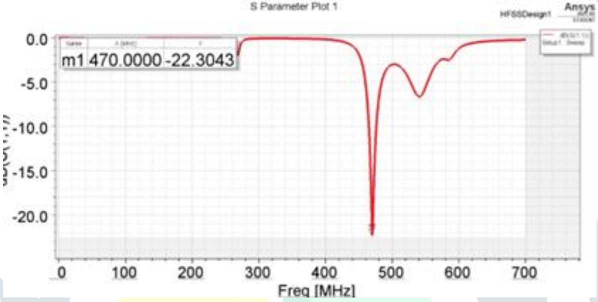


fig. 3a. S_{11} is -22.3dB for 470MHz

The return loss of -22.3dB demonstrates an incredible efficiency in both absorbing and transferring the incident power, with only a small part being reflected. Because it ensures that a substantial quantity of electromagnetic energy is successfully radiated or absorbed, the superior return loss of the antenna is crucial to its performance in the chosen ISM band as it lowers the likelihood of signal deterioration due to reflections. The antenna's design, which incorporates components like the metallic hexagonal patch, ring tone, and orthogonal slots, produces this outstanding return loss. It also demonstrates that the antenna exactly meets the operational requirements of the 470 MHz ISM band.

(b) Radiation pattern:

An examination of the slotted microstrip antenna's emission pattern while it operates in the 470 MHz ISM band can provide more insight into its directional characteristics and antenna performance. The electromagnetic energy that the antenna emits is displayed in the three-dimensional radiation pattern. The findings demonstrate that the proposed slotted microstrip antenna, which is intended to operate in the 470 MHz frequency band, has a unique radiation pattern. The radiation pattern displays the distribution of power emitted at various angles in the azimuth and elevation planes. This information is necessary to understand how the antenna directs its signal and how sensitive it is to changes in the direction of the transmitting or receiving device.

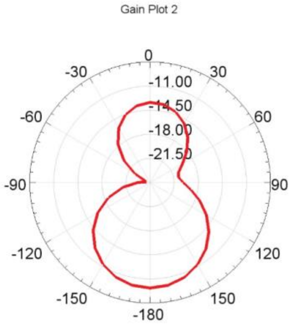


fig. 3b. Radiation Pattern

A symmetric and homogeneous radiation pattern is appropriate for ISM band applications because it guarantees reliable and consistent coverage. In conclusion, the radiation pattern measurements fully explain the electromagnetic characteristics of the slotted microstrip antenna operating at 470 MHz in the ISM band. This information is crucial for engineers and researchers who intend to utilize the antenna in situations where an efficient and well-defined radiation pattern is required for the best possible communication and signal reception.

(c) VSWR:

The Voltage Standing Wave Ratio (VSWR) is an important metric to evaluate a slotted microstrip antenna's effectiveness and performance. The unitless ratio, or VSWR, indicates the degree of impedance matching in the transmission line that is connected to the antenna. By comparing the standing wave's maximum amplitude to its lowest amplitude along the transmission line, this ratio can be found. When constructing slotted microstrip antennas for certain uses, 1.33 VSWR impedance match is a very useful match. A VSWR that is near to 1 indicates less signal reflection and shows how well the antenna transfers power to the linked transmission line. By effectively producing a significant amount of electromagnetic energy, the antenna reduces losses resulting from impedance mismatches. It is preferable that the VSWR be thus low.

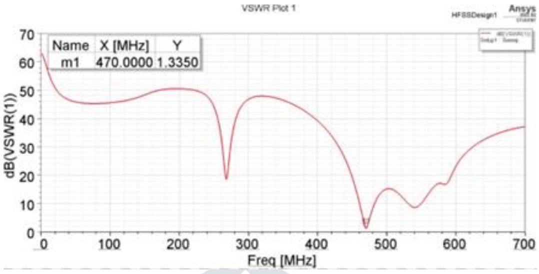


fig. 3c. VSWR graph with value 1.33.

The slotted microstrip antenna's 1.33 VSWR value shows that it is quantitatively aligned with the transmission line's impedance characteristics, guaranteeing maximum power transfer. This feature is essential for determining whether the antenna can provide reliable and effective communication performance within the designated frequency band in sectors like research, health, and business where accurate and continuous communication is required.

4. CONCLUSION

In An extensive analysis of the creation of a slotted microstrip antenna intended to function in the ISM band at a frequency of 470 MHz finished this article. The ISM band at 470 MHz is crucial for many industrial and rural communication applications because of its advantages, which include improved obstacle penetration and greater long-range propagation characteristics. The research highlighted the challenges of designing a slotted microstrip antenna for the 470 MHz ISM band, including maintaining appropriate radiation patterns, achieving optimal radiation efficiency, and ensuring impedance matching while maintaining compact dimensions. Increasing gain, bandwidth, and efficiency within the 470 MHz frequency range was the aim of the proposed design. The constructed antenna was able to perfectly match the 470 MHz ISM band's operational characteristics. It was made on a specific-sized FR-4 substrate with orthogonal slots, ring tone, and a hexagonal patch. Key performance indicators, including return loss, VSWR, and radiation pattern, were discussed and their results evaluated. A remarkable return loss of -22.3 dB was found during the return loss research, indicating good impedance matching and a decrease in signal reflections. The directional characteristics of the antenna were revealed by the radiation pattern analysis, and this information is essential for precise positioning and alignment. The VSWR value of 1.33 demonstrated an extremely good impedance match and the efficient transfer of power between the antenna and the transmission line. These comprehensive results proved the antenna's efficacy and acceptability for usage in the disciplines of science, medicine, and industry—all of which rely on reliable and secure communication. The slotted microstrip antenna design not only satisfies user demands and safety regulations, but also operates remarkably well in terms of functionality thanks to the meticulous evaluation of performance criteria.

TABLE 2:COMPARISION OF RESULTS

Ref	S11 (dB)	Gain (dB)	VSWR	Dimensions (mm^3)
1	-22	4.63	<2	24.25 × 31.43 × 3.5 mm
2	-15	2.58	-	50 × 40
3	-22	14.1	3	120 × 120 × 1
4	-25	2.1	-	128 × 64
5	-23	1.96	1.21	38 × 35 × 1.6
6	-19	2	-	-
Proposed	-22.3		1.33	124 × 124 × 1.6

5. ACKNOWLEDGMENT

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