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Design and Simulation of a Compact Tri-Band Patch Antenna For FSS and DBS in KU Band

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Abstract - For the transmission and reception of direct broadcast service (DBS) and fixed satellite service (FSS) in the Ku band, a tri-band patch antenna has been designed. The antenna is intended to function between the frequencies of 11.54 and 13.12 GHz, 13.88 and 14.66 GHz, and 17.06 and 18.17 GHz. Eight rectangular slots, two C-shaped slots on the patch, one plus-shaped slot on the ground, and seven defective ground structure (DGS) slots are all part of the proposed design. Many metrics, including reflection coefficient, gain, radiation efficiency, VSWR, and radiation pattern, are simulated using CST Suite 2022 software to assess the antenna's performance. The antenna has a physical size of 20 x 20 mm^2, and the simulation's findings help to improve the design's performance and efficacy. With good performance, the designed compact antenna attains the target frequency bands.

***Key Words* -** Tri-band patch Antenna, Gain, Efficiency, DGS, KU- Band(12GHz18GHz), DBS, FSS, VSWR, Return loss, Radiation pattern.

I. INTRODUCTION

Satellite technology is increasingly used in various applications, but bulky and large antennas are not always feasible due to space and environmental constraints. Low-profile patch antennas are being used for their multi-band performance, small size, robustness against interference, and affordability. Multiband antennas have become popular for Ku-band satellite communication systems due to space constraints and the proliferation of applications. Many patch antennas have been proposed for Ku-band satellite applications, including dual-band antennas, low-profile patch antennas, and loaded slot patch antennas.

The International Telecommunication Union (ITU governs two important applications of satellite communication: Fixed Satellite Services (FSS) and Direct Broadcast Services (DBS). The ITU has divided the globe into three regions, and for region 3, the frequency band requirements for FSS are 14-14.5 GHz (transmission) and 12.2-12.7 GHz (reception), while for DBS, they are 17.3 GHz-17.8 GHz (transmission) and 11.7 GHz-12.2 GHz (reception).

In this paper, we present the design of a tri-band patch antenna for KU band satellite applications. The antenna is constructed using three layers of ground, substrate, and patch. The ground and patch layers are made of conductive materials, while the substrate layer is made of cost-effective FR-4 material. The antenna operates at frequencies of 12.473 GHz, 14.208 GHz, and 17.644 GHz, which fall within the KU band range. The proposed design offers better efficiency, ranging from 43% to 73%, and a gain of approximately 2.19 dB to 5.64 dB at the three frequency bands.

MATERIAL SPECIFICATION:

1. Conductive Element:

The conductive element used in this patch antenna is copper annealed. Copper is a widely used material in antenna design due to its excellent electrical conductivity and thermal conductivity properties. Copper annealed is a type of copper that has been subjected to a thermal treatment process known as annealing. Annealing involves heating the copper to a high temperature and then cooling it slowly, which allows the material to recrystallize and become more ductile. The conductive metal used in the patch and ground layers in this antenna is copper. The specifications of copper annealed are shown in Table-I.

2. Substrate material:

The Substrate material used in this antenna design is FR-4 with a dielectric constant of 4.3(ε_r=4.3) and loss tangent (tan δ=0.025) The substrate material plays an important role in determining the electrical properties of the antenna, such as its impedance matching, radiation efficiency, and bandwidth. The

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FR-4 substrate material has a low cost and good mechanical properties, making it a popular choice for mass-produced antennas. The dielectric constant of FR-4 is typically in the range of 4-5, which allows for a compact antenna design with good radiation efficiency. The substrate thickness also affects the electrical properties of the antenna, particularly the resonant frequency, and bandwidth. The properties of the FR-4 substrate are shown in Table II.

Table-I: Properties of Copper Annealed Material

Parameter	Value
Electronic Mobility	40 $cm^2 V^{-1} s^{-1}$
Current density	10^5 - 10^6 A cm^{-1}
Tensile strength	240 MPa
Thermal conductivity	400 W $m^{-1} K^{-1}$
Density	8.96 g/cm^3

Table II: Properties of FR-4 lossy substrate

Parameter	Value
Dielectric constant (ε_r)	4.3
Dissipation factor (tan δ)	0.025
Moisture absorption	0.10%
Thermal Conductivity	0.25W/m/K
Density	1.850 gm/cm^3
Dielectric thickness	1.6mm

II. PROPOSED ANTENNA DESIGN

The proposed antenna design is illustrated in Fig. 1 and Fig. 2, where Fig. 1 shows the front view of the E slot and Fig. 2 depicts the back view of the antenna. The antenna is designed with dimensions as listed in Table III, with a total dimension of 20 × 20 mm^2. The substrate used for the design is 1.6 mm thick (h1) FR-4, which is preferred for its cost-effectiveness. The dielectric loss tangent and relative permittivity of the FR-4 substrate used are 0.025 and 4.3, respectively.

In the initial design, a truncated E-shaped slot was etched from the patch to obtain two frequency bands from 12.08 to 13.20 GHz and 13.96 to 15.05 GHz, with resonant frequencies of 12.65 GHz and 14.5 GHz, respectively. To further fine-tune the design, eight rectangular slots were added, which resulted in achieving the desired frequency bands of 11.7 GHz to 12.7 GHz and 14 to 14.5 GHz.

To achieve the transmitting and receiving modes of DBS, the patch design was modified with two C-shaped corner truncated slots, which allowed the third frequency band of 16.93–17.5 GHz to be achieved. However, finer tuning was required for this band, as the actual DBS transmission band is 17.3–17.8 GHz. To achieve all the frequency bands of FSS and DBS (transmission and reception) with enhanced

bandwidth, seven rectangular DGS slots, and a plus-shaped DGS slot were added in the backside design.

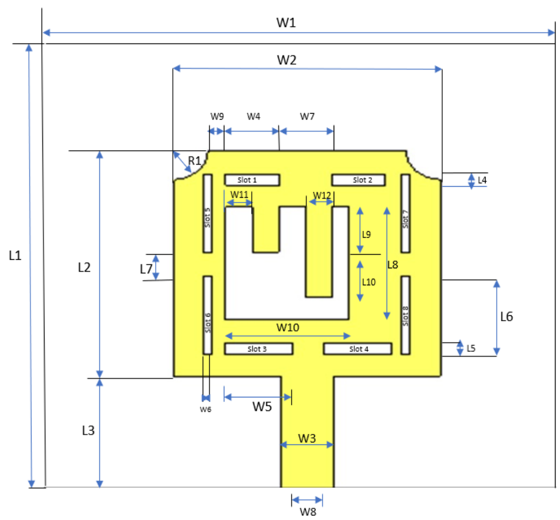

Figure-1: Antenna Front View

Figure-2: Antenna Back View

Dimensions of the antenna:

The dimensions (in mm) of the proposed designed antenna are shown in figure-1 and 2 and their values are in Table III.

Width	**Dimension**	**Length**	**Dimension**
W1	20	L1	20
W2	10	L2	10
W3	5	L3	5
W4	2	L4	0.5
W5	2.5	L5	0.5
W6	0.3	L6	3.5
W7	2	L7	1
W8	1.2	L8	5
W9	0.8	L9	2
W10	4.6	L10	2
W11	1	L11	12.8
W12	1	L12	5
W13	8.4	L13	6
W14	4.8	L14	0.8
W15	1	L15	2.8
W16	1.2	L16	1.9
W17	1.2	L17	2.6
W18	1	L18	1
W19	2.8	L19	0.6
W20	12	L20	2
Radius R1 = 1.3			
The thickness of substrate H1=1.6			

Table III: Dimensions of Antenna in mm.

Tool Description:

CST is a popular software tool used for the design and analysis of a variety of antennas. It offers a wide range of features and tools for optimizing and analyzing antennas, making it a preferred choice over other software tools. Although it is a licensed software, a free student edition of CST is available for use by researchers, engineers, and designers. It is important to ensure that any content generated using this software is original.

III. SIMULATED RESULTS AND DISCUSSION

1. Reflection Coefficient:

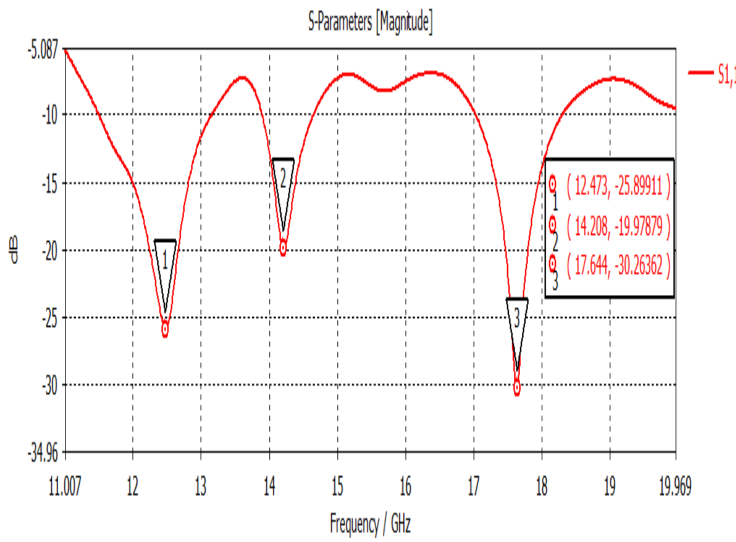

Figure-3: Reflection Coefficient(s-Parameters)

Based on Figure-3, it can be observed that the reflection coefficient of the antenna under consideration is -25.899 dB at a frequency of 12.473 GHz, -19.97 dB at 14.208 GHz, and -30.263 dB at 17.644 GHz. The reflection coefficient is a measure of the amount of power that is reflected from the antenna, and it is a crucial factor in determining the overall performance of the antenna.

2. VSWR:

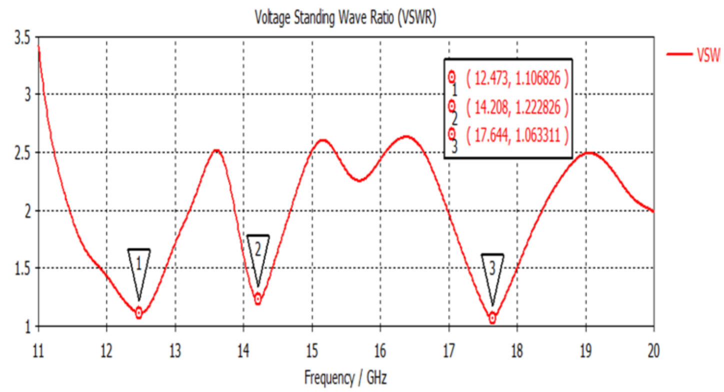

Figure-4: VSWR

Based on the information provided in Figure 4, it can be observed that the VSWR of the designed antenna is 1.06 at 12.473 GHz, 1.10 at 14.208 GHz, and 1.2 at 17.644 GHz. A VSWR of less than 1.5:1 is considered ideal for most applications, as it indicates a good impedance match between the antenna and the transmission line, resulting in minimal signal loss and optimal performance. However, a VSWR of up to 2:1 is considered marginally acceptable in low-power applications where power loss is critical. Overall, the VSWR values obtained for the designed antenna suggest that it has a good impedance match, which is essential for achieving maximum efficiency and performance.

3. Gain and Directivity:

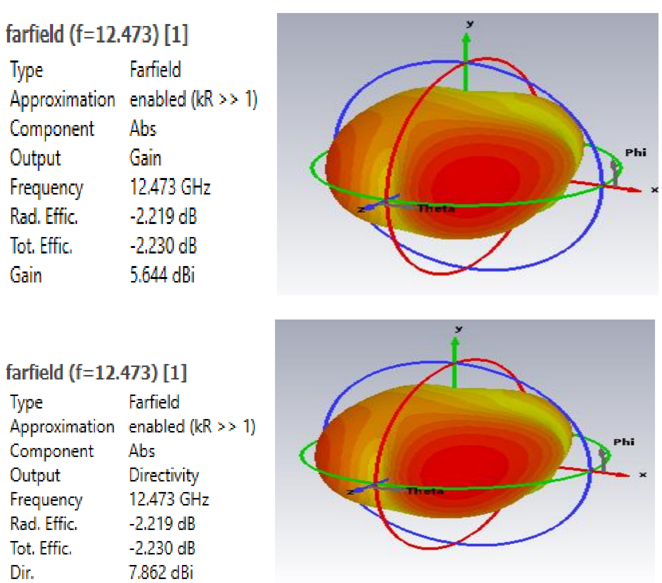

Figure-5(a): Gain and Directivity at 12.473 GHz

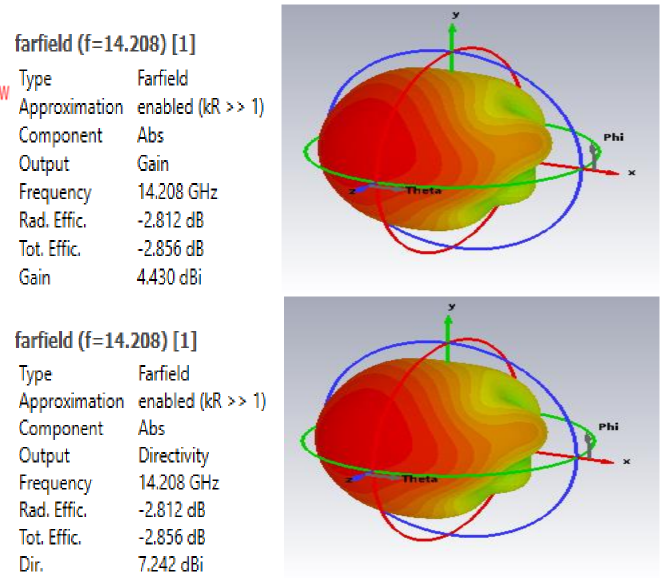

Figure-5(b): Gain and Directivity at 14.208 GHz

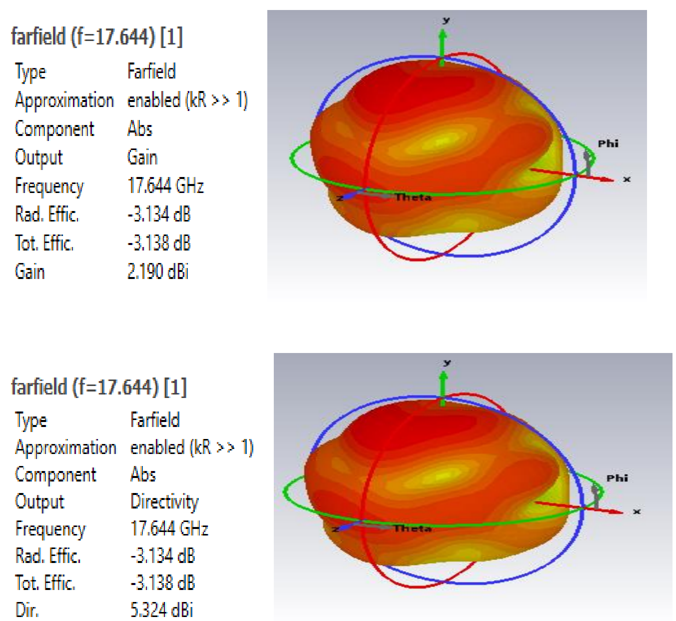

Figure-5(c): Gain and directivity at 17.644 GHz

From Figures 5(a), (b), and (c), the gain of the designed antenna is 5.644 dB at 12.473 GHz, 4.430 dB at 14.208 GHz, and 2.19 dB at 17.644 GHz. Gain is a measure of the ability of the antenna to radiate in any given direction. Additionally, the directivity of the designed antenna is 7.862 dB, 7.242 dB, and 5.324 dB at the respective frequencies. Directivity is a fundamental parameter used to describe the performance of an antenna. It is a measure of the concentration of radiation in a

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particular direction, and it is related to the gain of the antenna. The efficiency of the designed antenna can be calculated by taking the ratio of gain to directivity. Based on the figures provided, the efficiency of the designed antenna is estimated to be between 43% and 73%, depending on the frequency. Efficiency is a crucial factor in determining the overall performance of the antenna, as it indicates the percentage of the input power that is radiated as electromagnetic waves.

4. Radiation Pattern:

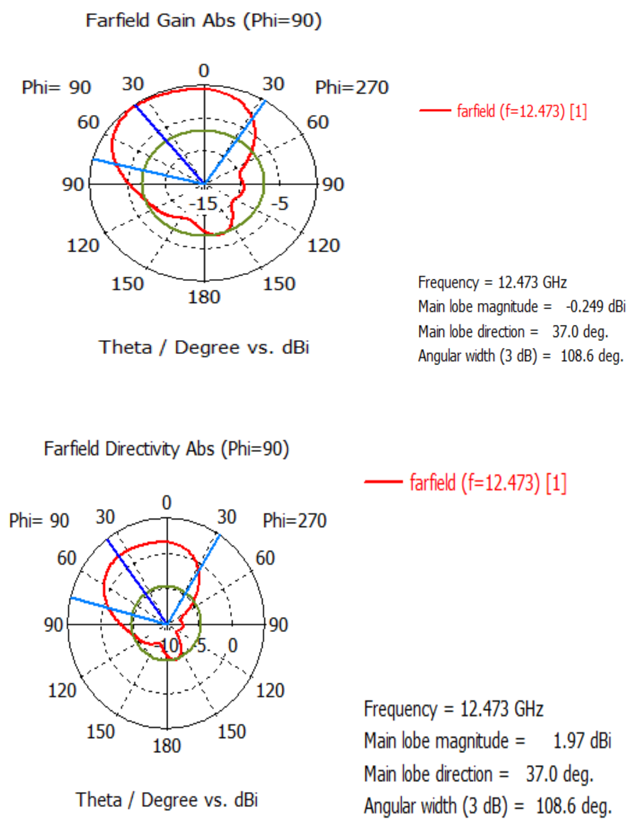

Figure-6(a): Farfield Region at 12.473 GHz

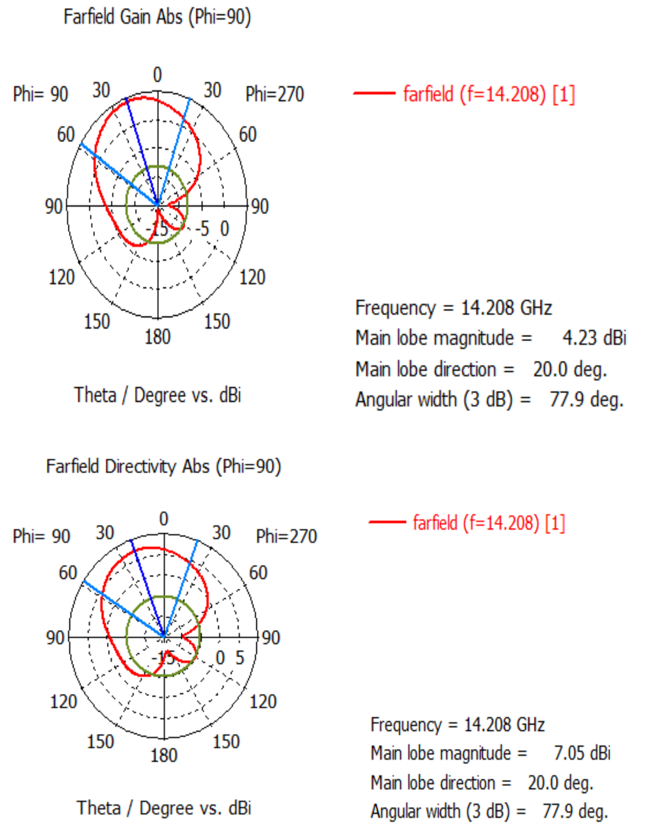

Figure-6(b): Farfield Region at 14.208 GHz

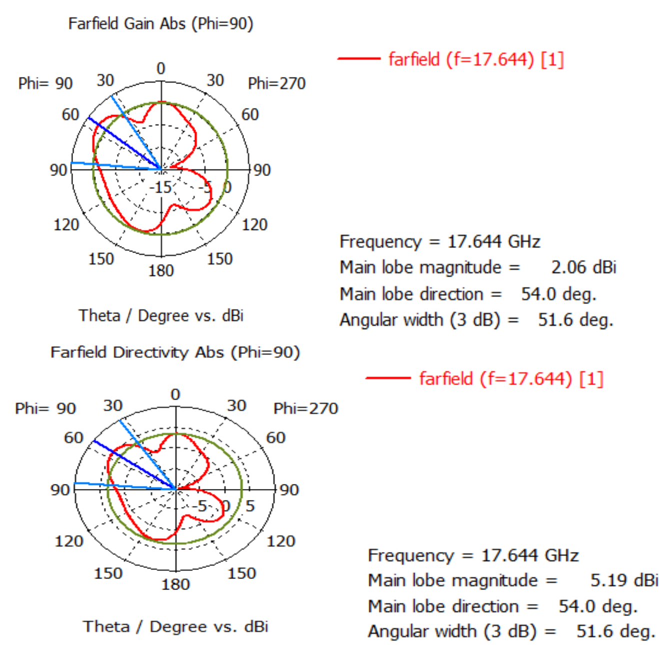

Figure-6(c): Farfield Region at 17.644 GHz

The radiation pattern of the designed antenna exhibits a bidirectional pattern in the E-plane and an omnidirectional pattern in the H-plane. This can be clearly seen from the graph shown above and below far-field regions. It is important to note that this observation is a result of the specific design and configuration of the antenna, which was developed with the intention of achieving these radiation patterns.

IV. CONCLUSION

In this project work, the primary objective was to design a tri-band antenna suitable for Ku band applications. To achieve this, a combination of different slots was utilized, including a truncated E-shaped slot, eight rectangular slots, two C-shaped slots in the patch, seven defective ground structure (DGS) slots, and a plus-shaped slot, to achieve the desired frequency bands for DBS and FSS transmission and reception. After designing the antenna, key parameters such as reflection coefficient, VSWR, efficiency, gain, and radiation pattern were analyzed to evaluate the antenna's performance. The results indicated that the antenna design met the desired specifications for these parameters. In addition, the antenna design presented in this project work serves as a foundation for the development of array antennas. By incorporating this design as an element in an array configuration, it would be possible to achieve enhanced gain, which would be particularly useful for FSS and DBS transmission and reception modes. Moreover, the proposed antenna design presented in this project work fulfills the spectrum requirements of ITU region 3.

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