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Design of Microstrip Trapezoidal Patch Antenna Using Coaxial Feeding Technique for Space Applications

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Abstract

A microstrip trapezoidal patch antenna structure has been proposed to serve different space applications including the fixed satellite applications, mobile and radiolocation services. This structure utilizes a 0.787 mm thick RT Duroid (5880) substrate of relative permittivity 2.2 and a dielectric loss tangent of 0.0009. A trapezium shaped patch has been formed on it. The patch is compact and has a novel geometry. The feeding technique employed is coaxial/probe feed. The parametric analysis done over HFSS-15 software to study the effects of the structural design over the behavior of antenna reveals the potentiality of the designed antenna to maintain a nearly constant gain upon the variation of several parameters individually. The use of parallel slots in the design offer a reduction in the size of the patch [5]. The performance of the antenna has been analyzed in terms of reflection coefficient, bandwidth and radiation pattern. The antenna yielded a simulated single band reflection coefficient of -22.5 dB and a peak gain of 4.7 dBi at 3.64 GHz and an impedance bandwidth of 10 MHz at -10 dB reflection coefficient. The fabricated design was tested over VNA for its reflection coefficient. The measured results have been included.

Index Terms: High Frequency Structural Simulator (HFSS), Radio Frequency (RF).

1. Introduction

The communication that was initiated by sound through voice witnessed the use of devices such as drums followed by the use of visual methods such as sign flags and smoke signals. These optical devices were, however, limited to the light portion of electromagnetic spectrum. Antennas, being one of the greatest natural resource of the mankind has been instrumental in harnessing the electromagnetic spectrum outside this visible

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region. Microstrip patch antennas have proven out to be a breakthrough in the field of antenna technology and are attracting a wide research interest. Abbreviated normally as MPA, they find application in different mobile services which include the applications and utilities provided by service operators in order to enhance the mobile experience of its users. These mobile services usually differ on an operator basis and remain under a completely "separate license". In addition to various mobile services, the microstrip patch antennas can also be utilized for fixed satellite and radio location purpose. The microstrip patch antennas as in Fig. 1 consist of a radiating patch element over a grounded base separated by a dielectric substrate [1]. The growing trend of these microstrip patch antennas is mainly due to their low- profile structure, conformability to non- planar surfaces, simplicity, reduced cost, mechanical robustness, compatibility with MMIC designs and the versatility offered in terms of centre frequency, space orientation of fields, patterns and impedance [2].

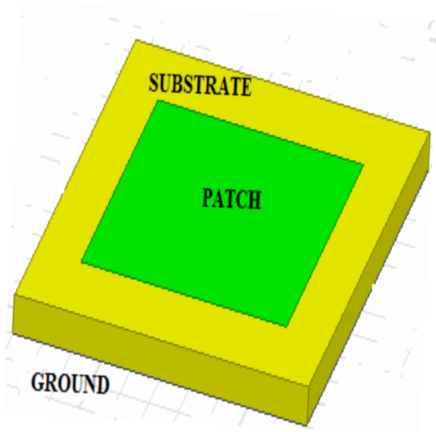

Fig.1. Microstrip Patch Antenna

Different existing microstrip patch antenna designs have been studied. The ACS-fed compact antenna for UWB applications in [3] produced an average gain of 3.6 dBi. The peak gains realized in [4] in lower, middle and upper bands included 3.1 dBi, 4.52 dBi and 4.89 dBi respectively. In [5], a mono layered high gain microstrip antenna configuration was built with a reflection coefficient of -11 dB. The peak gain achieved by a compact asymmetrically-slotted microstrip patch antenna with circular polarization in [6] was 4 dBi. The reflection coefficient achieved in large gain multilayered antenna apt for wireless applications in [7] was -17 dB. The microstrip danger symbol shaped patch antenna proposed for fixed satellite applications in [8] achieved a reflection coefficient of -35.7 dB, peak gain of 1.6 dBi and a bandwidth of 12 MHz at 2.7 GHz. At another resonant frequency, i.e. 4.57 GHz, the design exhibited a reflection coefficient of -10.1 dB, gain of 4.9 dBi and a bandwidth of 4.61 MHz. The reconfigurable single band microstrip patch antenna for satellite applications using FR4 epoxy substrate in [9] achieved a peak gain of 3.7 dBi with a -22.8dB reflection coefficient. The microstrip patch antenna with annular-ring slot intended for ISM band applications in [10] had a peak gain of 1.86 dBi at 2.4 GHz. The patch antenna designed at 2.4 GHz for WLAN applications in [11] displayed a maxim gain of 4.6 dBi at 2.4 GHz. Also, the maxim gain achieved by X band conformal antenna using microstrip patch in [12] was 2.2. The reference antenna used in [13] displayed a peak gain of 4.6 dBi with a reflection coefficient of -23.5 dB while the proposed quad band antenna achieved a minimum reflection coefficient of -17.6 dB with a 4.6 dBi gain. The trapezoidal patch antenna design proposed in this paper has been built over a RT Duroid 5880 substrate and uses a coaxial feeding technique. The design offers a single band resonance at 3.64 GHz with a reflection coefficient of -22.5 dB and a peak gain of 4.7 dBi and is fit to serve the S band applications including the fixed satellite applications, mobile services and radio location. The use of coaxial feeding mechanism provides for flexibility in the choice of the feed location, easy fabrication and less spurious radiations [14]. The section 2 of the paper gives the description of the antenna design. The tabulated dimensions of the design have been added at the end of the section. In depth description of the parametric analysis and the results (reflection coefficient, bandwidth and radiation pattern) has been given in sections 3 and 4 respectively.

2. Antenna Design

The antennas that may be designed for different space applications are frequency dependent. Based on the intended application in the requisite band(s), the resonant frequency is chosen and other specifications are calculated using the design equations given in Table 1. Following this, the structure is designed and simulated using the simulation software. The structure is then fabricated and the parametric values of the fabricated prototype are validated over the measurement setup. The figure 2 depicts the methodology for the proposed work.

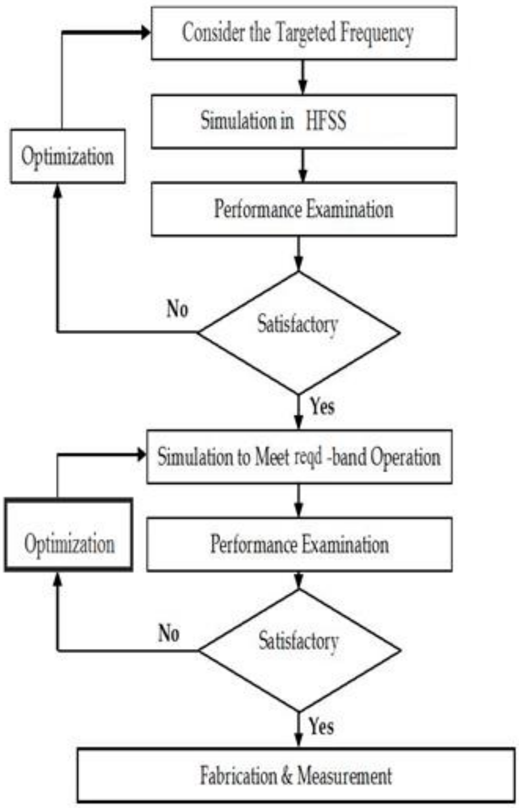

Fig.2. Methodology [15]

Table 1. Design Equations

Parameter	Formula
Width of the radiating patch (W)	$w = \left(\frac{c}{2\times f_r}\right)\left(\sqrt{\frac{\varepsilon_r+1}{2}}\right)$
Effective dielectric constant of the substrate ε_{reff}	$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2} \times \sqrt{\left(1+\left(\frac{12h}{w}\right)\right)}$
Effective length of the radiating patch (L)	$L = \frac{c}{2\times f_r \times \varepsilon_{reff}} - 2\Delta l$
Extension Length for patch (ΔL)	$\Delta l = .412\times h\times\left[\left(\frac{\varepsilon_{reff}+0.03}{\varepsilon_{reff}-.258}\right)\times\left(\frac{w+0.264h}{w+.8h}\right)\right]$

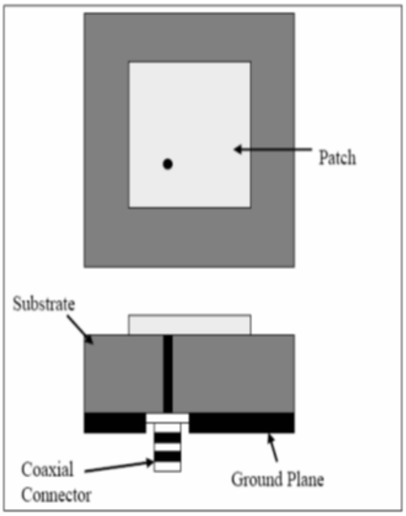

Fig.3. Coaxial feeding technique

The proposed design in Fig. 4 emphasizes mainly on the coaxial feeding and slotted patch techniques. The metallic patch (purple) is supported by a grounded dielectric substrate. A reduction in the size of the patch (as stated in upcoming sections) has been achieved by incorporating pair of parallel slots [16].

The trapezium shaped patch has been formed by subtracting triangles from the respective rectangles. An introduction of slots in the trapezoidal patch structure offers reduction of patch size. Also, a circular element has been added to the patch design. At first, the dimensions of the antenna have been specified using the following tabulated equations [17].

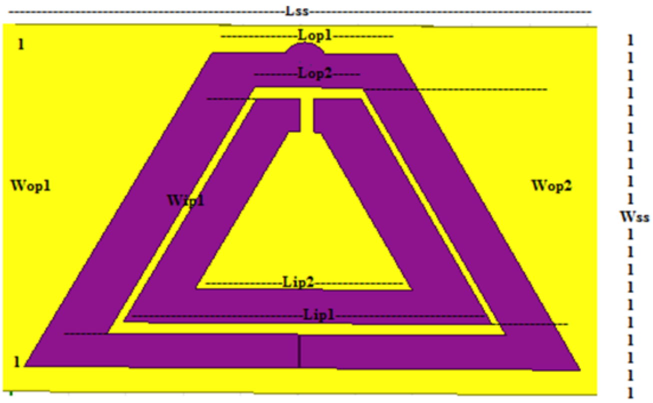

Fig.4. Proposed Design

The patch has been fed by a cylindrical probe that extends to it from the ground. The coaxial feeding technique that has been used employs an inner conductor extending through the dielectric and soldered to the radiating patch while the outer conductor remaining connected to the ground. It is mainly suited for substrates that are not thick.

Table 2. Dimensions of Antenna (in mm)

Dimension	Value (mm)
Length of substrate: Lss	53.1
Width of substrate: Wss	32.7
Length of outer side of outer patch1: Lop1	48.4
Width of outer side of outer patch: Wop1	34
Length of inner side of outer patch 2: Lop2	34.8
Width of inner side of outer patch2: Wop2	9.9
Length of outer side of inner patch1: Lip1	32.1
Width of outer side of inner patch1: Wip1	20
Length of inner side of inner patch 2: Lip2	18.9
Width of inner side of inner patch1: Wip2	14
Length of outer parallel slot, Los	.2
Width of outer parallel slot, W	3
Length of inner parallel slot, Lis	1.2
Width of inner parallel slot, W	3
Thickness of RT Duroid substrate, h0	.7
Radius of the circular Patch element	2

The design has been simulated over HFSS [18], fabricated and finally tested over Vector Network Analyzer [19]. The fabricated structure and the measurement setup have been shown in figures 5 and 6 respectively.

Fig.5. Fabricated Antenna

Fig.6. Testing of Fabricated Antenna

3. Parametric Study

Other than frequency, the performance of an antenna is largely influenced by several other parameters including the patch geometry. The changes made in the geometry of the patch are often reflected in the result parameters which may vary significantly. The effect on the performance of the antenna due to the variation of its different dimensions of the patch has been analyzed. The variations in the dimensions of parallel slots & spacing between inner & outer trapezoids have an impact on antenna characteristics.

3.1.1. Effects due to Parallel Slot

To design an antenna of compact dimensions, the necessary size reduction has been achieved by introducing a pair of slots in antenna design. This has resulted in mild changes in the resonant frequency along with a nearly constant gain. As the length of the slot is increased, there is comparatively less variations in the gain.

3.1.2. Effects due to Change in spacing between the Inner and Outer Slot Pair

The tabulated results indicate that the variations in the gain are small when the spacing between the inner and the outer trapezoids is increased at the left side.

Table 3. Various Dimensions of Outer Parallel Slot Width

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
0.2	3.60	-19. 8	4.6
0.15	3.62	-29.1	4.4
0.25	3.59	-26.3	4.6

Table 4. Various Dimensions of Inner Parallel Slot Width

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
1.25	3.6	-19. 8	4.6
1.2	3.5	-20.2	4.4
1.3	3.6	-21.6	4.6

Table 5. At Left Side (Shifting Outer Trapezium Side)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
.82	3.6	-19. 8	4.6
.62	3.5	-15.0	4.4
1.02	3.6	-13.5	4.6

Table 6. At Left Side (Shifting Inner Trapezium Side)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
.677	3.60	-19. 8	4.6
.477	3.61	-11.3	4.0

Table 7. At Right Side (Shifting Outer Trapezium Side)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
.677	3.60	-19. 8	4.6
.477	3.61	-11.3	4.0
.877	3.57	-17.5	4.3

Table 8. At Left Side (Shifting Inner Trapezium Side)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
.677	3.605	-19. 8	4.6
.477	3.61	-24.1	4.6

Table 9. Bottom (Shifting Inner Trapezium)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
.677	3.605	-19. 8	4.6
.477	3.61	-17.2	4.4
.877	3.565	-19.9	4.6

Table 10. (Top Shifting Outer Trapezium)

Width(mm)	Resonating Freq(GHz)	Reflection Coefficient(dB)	Gain(dB)
1	3.60	-19. 8	4.6
.5	3.64	-22.5	4.7

3.1.3 Effects due to Change in Radius of Circular Element

An increase in the radius of the circular design element of patch produces less varied output as compared to decrease in its radius.

Table 11. Effects of Change in Radius of Circular Element of Patch

Radius(mm)	Resonating Freq. (GHz)	Bandwidth (%)	Gain(dB)
2	3.60	2.8	4.6
2.5	3.63	3.3	4.4

4. Results and Discussion

In this section, the results have been discussed. The design simulations have been carried over HFSS. The reflection coefficient has been validated over VNA. The results have been shown in the figures 6, 7, 8 and 9.

4.1. Reflection Coefficient and Bandwidth

The parametric analysis of the designed structure revealed that the best simulated results were obtained corresponding to the resonant frequency of 3.605 GHz. As seen in Fig. 7, the antenna resonates at a single frequency of 3.605 GHz with a reflection coefficient of -12.6 dB and a bandwidth [20] of 10 MHz ranging from 3.6016 GHz to 3.61078 GHz. The structure, thus, offers single band resonance and may be used for applications including the mobile services, fixed satellite and radiolocation services.

During the fabrication, copper has been etched out of the circular element of the patch. This mismatch of the results is due to this fault in fabrication.

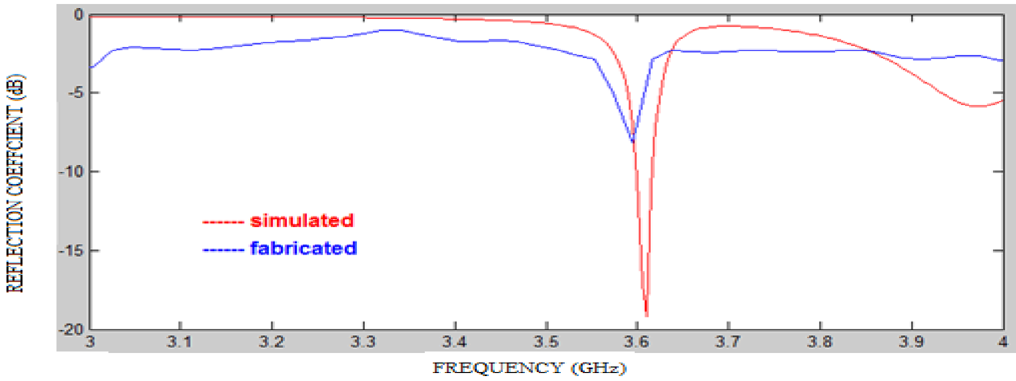

Fig.7. Reflection Coefficient Versus Frequency Plot

4.2. Radiation Pattern

The fig. 8 shows the plot of the overall radiation pattern of the proposed antenna on a dB scale. The upper region of the polar plot has been considered as the radiations are mostly concentrated in this region. The maximum gain [21] (gain total) achieved at resonant frequency was 4.677dB.

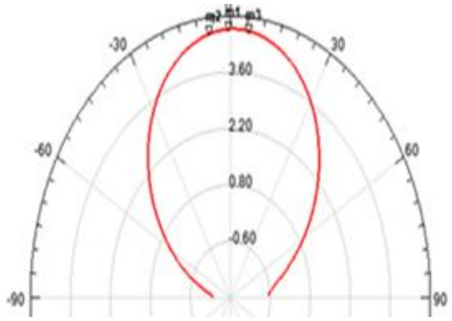

Fig.8. Gain Total plot of radiation pattern [21]

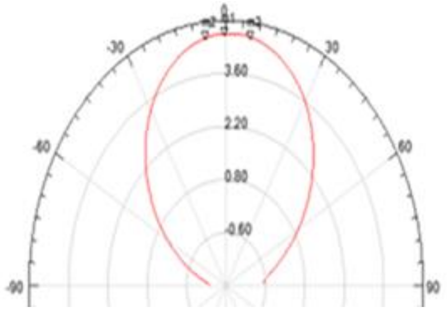

Fig.9. Gain Theta plot of radiation pattern

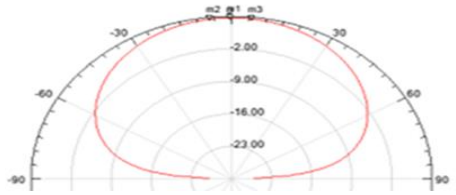

Fig.10. Gain Phi plot of radiation pattern

Also, the gain theta plot indicates the gain in elevation plane for a fixed theta (Theta =0) to be 4.6572 dB and that in Azimuthal plane for a fixed phi (Phi=180) to be 4.6572 dB.

A tabulated comparison of the proposed trapezoidal patch antenna with the other two reference antennas in terms of resonant frequency, gain and reflection coefficient has been shown below. Both the reference antennas (hexagonal and the flower shaped antenna) meant to serve the UWB applications have gains (0.8 dBi and 1.8 dBi) and reflection coefficients (-10.8 dB and -20 dB) that are less than that of the proposed structure that has a gain of 4.7 dB and a reflection coefficient of -22.5 dB. The proposed design is thus efficient in terms of gain and reflection coefficient for S- band space applications.

Table 12. Comparison of the reference antennas and proposed antenna results

Design	Resonant Frequency (GHz)	Gain (dBi)	Reflection Coefficient (dB)
Reference antenna 1 (Proposed UWB Antenna with Hexagon shape)	2.3	0.8	-10.8
Reference antenna 2 (Proposed UWB Antenna with Flower shape)	2.3	1.8	-20
Proposed Trapezoidal Patch Antenna	3.64	4.7	-22.5

5. Conclusions

The proposed antenna has been designed with a great focus over the S band applications. A coaxial feed and a thin RT Duroid 5880 substrate have been utilized. The required reduction in the patch size has been achieved by the incorporation of a pair of parallel slots in the design. The designed antenna achieved a reflection coefficient of -22.5 dB and a peak gain of 4.7 dBi at 3.64 GHz. The design is in particular beneficial to offer a significant frequency range so as to serve for the fixed satellite (space to earth) applications, mobile applications and radio location purpose.

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Deepanshu Kaushal completed his B. Tech. in Electronics & Communication from Punjab Technical University in 2014. He is currently a IInd year M. Tech (E.C.E.) student of Pondicherry University and is doing his project on ‘Microstrip Slotted Patch Antennas for Multiband Operation’ under the guidance of Dr. T. Shanmuganantham (Assistant Professor, Department of Electronics Engineering, Pondicherry University, Pondicherry). His area of interest includes Antennas, Fractals and Metamaterials. He has 19 conference papers and 9 journals till date.

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