Design and Analysis of Different Patch Geometry and Complementary Split Ring Resonator for X-band Applications

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ABSTRACT--- In this paper, a comparative study between the probe feed and strip line feed on a circular, rectangular, triangular and hexagonal Patch Antenna are presented in this paper to compare the performance of antenna parameters. Rectangular and Circular configurations are most popular because they exhibit better characteristics but here triangular and hexagonal shapes are also taken due to advantage of compact size. At later stage, two metamaterial inspired rectangular and circular complementary split ring resonators are proposed and designed using microstrip line feeding to achieve antenna miniaturization. The proposed antennas are structured with flame retardant FR4 Epoxy substrate has thickness h=1.6mm and relative permittivity εr=4.4. The proposed microstrip patch antennas are designed for X-band application. The proposed antennas are implemented and pretended utilizing High Frequency Structure Simulator (HFSS) software version v17.2.

Keywords— Complementary Split Ring Resonator(CSRR), Metamaterial, Probe feeding, strip line feeding, FR4 Epoxy, HFSS, Microstrip Patch Antenna(MPA), X-band

I. INTRODUCTION

Microstrip patch antennas(MPA) are utilized in numerous applications because they have certain advantages like less space occupancy, inexpensive to manufacture and is easy to design when compared to the other antennas. Different kinds of shapes available for patch antennas. In literature traditional shapes like circular and rectangular patch antennas are given more importance. Right now specialists are extremely pulled in by the triangular shape and hexagonal shape than the traditional shapes because of their less size contrasted with old structures. The merits and demerits of each shape is evaluated by comparing their performance parameters. Coaxial probe feeding and microstrip line feeding are used to excite the proposed antennas. These two feeding techniques are utilized to fed the RF power directly to radiating patch utilizing an associated element.

II. ANTENNA DESIGN FORMULAE

A. Selecting a Template (Heading 2)

The formulae utilized in calculating antenna design parameters of circular, rectangular and triangular patch shapes are as shown below.

A. Rectangular Patch Antenna
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\[
\frac{\Delta L}{h^*} = 0.412 \left( \frac{(\varepsilon_{\text{reff}} + 0.3)w^h + 0.264}{(\varepsilon_{\text{reff}} - 0.258)w^h + 0.8} \right)
\]

\[
w = \frac{c}{2f_r \sqrt{\varepsilon_r + 1}}
\]

\[
\varepsilon_{\text{reff}} = \frac{\varepsilon_r + \frac{1}{2} \left( 1 + \frac{12h}{w} \right)^{-\frac{1}{2}}(w^h + 0.264)}{1}\]

\[
W_g = 6h + W
\]

\[
L = \frac{c}{2f_r \sqrt{\varepsilon_{\text{reff}}}} - 2\Delta L
\]

**B. Circular Patch Antenna**

\[
a = \frac{F}{\left\{ 1 + \frac{2h}{n\pi F} \left[ \ln \frac{\pi f}{2h} + 1.7726 \right] \right\}^2} \]

\[
F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}
\]

\[
\varepsilon_{\text{eff}} = \frac{1}{2} \left( \varepsilon_r + 1 \right) + \frac{1}{4} \frac{(\varepsilon_r - 1)}{\sqrt{1 + \frac{12h}{a}}}
\]

\[
a_e = \frac{1.8412c}{2\pi f_r \sqrt{\varepsilon_r}}
\]

**C. Triangular Patch Antenna**

\[
f_r = \frac{ck_{mn}}{2\pi \sqrt{\varepsilon_r}}
\]

\[
k_{mn} = \frac{4\pi}{3a} \sqrt{m^2 + mn + n^2}
\]

The resonant frequency for the m=0, n=1 (fundamental resonant mode) is given by,

\[
f_r = \frac{2c}{3a \sqrt{\varepsilon_r}}
\]

\[
a = \frac{2c}{3f_r \sqrt{\varepsilon_r}}
\]

Where, C is velocity of light

**TABLE 1 Parameters of Patch Antenna from the above formulas**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name of the Parameter</th>
<th>Calculated Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>rectangular patch Length, L</td>
<td>9.12 mm</td>
</tr>
<tr>
<td>2</td>
<td>rectangular patch width, W</td>
<td>7.44 mm</td>
</tr>
<tr>
<td>3</td>
<td>ground Length, Lg</td>
<td>18.72 mm</td>
</tr>
<tr>
<td>4</td>
<td>ground width, Wg</td>
<td>16.02 mm</td>
</tr>
<tr>
<td>5</td>
<td>substrate thickness, h</td>
<td>1.6 mm</td>
</tr>
<tr>
<td>6</td>
<td>Substrate dielectric permittivity, (\varepsilon_r)</td>
<td>4.4</td>
</tr>
<tr>
<td>7</td>
<td>Effective dielectric constant, (\varepsilon_{\text{reff}})</td>
<td>3.67</td>
</tr>
<tr>
<td>8</td>
<td>Resonant frequency, (f_r)</td>
<td>9 GHZ</td>
</tr>
<tr>
<td>9</td>
<td>equilateral triangle patch Side length, a</td>
<td>9.5 mm</td>
</tr>
<tr>
<td>10</td>
<td>circular patch effective radius, (a_e)</td>
<td>4 mm</td>
</tr>
</tbody>
</table>

**III. ANTENNA DESIGN MODEL**

The ground plane has a length (Lg) and width (Wg) is kept consistent for every one of the shapes considered here.
IV. SIMULATED RESULTS AND DISCUSSION

4.1 Rectangular Patch Antenna utilizing coaxial feeding

**RETURN LOSS**

The return loss value for rectangular patch antenna utilizing probe feeding obtained is -31.0034 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 940 MHz.

**VSWR**

The VSWR for rectangular patch antenna utilizing probe feeding obtained value is 1.0580 at a frequency of 9.4 GHz.

**GAIN**

The gain for rectangular patch antenna utilizing probe feeding obtained is 3.4577 dB.

**RADIATION PATTERN**

The radiation pattern value for rectangular patch antenna utilizing probe feeding is 1.1935 V.
4.2 Circular Patch Antenna utilizing probe Feeding

RETURN LOSS

The return loss value for Circular Patch Antenna utilizing probe feeding obtained is -14.5125 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 910 MHz.

VSWR

The VSWR for Circular Patch Antenna utilizing probe feeding obtained value is 1.4633 at a frequency of 9.4 GHz.

GAIN

The gain for Circular Patch Antenna utilizing probe feeding obtained is 3.2479 dB.
**DIRECTIVITY**

The directivity value for Triangular Patch Antenna utilizing probe feeding obtained is 3.7102 dB.

**VSWR**

The VSWR for Triangular Patch Antenna utilizing probe feeding obtained value is 1.5046 at a frequency of 8.9 GHz.

**GAIN**

The gain for Triangular Patch Antenna utilizing probe feeding obtained is 2.7473 dB.

**RADIATION PATTERN**

The radiation pattern for Triangular Patch Antenna utilizing probe feeding is 1.1271 Volts.

**RETURN LOSS**

The return loss value for Hexagonal Patch Antenna utilizing probe feeding obtained is -11.6644 dB at a frequency of 10 GHz. Bandwidth obtained from below graph is 840 MHz.

**VSWR**

The VSWR for Hexagonal Patch Antenna utilizing probe feeding obtained value is 1.7067 at a frequency of 10 GHz.

**GAIN**

The gain for Hexagonal Patch Antenna utilizing probe feeding obtained is 2.8605 dB.
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RADIATION PATTERN
The radiation pattern for Hexagonal Patch Antenna utilizing probe feeding is 0.94388 Volts.

DIRECTIVITY
The directivity value for Hexagonal Patch Antenna utilizing probe feeding obtained is 3.7547 dB.

4.5 Rectangular Patch Antenna utilizing strip Line Feeding

RETURN LOSS
The return loss value for Rectangular Patch Antenna utilizing strip line feeding obtained is -22.5996 dB at a frequency of 8.5 GHz. Bandwidth obtained from below graph is 490 MHZ.

VSWR
The VSWR for Rectangular Patch Antenna utilizing strip line feeding obtained value is 1.1601 at a frequency of 8.5 GHz.

GAIN
The gain for Rectangular Patch Antenna utilizing strip line feeding obtained is 5.9370 dB.

RADIATION PATTERN
The radiation pattern for Rectangular Patch Antenna utilizing strip line feeding is 13.018 Volts.
DIRECTIVITY

The directivity value for Rectangular Patch Antenna utilizing strip line feeding obtained is 7.1400 dB.

Fig.37 Directivity obtained for Rectangular MPA using strip line feeding

RETURN LOSS

The return loss value for Circular Patch Antenna utilizing Strip line feeding obtained is -12.3646 dB at a frequency of 9.4 GHz. Bandwidth obtained from below graph is 410 MHZ.

Fig.38 Return Loss obtained for Circular MPA using strip line feeding

VSWR

The VSWR value for Circular Patch Antenna utilizing Strip line feeding obtained is 1.6346 at a frequency of 9.4 GHz.

Fig.39 VSWR obtained for Circular MPA using strip line feeding

GAIN

The gain for Circular Patch Antenna utilizing Strip line feeding is 3.4577 dB.

Fig.40 Gain obtained for Circular MPA using strip line feeding

RADIATION PATTERN

The radiation pattern for Circular Patch Antenna utilizing Strip line feeding is 5.597 V.

Fig.41 Radiation Pattern obtained for Circular MPA using strip line feeding

DIRECTIVITY

The directivity value for Circular Patch Antenna utilizing Strip line feeding obtained is 6.8944 dB.

Fig.42 Directivity obtained for Circular MPA using strip line feeding

RETURN LOSS

The return loss value for Triangular Patch Antenna utilizing strip line feeding obtained is -30.1583 dB at a frequency of 8.9694 GHz. Bandwidth obtained from below graph is 400 MHZ.

Fig.43 Return Loss obtained for Triangular MPA using strip line feeding
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Fig. 43 Return Loss obtained for Triangular MPA using strip line feeding

VSWR
The VSWR for Triangular Patch Antenna utilizing strip line feeding obtained value is 1.0641 at a frequency of 8.9694 GHz.

Fig. 44 VSWR obtained for Triangular MPA using strip line feeding

GAIN
The gain for Triangular Patch Antenna utilizing strip line feeding obtained is 5.3247 dB.

Fig. 45 Gain obtained for Triangular MPA using strip line feeding

RADIATION PATTERN
The radiation pattern for Triangular Patch Antenna utilizing strip line feeding is 14.289 V.

Fig. 46 Radiation Pattern obtained for Triangular MPA using strip line feeding

DIRECTIVITY
The directivity value for Triangular Patch Antenna utilizing strip line feeding is 6.7556 dB.

Fig. 47 Directivity obtained for Triangular MPA using strip line feeding

4.8 Hexagonal Patch Antenna utilizing strip Line Feeding

RETURN LOSS
The return loss value for Hexagonal Patch Antenna utilizing strip line feeding obtained is -24.4239 dB at a frequency of 9.7085 GHz. Bandwidth obtained from below graph is 530 MHz.

Fig. 48 Return loss obtained for Hexagonal MPA using strip line feeding

VSWR
The VSWR value for Hexagonal Patch Antenna utilizing strip line feeding obtained is 1.1279 at a frequency of 9.7085 GHz.

Fig. 49 VSWR obtained for Hexagonal MPA using strip line feeding

GAIN
The gain for Hexagonal Patch Antenna utilizing strip line feeding obtained is 5.5316 dB.
The radiation pattern for Hexagonal Patch Antenna utilizing strip line feeding is 10.823 V.

The directivity value for Hexagonal Patch Antenna utilizing strip line feeding obtained is 6.8622 dB.

The return loss value for Rectangular Complementary Split Ring Resonator obtained is -21.6873 dB at a frequency of 9.1 GHz. Bandwidth obtained from below graph is 310 MHz.
DIRECTIVITY

The directivity value for Rectangular Complementary Split Ring Resonator obtained is 6.7281 dB.

Fig.57 Directivity obtained for Rectangular CSRR

4.10 Circular Complementary Split Ring Resonator:

RETURN LOSS

Multiband operation obtained for Circular complementary Split Ring Resonator Antenna. The return loss value for first band of Circular complementary Split Ring Resonator Antenna obtained at 10 GHz is -10.9554 dB at a frequency of 10 GHz. Bandwidth obtained for first band from below graph is 130 MHz. The return loss value for second band of Circular complementary Split Ring Resonator Antenna obtained at 11.4 GHz is -22.3030 dB at a frequency of 11.4 GHz. Bandwidth obtained for second band from below graph is 360 MHz.

Fig.58 Return loss obtained for Circular CSRR

VSWR

The VSWR value for first band of Circular complementary Split Ring Resonator Antenna obtained is 1.7905 at a frequency of 10 GHz. The VSWR value for second band of Circular complementary Split Ring Resonator Antenna obtained is 1.1662 at a frequency of 11.4 GHz.

Fig.59 VSWR obtained for Circular CSRR

GAIN

The gain for Circular complementary Split Ring Resonator Antenna obtained is 4.9004 dB.

Fig.60 Gain obtained for Circular CSRR

RADIATION PATTERN

The radiation pattern for Circular complementary Split Ring Resonator Antenna is 6.5245 V.

Fig.61 Radiation Pattern obtained for Circular CSRR

DIRECTIVITY

The directivity value for Circular complementary Split Ring Resonator Antenna obtained is 6.7603 dB.

Fig.62 Directivity obtained for Circular CSRR
V. RESULT ANALYSIS

Simulations results of antenna performance parameters are given table 2 and table 3.

<table>
<thead>
<tr>
<th>TABLE 2: SIMULATIONS RESULTS OF ANTENNA PERFORMANCE PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resonant frequency (GHz)</td>
</tr>
<tr>
<td>--------------------------</td>
</tr>
<tr>
<td>Rectangular Patch using coaxial feed</td>
</tr>
<tr>
<td>Circular Patch using coaxial feed</td>
</tr>
<tr>
<td>Triangular Patch using coaxial feed</td>
</tr>
<tr>
<td>Hexagonal Patch using coaxial feed</td>
</tr>
<tr>
<td>Rectangular Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Circular Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Triangular Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Hexagonal Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Rectangular complementary split ring resonator</td>
</tr>
<tr>
<td>Circular complementary split ring resonator</td>
</tr>
<tr>
<td>Rectangular Patch using Microstrip line feed</td>
</tr>
</tbody>
</table>

From the above results it is obtained that with all patch designs rectangular patch with coaxial feeding and triangular patch with microstrip line feeding has better return loss compared to other designs.

Rectangular, circular and triangular patch using microstrip line feeding has more gain when compared to rectangular, circular and triangular patch using coaxial feeding.

Rectangular patch using microstrip line feeding has better directivity compared to other patch designs.

Rectangular Patch using probe feed, circular patch using probe feed has better bandwidth compared to other patch designs.

Rectangular complementary split ring resonator and circular complementary split ring resonator have more gain when compared to rectangular, circular and triangular patch using probe feeding.

Better directivity and gain obtained for rectangular complementary split ring resonator and circular complementary split ring resonator even though it has less metalized area on the substrate. So rectangular and circular complementary split ring resonator requires less cost compared to remaining antennas.

VI. CONCLUSION

In this paper, Rectangular, circular, triangular and hexagonal patch antenna with probe feed and strip line feed are designed and analyzed. At later stage, two meta-material inspired SRR-loaded antennas, rectangular complementary split ring resonator and circular complementary split ring resonator are designed and analyzed. Each shape has its own advantages in any of the antenna performance parameters for X-band application. From the above results the rectangular patch antenna provides better performance parameters as compared to other designs.

The fundamental objective for the X-band application is high directivity and high gain and is accomplished by rectangular patch antenna utilizing strip line feeding. Wider bandwidth is achieved by the rectangular patch antenna using Microstrip line feed.

<table>
<thead>
<tr>
<th>TABLE 3: SIMULATIONS RESULTS OF ANTENNA PERFORMANCE PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Directivity (dB)</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
<tr>
<td>Rectangular Patch using coaxial feed</td>
</tr>
<tr>
<td>Circular Patch using coaxial feed</td>
</tr>
<tr>
<td>Triangular Patch using coaxial feed</td>
</tr>
<tr>
<td>Hexagonal Patch using coaxial feed</td>
</tr>
<tr>
<td>Rectangular Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Triangular Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Hexagonal Patch using Microstrip line feed</td>
</tr>
<tr>
<td>Rectangular complementary split ring resonator</td>
</tr>
<tr>
<td>Circular complementary split ring resonator</td>
</tr>
</tbody>
</table>

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using probe feeding. Triangular patch antenna using strip line feeding provides finest return loss, gain and directivity even though it has compact size compared to rectangular and triangular.

Meta-material inspired rectangular complementary split ring resonators (CSRR) has obtained finest return loss, directivity, gain and radiation pattern compared to remaining antennas. Circular complementary split ring resonator (CSRR) has obtained dual band in X-band frequency range. Hence the rectangular complementary split ring resonator (CSRR) and circular complementary split ring resonator (CSRR) has obtained finest results even though it occupies less metalized area on substrate.

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REFERENCES