Abstract—A single probe-fed square patch antenna cut from a rectangular patch, having symmetric pattern of T slots is designed. The software used to model and simulate the microstrip patch antenna is Zeland Inc’s IE3D software. IE3D is a full-wave electromagnetic simulator based on the method of moments. The proposed antenna is capable of generating resonant frequency with single feeds. The 50Ω feed position can be achieved by the feed points placed along the axis of the square patch. Experimental result for the characteristics of microstrip antenna are presented and discussed in this paper.

Index Terms—MSA (Microstrip antenna), RMSA (Rectangular microstrip antenna), LP (linear Polarization).

I. MICROSTRIP PATCH ANTENNA

Patch antennas play a very significant role in today’s world of wireless communication systems. The prospect of this design is to obtain a small size, light weight and low cost miniaturized antenna with good antenna characteristics and ease of integration using feed-network.

II. RECTANGULAR MICROSTRIP PATCH ANTENNA

A RMSA is design for a resonant frequency of 2.4 GHz. This RMSA is cut into square patch having T slots of unequal length and width to get a symmetric pattern so as to reduce the total area on the patch. There are numerous methods to increase the bandwidth of antennas, including increase of the substrate thickness and the use of a low dielectric substrate, hence duoroid having \( r = 2.4, \) thickness \( h = 1.58 \text{mm} \) is selected. This paper presents linearly polarized microstrip antenna for wireless communication system which is suitable for the 2.217GHz of operation as shown in fig.1a and fig.1b.

![Patch Antenna Layout](image1)

![Patch Antenna with co-axial feed](image2)

Fig.1 a. Patch Antenna Layout         Fig.1 b. Patch Antenna with co-axial feed

First a rectangular patch antenna is designed using the following design equations [1]

1. Width of patch:
   \[ W = \frac{c}{2f_0 \sqrt{\varepsilon_r} + 1} \]  

2. Effective dielectric constant:
   \[ \varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} [1 + \frac{10h}{W}]^{-0.5} \]

3. Resonant frequency:
   \[ f_0 = \frac{c}{2\sqrt{\varepsilon_e}} \left( \frac{m}{L} \right)^2 + 2 \left( \frac{n}{W} \right)^2 \]  

where:
- \( c = 3 \times 10^8 \text{ m/s} \)
- \( h = \text{height of substrate} \)
- \( r = \text{dielectric constant of the substrate} \)

Effective length is given by
\[ L_e = L + 2\Delta L = \left[ \frac{\lambda}{2\sqrt{\varepsilon_r}} \right] \]

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Square patch from Rectangular Patch:
This rectangular patch is than cut in the form of a square having length \( L_s = 39 \text{ mm} \) and width \( W_s = 39 \text{ mm} \) reducing the surface edges. The square patch integrates four T shaped slots which form a symmetric pattern on the x and y axis. The co-ordinates at which the four cross slot are placed are: T shape 1 \( (x = 0, y = 13.5), \) T shape 2 \( (x = 0, y = -13.5), \) T shaped 3 \( (x = 13.5, y = 0) \) and T shaped 4 \( (x = -13.5, y = 0) \).

For the rectangular patch cut into square patch the area reduces by 18.75%. Furthermore, T shaped slots etched in the
square patch reduces the surface area of the proposed antenna.

This rectangular patch is then cut in the form of a square patch having length \( L_s = 39 \text{mm} \) and width \( W_s = 39 \text{ mm} \) reducing the surface edges. The square patch integrates four T slots on the x axis and y axis. For the rectangular patch cut into square patch the area reduces by 18.75%. Furthermore, T slots are etched in the square patch reduces the surface area of the proposed antenna. The calculation of patch dimensions is based on the transmission line model [2]. A substrate of low dielectric constant is selected to obtain a compact radiating structure that meets the demanding bandwidth specification [3].

Coupling of power through a probe is one of the basic mechanisms for the transfer of microwave power. The probe can be an inner conductor of a coaxial line in the case of coaxial line feeding. The coaxial cable is attach to the back side of the printed circuit board and coaxial center conductor after passing through the substrate is soldered to the patch metalization. The location of the feed is determined for the given mode so that the best impedance match is achieved. Excitation of the patch is achieved through the coupling of the feed current \( J_z \) to the \( E_z \) field of the patch mode [3], [4]. The coupling constant can be obtained as:

\[
\text{Coupling} = \iiint E_z J_z dv \quad (5)
\]

\[
= \cos (\pi x o L) \quad (6)
\]

where \( L = \text{resonant length of the patch} \)

\( X_o = \text{offset of the feed point from the patch edge} \).

The above expression shows that coupling is maximum for a feed located at a radiating edge of the patch (\( X_o = 0 \) or \( L \)).

After selecting the patch dimensions \( L \) and \( W \) for a given substrate, the next task is to determine the feed location (\( x_o, y_o \)) so as to obtain a good impedance match between the generator impedance and the input impedance of the patch element. It is observed that the change in feed location gives change in impedance hence provides a simple method for impedance matching [5]. We see that if the feed is located \( x_o = x_f \) and \( 0 \leq y_f \leq W \), the input resistance at resonance for the dominant mode \( \text{TM}_{10} \) mode can be expressed as

\[
R_{in} = R_c \cos^2 \left( \frac{\pi x_f L}{L} \right) \quad R_r \gg R_{in} \quad (7)
\]

where \( x_f \) is the inset feed distance from the radiating edge and \( R_r \) is the radiation resistance at resonance when the patch is fed at a radiating edge. The radiation resistance \( R_r \) with an estimated accuracy of 10% average for \( h \leq 0.03\lambda_0 \) and \( \varepsilon_r \leq 10 \) are given as

\[
R_r = \frac{V_0^2}{2P_R} \quad (8)
\]

\[
= \varepsilon_{re} Z_o 120f_2 \quad (9)
\]

where \( Z_o \) is the characteristic impedance of which the patch is a segment.

The inset distance is selected such that \( R_{in} \) is equal to the feed line impedance, usually taken to be 50\( \Omega \). Although the feed point can be selected anywhere along the patch with, it is better to choose \( y_f = W/2 \) if \( W \gg L \) so that \( \text{TM}_{\text{odd}} \) modes are not excited along with the \( \text{TM}_{10} \) mode [6]. Determination of exact feed point requires an iterative solution for impedance to match. The above equation provides a useful solution for the purpose. Kara has suggested an expression for \( x_f \) that does not need calculation of radiation resistance [4]. It is approximately given as

\[
X_f = \frac{L}{2} \sqrt{\varepsilon_{re}(L)} \quad (10)
\]

where \( \varepsilon_{re}(L) \) is defined

\[
\varepsilon_{re}(L) = \left[ (\varepsilon_r+1)/2 \right] + \left[ (\varepsilon_r-1)/2 \right] F(L/h) \quad (11)
\]

Radiation Efficiency \( \varepsilon_r \): The radiation efficiency is defined as the ratio of radiated power \( P_r \) to the input power \( P_i \), that is

\[
\varepsilon_r = \frac{P_r}{P_i} \quad (12)
\]

The input power gets distributed in the form of radiated power, surface wave power, and dissipation in the conductors and dielectric [5], [7].

It has been observed that radiation efficiency depends on the substrate thickness and permittivity, and is not effected very much either by the patch shape or feed. Numerical values indicate that radiation efficiency is almost independent of aspect ratio \( W/L \) of the rectangular patch [6], [7].

**BANDWIDTH:** If the antenna input impedance can be matched to its feeding structure across a certain frequency range, that frequency range will define the antenna bandwidth (BW) [4], [7], [8]. The bandwidth can be specified in terms of the return loss or the voltage standing wave ratio (VSWR). The typical values for micro strip antennas are VSWR < 2 or return loss (\( S_{11} \) in db) < -10db [9]. Furthermore, the BW is inversely proportional to the quality factor \( Q \) and given by

\[
BW = \frac{VSWR - 1}{Q \sqrt{VSWR}} \quad (13)
\]

The minimum quality factor is given by

\[
Q_{\text{min}} = \frac{1 + 3(k_0R)^2}{(k_0R)^2} 3 \left[ 1 + (k_0R)^2 \right] \quad (14)
\]

where \( R \) is the minimum sphere radius which completely encloses the antenna.
IV. GEOMETRY AND DESIGN PROCEDURE

The proposed design structure incorporates four T slots pattern providing linear polarization with single feed. The Table I shows the parameter of the proposed patch antenna.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>39mm</td>
</tr>
<tr>
<td>W</td>
<td>48mm</td>
</tr>
<tr>
<td>Area of RMSA</td>
<td>1872mm²</td>
</tr>
<tr>
<td>Ls</td>
<td>39mm</td>
</tr>
<tr>
<td>Ws</td>
<td>39mm</td>
</tr>
<tr>
<td>Slot 1</td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>15mm</td>
</tr>
<tr>
<td>W1</td>
<td>3mm</td>
</tr>
<tr>
<td>Slot 2</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>10mm</td>
</tr>
<tr>
<td>L2</td>
<td>3mm</td>
</tr>
<tr>
<td>Total Area</td>
<td>1221mm²</td>
</tr>
</tbody>
</table>

V. SIMULATED RESULTS

The behaviour of the antenna is simulated and optimized using Zeland IE3D software. The IE3D (Zeland Software) is an integrated full wave electromagnetic simulation and optimization package for the analysis and design of microstrip antennas based on method-of-moments.

![Graph of Impedance vs. frequency for Patch Antenna](image1)

Impedance=50 Ohms at frequency=2.217GHz

![Graph of return loss vs. frequency for patch antenna](image2)

Return Loss=-18.5dB at frequency=2.217GHz

![Graph of Directivity vs. Frequency for Patch Antenna](image3)

Directivity=7.3dBi at frequency=2.217GHz

![Graph of Gain vs. Frequency for Patch Antenna](image4)

Gain=6.2dBi at frequency=2.217GHz
Fig. 5. 2-D Radiation Pattern (Elevation and Azimuth Pattern)

Fig. 6. 3-D Radiation Pattern

Fig. 7. 3-D Radiation Pattern (Mapped 3-D)

Fig. 8. 3-D Radiation Pattern (True 3-D)

Fig. 9. Smith Chart

Fig. 10. Graph of Radiation Efficiency for Patch Antenna
Radiation Efficiency = 79% at frequency = 2.217GHz
VI. CONCLUSION

A compact microstrip antenna with a single feed placed on the axis is presented. After simulation, 2.217GHz frequency operation obtained can be subjected to various applications in today’s modern wireless communication world. The above antenna geometry allows linear polarization of the radiated field by appropriately locating the feeds. In the proposed design a size reduction of 34.78% is been achieved with a VSWR= 1.28 and radiation and antenna efficiency of 79% and 78.2% respectively.

REFERENCES


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