Chapter 5

Bandwidth Enhancement of Microstrip Patch Antennas 
by Loading Slots

In this chapter, an attempt has been made to enhance impedance bandwidth of a rectangular patch antenna by loading a slots and shorting pin on the patch. Using this bandwidth enhancement techniques two antenna structures have been proposed, first one is dual inverted C-slot patch antenna and second one is π-shaped slot loaded patch antenna. The proposed antenna structures are analyzed using circuit theory concept based modal expansion cavity model and results are verified with simulation and experimental observations. The antenna characteristics such as return loss, gain, efficiency and radiation pattern have been presented at various frequencies.

5.1 Introduction

Microstrip patch antenna for broadband operation can be achieved by following techniques. First multi patch structures which include stacking and coplanar structures, second different feeding techniques which include coaxial, proximity, aperture and microstrip line feed and third is metamaterial substrate and photonic band gap structures. But some of these broad banding techniques increase the size of the antenna either in the horizontal or vertical directions. The loading of slot, notch, stub, shorting pin, shorting wall and capacitors increases the bandwidth without increasing the area of the geometry. Therefore, a number of structures based on slot and shorting pin loading techniques have been reported by the researchers such as V-slot [1], half U-slot [2,3], M-slot [4], L-shaped slot, stepped U-slot, half stepped U-slot, compact shorted square and edge center shorted square with stepped slot [5], C-shaped [6], plus shaped [7], cross-shaped [8] and multi slotted microstrip patch antenna [9].
The first and second sections of this chapter present the analysis of dual inverted C-slot and π-shaped slot loaded rectangular patch antennas. The proposed antennas have provided wide bandwidth with and without notch band characteristics respectively. The details about the antenna structures, design specifications, analytical methods and results are discussed in the following sections.

5.2 Dual Inverted C-slot loaded Patch Antenna

Compact shorted rectangular patch antenna with dual inverted C-slot has been analyzed using cavity model in this section. The improvement in bandwidth and antenna miniaturization has been achieved by using slot and shorting pin. The theoretical and simulated results are verified experimentally. Complete descriptions of proposed antennas are presented below.

5.2.1 Antenna Design and Analysis

The geometry of proposed antenna for wideband characteristics is shown in Figure 5.1. An antenna shown in figure is a simple rectangular patch antenna of dimension \((L\times W)\) and separated from ground plane with a foam substrate \((\varepsilon_r = 1.07)\) of thickness \((h)\). An inverted C-slot with dimension \((L_1 \times L_{b1} \times W_{v1})\) and \((L_2 \times L_{b2} \times W_{v2})\) incorporated in the middle of the patch. So, the arms are symmetrically positioned with respect to the feed point \((X_0, Y_0)\) and shorting pin \((X_s, Y_s)\). The probe feed and shorting pin are located close to the center of the patch for good excitation of the antenna.

The current distribution of the proposed antenna structure is shown in Figure 5.2. From the figure, it is clearly seen that due to the effect of slot and shorting pin maximum current is achieved near the slot and whole currents are flowing towards the shorting pin.
Bandwidth Enhancement of Microstrip Patch Antennas by Loading Slots

**Figure 5.1.** Geometry of the shorted inverted C-shaped patch antenna (a) Top view (b) Side view

**Figure 5.2.** Current distributions of the proposed antenna $f_r = 2.2\,\text{GHz}$

Rectangular patch is considered as a parallel combination of capacitance $C_1$, inductance $L_1$ and resistance $R_1$ are shown in Figure 5.3. The values of $R_1, L_1$, and $C_1$ can be calculated as [10].
Figure 5.3. Equivalent Circuit of the rectangular patch antenna

C-slot can be considered as a combination of three slots as shown in Figure 5.1. Among these, two slots are of the arms of the C-slot and these are vertical. The third one is the base of the C-slot and it is horizontal [11]. The equivalent circuit of a narrow slot comprises a series combination of the radiation resistance $R_c$ and reactive components $X_c$ as shown in Figure 5.4.

Figure 5.4. Equivalent Circuits of the (a) Slot and (b) proposed antenna

Therefore, the impedance of the vertical slot can be given as

$$Z_{cv1} = R_{cv} + jX_{cv}$$

where,

$$R_{cv} = 60E + \ln(kL_{V1}) + \frac{1}{2} \sin(kL_{V1}) \left[ S_i(2kL_{V1})2S_i(kL_{V1}) \right]$$

$$+ \frac{1}{2} \cos(kL_{V1}) \left[ C + \ln \left( \frac{kL_{V1}}{2} \right) + C_i(2kL_{V1})2C_i(kL_{V1}) \right]$$

(2)
and

\[
X_{cv} = 30 \cos^2 \alpha \left\{ \frac{2S_i(k_{L_{V_1}}) + \cos(k_{L_{V_1}})\left[2S_i(k_{L_{V_1}}) - S_i(2k_{L_{V_1}}) - \sin(k_{L_{V_1}})\right]}{2C_i(k_{L_{V_1}}) - C_i(2k_{L_{V_1}}) - C_i\left(\frac{2k_{W_{V_1}}^2}{L_{V_1}}\right)} \right\}
\tag{3}
\]

in which, \( E \) is Euler's constant = 0.5772, \( k \) is propagation constant in free space, \( S_i \) and \( C_i \) are the sine and cosine integrals defined as

\[
S_i(x) = \int_0^x \frac{\sin t}{t} \, dt
\tag{4}
\]

and

\[
C_i(x) = \int_x^\infty \frac{\sin t}{t} \, dt
\tag{5}
\]

Similarly the impedance of the base slot can be calculated as

\[
Z_{cb} = R_{cb} + jX_{cb}
\tag{6}
\]

Where,

\[
R_{cb} = 60E + \ln(k_{L_{B_1}}) + \frac{1}{2} \sin(k_{L_{B_1}})\left[2S_i(2k_{L_{B_1}}) - S_i(k_{L_{B_1}})\right]
+ \frac{1}{2} \cos(k_{L_{B_1}})\left[C + \ln\left(\frac{k_{L_{B_1}}}{2}\right) + C_i(2k_{L_{B_1}}) - 2C_i(k_{L_{B_1}})\right]
\tag{7}
\]

and

\[
X_{cb} = 30 \cos^2 \alpha \left\{ \frac{2S_i(k_{L_{B_1}}) + \cos(k_{L_{B_1}})\left[2S_i(k_{L_{B_1}}) - S_i(2k_{L_{B_1}}) - \sin(k_{L_{B_1}})\right]}{2C_i(k_{L_{B_1}}) - C_i(2k_{L_{B_1}}) - C_i\left(\frac{2k_{W_{B_1}}^2}{L_{B_1}}\right)} \right\}
\tag{8}
\]

Where,

\( L_{V_1} \) and \( W_{V_1} \) = length and width of the vertical slot,
\( L_{B_1} \) and \( W_{B_1} \) = length and width of the base slot
\( R_{CV} \) and \( X_{CV} \) = Radiation resistance and reactive component of the vertical slot
\( R_{CB} \) and \( X_{CB} \) = Radiation resistance and reactive component of the base slot
\( Z_{CV} \) and \( Z_{CB} \) = Input impedance of the vertical and base slot

Similarly the impedance of the C-slot 2 can be obtained by putting its dimensions in equation (1) and (6).

Hence the total input impedance of the shorted dual inverted C-slot loaded patch antenna can be calculated from Figure 5.5.
Figure 5.5. Modified equivalent circuits of the proposed antenna

\[
Z_{in} = \frac{Z_p Z_{C1} Z_{C2} Z_s}{Z_{C1} Z_{C2} Z_s + Z_p Z_{C2} Z_s + Z_p Z_{C1} Z_s + Z_p Z_{C1} Z_{C2}}
\]  

(9)

where,

\[Z_{C1} \text{ and } Z_{C2}\] is the impedance of the C-slot1 and C-slot2 can be calculated from Figure 5.4(b).

\[
Z_{C1} = \frac{Z_{CV1} + 2Z_{CB1}}{Z_{CV1} Z_{CB1}}
\]  

(10)

\[
Z_{C2} = \frac{Z_{CV2} + 2Z_{CB2}}{Z_{CV2} Z_{CB2}}
\]  

(11)

\[Z_p\] is the impedance of the simple rectangular patch calculated from Figure 5.3

\[
Z_p = \frac{1}{\frac{1}{R_1} + \frac{1}{j \omega L_1} + j \omega C_1}
\]  

(12)

\[Z_s\] is the impedance of the shorting pin

\[
Z_s = \frac{1}{j \omega L_s}
\]  

(13)

Where,

\[
L_s = \frac{\eta_0 \omega h}{2 \pi c} \ln \left[ \frac{4 c}{E \omega d \sqrt{\varepsilon_s}} \right]
\]  

(14)

d is the diameter of shorted pin, \(E\) is the Euler constant, \(\eta_0 = 120 \pi \Omega\), \(c\) is the velocity of light \((3 \times 10^8 m/s)\).
5.2.2 Radiation Pattern

The radiation pattern of the dual inverted C-slot loaded shorted patch antenna can be calculated as [12]

\[
E(\theta) = -\frac{j k_0 W e^{-jk_0 r}}{\pi r} \cos(k h_1 \cos \theta) \frac{\sin(k_0 L \sin \theta \sin \phi)}{k_0 W} \frac{\sin \phi}{\sin \theta \sin \phi} \frac{\cos \left(\frac{k_0 L}{2} \sin \theta \sin \phi\right) \cos \phi}{\cos \left(\frac{k_0 L}{2} \sin \theta \sin \phi\right) \cos \phi} (0 \leq \theta \leq \pi / 2)
\]

(15)

\[
E(\phi) = -\frac{j k_0 W e^{-jk_0 r}}{\pi r} \cos(k h_1 \cos \theta) \frac{\sin(k_0 L \sin \theta \sin \phi)}{k_0 W} \frac{\sin \phi}{\sin \theta \sin \phi} \frac{\cos \left(\frac{k_0 L}{2} \sin \theta \sin \phi\right) \cos \phi}{\cos \left(\frac{k_0 L}{2} \sin \theta \sin \phi\right) \cos \phi} (0 \leq \theta \leq \pi / 2)
\]

(16)

Where,

\[ V \] is radiating edge voltage

\[ r \] is the distance of an arbitrary point

\[
k = k_0 \sqrt{\varepsilon_r}
\]

\[
k_0 = \frac{2\pi}{\lambda}
\]

5.2.3 Gain and Efficiency

Gain of the proposed antenna structures are calculated as [10, 13]

\[
G = \eta \cdot D
\]

(17)

\[ D \] is the directivity of the proposed antenna defined as

Where,

\[
D = \frac{4W}{I_1 \lambda_0^2}
\]

(18)

and,

\[
I_1 = \int_0^\pi \sin^2 \left(\frac{k_0 W \cos \theta}{2}\right) \tan^2 \theta \sin \theta d\theta
\]

\[ \eta \] is the efficiency of the antenna, defined as the ratio of the radiated power to the input power may be expressed as

\[
\eta = \frac{R_r}{R_d}
\]

(19)

Where,
\[ R_r = \frac{1}{2 \omega_1 C_1} \]  

and

\[ R_T = \frac{Q_r}{\omega C_1} \]  

(20)

(21)

\(Q_r\) is the quality factor of the antenna.

### 5.2.4 Design Parameters

**Table 5.1. Design specifications of dual inverted C-slot patch antenna**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dielectric constant of the materials used ((\varepsilon_r))</td>
<td>1.07 foam</td>
</tr>
<tr>
<td>Thickness of substrate used ((h))</td>
<td>10.0mm</td>
</tr>
<tr>
<td>Length of the rectangular patch ((L))</td>
<td>30.0mm</td>
</tr>
<tr>
<td>Width of the rectangular patch ((W))</td>
<td>15.0mm</td>
</tr>
<tr>
<td>Length of the vertical slot 1 ((L_{v1}))</td>
<td>8.0mm</td>
</tr>
<tr>
<td>Width of the vertical slot 1 ((W_{v1}))</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Length of the base slot 1 ((L_{b1}))</td>
<td>8.0mm</td>
</tr>
<tr>
<td>Width of the base slot 1 ((W_{b1}))</td>
<td>5.0mm</td>
</tr>
<tr>
<td>Length of the slot 2 ((L_{v2}))</td>
<td>5.0mm</td>
</tr>
<tr>
<td>Width of the slot 2 ((W_{v2}))</td>
<td>0.5mm</td>
</tr>
<tr>
<td>Length of the base slot 2 ((L_{b2}))</td>
<td>4.5mm</td>
</tr>
<tr>
<td>Width of the base slot 2 ((W_{b2}))</td>
<td>6.5mm</td>
</tr>
<tr>
<td>Position of shorting pin ((X_s, Y_s))</td>
<td>(1.5,0)mm</td>
</tr>
<tr>
<td>Feed point ((X_f, Y_f))</td>
<td>(-2.5,0)mm</td>
</tr>
</tbody>
</table>

### 5.2.5 Designed Antenna Characteristics
Figure 5.6. Comparative plot of proposed antenna structures

Figure 5.7. Comparative plot of return loss with frequency along with theoretical, simulated and experimental results of proposed ANTENNA3
Figure 5.8. Variation of return loss with frequency for different values of vertical length

Figure 5.9. The theoretical and simulated gain versus frequency plot of proposed antenna
Figure 5.10. The theoretical and simulated radiation pattern for the proposed antennas

5.2.6 Discussion of Results

There the three antenna structures are shown in Figure 5.6. ANTENNA 1 is the shorted rectangular patch, ANTENNA 2 is the shorted rectangular patch with single C-slot and ANTENNA 3 is the shorted rectangular patch with inverted dual C-slot. It is observed from the figure that the bandwidth of the antennas are almost same but the resonant frequency of each antenna depends on the antenna structures. The resonant frequencies for ANTENNA 1, ANTENNA 2 and ANTENNA 3 are 3.1GHz, 2.75GHz and 2.2 GHz respectively.

The comparative plot of variation of return loss with frequency for shorted inverted dual C-slot rectangular patch antenna is shown in Figure 5.7 along with experimental [14] and simulated results using IE3D [15]. From the figure, it is observed that the theoretical and measured bandwidth of the proposed antenna is found to be 7.6% and 5.4% respectively. The theoretical results deviate from simulated and experimental results, due to approximations have taken in cavity model analysis.
The variations of return loss with frequency for different vertical lengths \((L_{v1})\) of C-slot 1 are shown in Figure 5.8 and that plays a crucial role in controlling the resonance frequency and bandwidth of the antenna. It is found that on increasing the vertical length graph is shifted towards lower frequency side. Similar types of results are obtained for C-slot 2 vertical length variations.

Figure 5.9 shows gain verses frequency plot for proposed antenna. The maximum achievable peak gain is 3.8dBi and the theoretical and simulated results are in close agreement.

Figure 5.10 shows the radiation pattern of the proposed antenna along with simulated results. It is observed from the figure that the antenna radiates in broadside direction.

5.3 Pair of π-Shaped Slot Loaded Patch Antenna

The motive of the present work is to obtain a wideband frequency notched characteristics of the antenna by loading a pair of π-shaped slot and shorting pin on the patch. The area of all three antenna structures are kept approximately same and their slots effect on antenna bandwidth are studied. The proposed antenna structures are theoretically analyzed, simulated using IE3D and these results are verified experimentally. Before discussing the characteristics of designed antenna, first of all analysis and design considerations of proposed antenna are presented.

5.3.1 Antenna Design and Equivalent Circuit

The geometrical configurations of the three resonating patch antennas are shown in Figure 5.11, in which the effect of loading a slot on the patch has been studied. The Antenna 1 is a shorted π-shape slot loaded patch antenna, Antenna 2 is the pair of π-shape slot loaded patch antenna and Antenna 3 is the triple π-shape slot loaded patch antenna. The resonant frequencies are adjusted by antenna dimensions. The appropriate design parameters are given in Table 5.2.
Figure 5.12 shows the photograph of the fabricated proposed Antenna 2, where \( L \times W \) is the dimensions of the rectangular patch. The patch is separated from the ground plane with a foam substrate of thickness \( h \) and patch is excited by SMA connector. The inner and outer conductor of the connector is connected to the patch and the ground plane. The slots are symmetrically positioned with respect to the feed point \((x_f, y_f)\) and shorting pin \((x_s, y_s)\).

**Figure 5.11.** Geometry of the shorted (a) \( \pi \)-shaped slot loaded patch antenna (b) Pair of \( \pi \)-shaped slot loaded patch antenna (c) three \( \pi \)-shape slot loaded patch antenna (d) Side View of the proposed antenna geometries
Bandwidth Enhancement of Microstrip Patch Antennas by Loading Slots

Figure 5.12. Photograph of the fabricated antenna

The current distribution of the proposed Antenna 2 is observed at frequencies 0.86GHz and 1.25GHz as shown in Figure 5.13. From the figure, it is observed that when slots and shorting are incorporated on the patch, it alters the resonating behavior of the initial patch. Thus, on the initial patch current of different lengths, directions and strengths flows along the slots and shorting pin that is responsible for broad bandwidth with frequency notched characteristics.

![Current Distribution](image)

(a) $f_r = 0.86 \text{ GHz}$

(b) $f_r = 1.25 \text{ GHz}$

Figure 5.13. Current distribution of the Pair of $\pi$-shaped slot loaded patch antenna

The proposed Antenna 2 is considered as a combination of five slots, in which four slots are the arms of the $\pi$ shape and fifth one is the base of the $\pi$ shape [12]. The equivalent circuit of the proposed Antenna 2 is shown in Figure 5.14.
For calculating the impedance of the slot the dimensions of the π-shaped slots are putting in equation (1) and (6). From the Figure 5.11(b) and Table 5.2, it is clearly seen that slot1 and slot2 are having same dimensions while slot3 and slot4 are having same dimensions. Thus, the impedance of the slot1 and 2 and slot3 and 4 will be equal as \((Z_{V_1} = Z_{V_2})\) and \((Z_{V_3} = Z_{V_4})\) respectively. Similarly impedance of the base is calculated and it is defined as \((Z_B)\).

**Figure 5.14** Equivalent circuits of the proposed Antenna2.

When shorting pin is loaded on the patch, a parallel inductance \(L_s\) is added with the antenna circuit as shown in Figure 5.14. The value of \(L_s\) is calculated by using equation (14).

The proposed antenna can be considered as a parallel combination of impedances of the patch, slots and shorting pin. The modified version of the Figure 5.14 is shown in Figure 5.15. From this figure, the total input impedance is calculated as

\[
Z_{in} = \frac{Z_pZ_NZ_s}{Z_pZ_s + Z_NZ_s + Z_pZ_N}
\]  

(22)

in which,

- \(Z_p\) is the impedance of the patch,
- \(Z_N\) is the impedance of the slots and
- \(Z_s\) is the shorting pin impedance and they are calculated as
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\[ Z_p = \frac{1}{\frac{1}{R_1} + j\omega C_1 + \frac{1}{j\omega L_1}} , \quad Z_S = j\omega L_i \quad \text{and} \quad Z_N = \frac{Z_{V_i} Z_{V_3} Z_B}{2Z_B (Z_{V_1} + Z_{V_3}) + Z_{V_1} Z_{V_3}} \]

![Equivalent Circuit Diagram]

**Figure 5.15.** Modified equivalent circuits of the proposed Antenna2

For the theoretical analysis of the radiation pattern the dimensions of the proposed Antenna 2 are put in equation (15) and (16).

### 5.3.2 Design Specifications of the Proposed Antenna

**Table 5.2.** Design specification for the proposed antennas (the units of the design parameters are in mm)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( h )</td>
<td>26.9, 1.07, 120, 110, 70, 8, 25, 15, 40, 7, 120</td>
</tr>
<tr>
<td>( \varepsilon_r )</td>
<td>110, 100, 8, 10, 13, 40, 6, 140, 110, 130, 8</td>
</tr>
<tr>
<td>( L_1 )</td>
<td>5, 7, 7, 75, 8, 56, 9, 32, 7</td>
</tr>
</tbody>
</table>
### Table 5.3. Characteristics of the proposed antennas

<table>
<thead>
<tr>
<th>Antennas</th>
<th>Characteristics</th>
<th>Pass Band Frequencies (GHz)</th>
<th>Stop Band Frequency (GHz)</th>
<th>Bandwidth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antenna1</td>
<td>Wide bandwidth</td>
<td>(0.95-1.24)</td>
<td>No</td>
<td>26.36%</td>
</tr>
<tr>
<td>Antenna2</td>
<td>wide bandwidth with frequency notched characteristics</td>
<td>(0.81-0.89) and (1.02-1.47)</td>
<td>(0.89-1.02)</td>
<td>(9.41%) and (36.14%)</td>
</tr>
<tr>
<td>Antenna3</td>
<td>wide bandwidth with frequency notched characteristics</td>
<td>(0.7-0.75) and (1.0-1.36)</td>
<td>(0.75-1.0)</td>
<td>(4.24%) and (30.51%)</td>
</tr>
</tbody>
</table>

#### 5.3.3 Designed Antenna Characteristics

![Comparative variation of return loss with frequency for the proposed antennas](image)

**Figure 5.16.** Comparative variation of return loss with frequency for the proposed antennas
Figure 5.17. Variation of return loss with frequency for the pair of π-shape slot loaded proposed antenna

Figure 5.18. Variation of return loss with frequency at different base slot length
Figure 5.19. Variation of return loss with frequency at different vertical slot lengths $L_{v1}$ and $L_{v2}$

Figure 5.20. Variation of return loss with frequency at different vertical slot lengths $L_{v3}$ and $L_{v4}$
Figure 5.21. Variation of return loss with frequency for different substrate material

Figure 5.22. The gain versus frequency plot of the proposed antenna
Figure 5.23. The efficiency versus frequency plot of the proposed antenna

(a) $E_\theta$ at 0.86GHz

(b) $E_\phi$ at 1.05GHz
5.3.4 Discussion of Results

The comparative plot of three antenna structures is shown in Figure 5.16. Antenna 1 is the shorted single π-shaped slot loaded patch antenna which provides broad bandwidth. Antenna 2 is a modified version of Antenna 1 with additional π-shaped slots that achieves desired wider bandwidth with frequency notched characteristics. Further, for obtaining the Antenna 3 structure two vertical slots $L_{V5}$ and $L_{V6}$ are added in the Antenna 2, it decreases the bandwidth and shift the resonating frequencies towards lower side. Thus, slots play an important role in controlling the bandwidth and resonating frequencies of the antennas. The detailed characteristics of the antennas are given in Table 5.3.

Figure 5.17 shows the return loss versus frequency characteristics of the proposed antenna. From the figure, it is observed that the bandwidth of the antenna at lower resonance frequency is 9.52% (theoretical) and 9.41% (simulated) whereas at upper resonance frequency, it is 30.0% (theoretical) and 36.14% (simulated) with frequency band ranging from 0.81GHz to 1.47GHz in which frequency notched is created at
0.89GHz to 1.02GHz. On the other hand in the experimental result antenna resonates from 0.78GHz to 0.9GHz and from 1.02GHz to 1.5GHz. The simulated and theoretical results are verified with experimental results which are in close agreement. The small discrepancy occurs between theoretical, simulated and experimental results because the simulation method and theoretical analysis are not precise enough and also due to fabrication error such type of discrepancy occurred.

Figure 5.18 shows the effect of base slot length \( L_{b2} \) on the antenna characteristics and it is found that \( L_{b2} \) plays a crucial role in controlling the resonance frequency and operating bandwidth of the proposed antenna. On increasing the \( L_{b2} \), the lower and upper resonance frequencies shift towards higher frequency side and corresponding bandwidth of lower and upper operating bands decreases. The maximum and compressed bandwidths are obtained at 99.0mm and 103.0mm respectively.

Figure 5.19 shows the variation of return loss with frequency for different vertical slot lengths \( L_{v1} \) and \( L_{v2} \) \((L_{v1} = L_{v2})\). In this case, other parameters are kept constant except \( L_{v1} \) and \( L_{v2} \). Slot length are varied from 74.0mm to 78.0mm, the lower operating band is unchanged whereas the upper frequency band shifts towards higher frequency side and corresponding bandwidth decreases.

Figure 5.20 shows the return loss curves for different vertical slot lengths \( L_{v3} \) and \( L_{v4} \) \((L_{v3} = L_{v4})\), whereas \( L_{v1} \) and \( L_{v2} \) are fixed at 75.0mm. On varying the length of \( L_{v3} \) and \( L_{v4} \) from 55.0mm to 59.0mm the proper band-notch characteristic is obtained and upper frequency bandwidth is compressed and improves the return loss.

The proposed antenna characteristics are observed for different substrate materials as shown in Figure 5.21. It is found that the antenna is very sensitive to the dielectric properties of the materials. The operational frequency band is completely changed with changing the substrate material. The proposed antenna provides wide bandwidth with frequency notched characteristics for foam substrate whereas for the other materials antenna shows dual band and multiband characteristics.
The gain of the proposed antenna for entire operating frequency range is presented in Figure 5.22. The maximum gain 7.39dBi is occurred at lower operating bands, whereas 8.13dBi for upper operating bands. It decreases drastically for the frequency band 0.89GHz to 1.02GHz due to the frequency rejection property of the antenna.

The radiation efficiency versus frequency plot is shown in Figure 5.23. The maximum radiation efficiency 90% is achieved for overall frequency band excluding the rejected frequency band.

The plots of Figure 5.24 (a)-(d) shows the theoretical and simulated E-plane radiation pattern of the proposed antenna at different frequencies 0.86GHz, 1.05GHz, 1.17GHz and 1.35GHz. The number of lobes in the pattern represents a division of the radiated energy and the nulls represent angles at which no energy is transmitted. From the Figure 5.24(a) and (b), it is observed that the tilt angle of the radiation pattern in the direction of maximum radiation is 45° and 50° whereas the beamwidth between half power points is about 61° and 60.5° respectively. While from the Figure 5.24(c) at 55° tilt angle, the 3dB beamwidth is 68.13°. On the other hand at frequency 1.35GHz as shown in Figure 5.24(d), the antenna radiates most of the power at an angle 87.0° with 70.8° beamwidth.

This chapter has presented the analysis and effect of slots on the antenna characteristics. In next chapter the broad bandwidth of microstrip patch antenna has been achieved by introducing notches.
Reference


2008.

