CHAPTER 6

A NOVEL ME MONOPOLE ANTENNA FOR C-BAND WIRELESS APPLICATIONS

6.1 Introduction

UWB communication system ranging from 3.1GHz - 10.6GHz, requires a compact antenna having wide band characteristics over the entire range of operation. Monopole antennas have been proposed as they possess appealing characteristics of wide bandwidth, simple structure, omnidirectional radiation pattern, and ease of design. Broadband planar monopole antennas have all the advantages in terms of cost and ease of fabrication but they also suffer from the disadvantages of providing low gain and unstable radiation pattern. Recently, the demand for low profile, light weight, easy to design and fabricate, low cost broadband antennas have attracted researchers for short distance communication devices being used in modern communication systems [133, 134]. WiMAX and WLAN have become very popular wireless communication systems and are widely studied, with their applications being applied in mobile devices [133-136]. It is strongly felt that to enhance the performance of the antenna to make it functional in a complicated and diversified environment like WLAN and WiMAX, the antenna must be able to cover multiple frequency bands, to provide stable omnidirectional radiation patterns and desired gain, and also to justify its suitability for WLAN (2.4GHz - 2.484GHz, 5.15GHz - 5.35GHz and 5.725GHz - 5.825GHz) and WiMAX (3.3GHz - 3.69GHz and 5.25GHz - 5.85GHz) communication systems. Many times it is also desired to use WLAN and WiMAX simultaneously in the same system. Hence, there was a need to design a single antenna which can cover multiple frequency bands and to meet this requirement, several planar printed monopole antennas using slot structures and toothbrush patch have been proposed and designed to achieve either a wide band property or a dual band feature to meet wide band communication system applications [137-140]. But some of these antennas were not able to meet the ever increasing multiple band communication requirements and to solve this challenge, several multiband monopole antennas with meander lines have been presented [141-144]. But it is observed that some of these reported
multiband antennas cannot be integrated into portable devices as an internal antenna because of their large sizes or complex structures. In addition to above described antennas, monopole antennas, fed by microstrip, have been widely studied and applied to modern portable terminals as they are having advantages of maintaining simple structures with ease of fabrication and debugging [142, 145]. However, most of these monopole antennas are having a disadvantage of large size and low gain. In complementary antenna, equal E-plane radiation pattern and H-plane radiation pattern are obtained by exciting an electric dipole and a magnetic dipole simultaneously [146, 147]. But these antennas also suffer the major disadvantages of unstable gain and complex circuitry over a wide operating frequency band.

To overcome these challenges, a wideband unidirectional antenna, under the name ME dipole antenna, with 43.8% impedance bandwidth and equal E-plane and H-plane radiation patterns, has been proposed [148]. A multiband planar monopole ME monopole antenna providing two wide bands for covering seven-band LTE/GSM/UMTS operation was presented and achieved impedance bandwidth of 38.5% for 704 MHz - 1040MHz and 44.7% for 1.56GHz - 2.46GHz [149]. To the best of knowledge of the authors, no non-planar ME monopole antenna has been reported so far.

In this chapter, the first non-planar ME monopole antenna has been designed, fabricated and analyzed for UWB applications. The novel ME monopole antenna with dual I-shaped feed and a truncated ground plane, has been operating from 4.5GHz - 8.5GHz, and having a wide potential for satellite communication as well as radio navigation. The antenna has achieved the peak gain of 7.4dBi in the operating range of frequency. The antenna has almost identical radiation pattern for both E-plane and H-plane, indicating omnidirectional radiation pattern.

This novel proposed antenna has provided not only high peak gain with stable radiation pattern, as compared to various planar antenna designed and presented so far, but also the cost of fabrication is very less.

6.2 Antenna Design and Geometry

The geometry of proposed antenna has been shown in Figure 6.1a and Figure 6.1b. The dimension of ground plane has been chosen as-length, GL=65mm and width, GW=98mm,
which is an optimized ground plane size taken for antenna design. The antenna primarily consists of three parts: radiating structure, a feeding structure and a ground plane. The radiating structure has been designed using vertically oriented shorted patch as magnetic monopole and a planar E-shaped patch as an electric monopole, with middle strip length greater than the length of upper strip as well as lower strip, hence providing it a unique shape. The height of the antenna, H, has been maintained as 16mm. To meet the low impedance characteristic of monopole, the two 'I'-shaped feeding structures have been connected in parallel which excite the magnetic monopole and electric monopole equally to provide wide impedance matching. These two 'I'-shaped feeding structure are separated by spacing Δs=1mm. The longest vertical portion of each 'I'-shaped feed behaves like a 50ohm transmission line. A coaxial probe has been connected at the center of two transmission lines via 8mm long and 3mm wide, copper strip, Ws. One end of the coaxial cable has been connected to the SMA connector, which is located underneath the ground plane and having radius of 0.635mm. The length over the ground plane has been chosen as Δh = 2mm. With each transmission line, a coupled line has been connected to couple the electromagnetic energy to electric monopole and magnetic monopole. This coupled line has been designed using one horizontal copper strip and one vertical copper strip. The inductive reactance, which has been provided by the horizontal copper strip, is counter balanced by capacitive reactance provided by the vertical copper strip. A copper sheet with 0.3mm thickness, has been used to constitute ground plane and all other parts of the proposed antenna. The designed antenna has been optimized and simulated on MOM based IE3D software. The 3-D view of proposed antenna has been shown in Figure 6.1c. The purpose of optimization is to maximize the impedance bandwidth and gain while maintaining unidirectional as well as stable radiation pattern throughout the range of operation. The prototype of proposed antenna is shown in Figure 6.2 and Table 6.1 represents the optimized geometrical parameters of the proposed antenna.
Figure: 6.1a Side view of the proposed antenna

Figure: 6.1b Top view of proposed antenna
Figure: 6.1c 3-D view of proposed antenna

Figure: 6.2 Prototype of proposed antenna
Table 6.1 Optimized dimensions of the proposed ME monopole antenna

<table>
<thead>
<tr>
<th>Parameter</th>
<th>GL</th>
<th>GW</th>
<th>L1</th>
<th>L2</th>
<th>L3=L4</th>
<th>L5</th>
<th>W1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value(mm)</td>
<td>65</td>
<td>98</td>
<td>20</td>
<td>15</td>
<td>7</td>
<td>8.5</td>
<td>5.5</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Parameter</th>
<th>W2</th>
<th>Ws</th>
<th>h1</th>
<th>h3=h4</th>
<th>H=S</th>
<th>Δh</th>
<th>Δs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value(mm)</td>
<td>6.5</td>
<td>3</td>
<td>2</td>
<td>13</td>
<td>16</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

6.3 Current Distribution

To represent the working of ME monopole antenna, the current distribution of proposed antenna has been shown at 4.7GHz, indicated in Figure 6.3. It is observed that at time t=0, the horizontal current on the planar E-shaped electric monopole dominates and the current on vertically oriented shorted patch is negligible. Hence, the electric monopole mode is strongly excited at time t=0. At time t=T/4, the horizontal current on E-shaped patch becomes very weak, and the current on vertically oriented shorted patch dominates. This behavior of current indicates that the current loop is radiating as magnetic monopole, which is strongly excited at t=T/4. For another two cycles, the process repeats but the direction of current gets reversed.
6.4 Analysis of ME Monopole Antenna

According to the structure and function of the ME monopole antenna, the input impedance of antenna $Z_{in}$, can be expressed using equation 6.1, as

$$Z_{in} = Z_L + Z_c(CD) + (Z_L(BD) \parallel Z_c(DF)) + Z_c(BD') + (Z_L(B'D') \parallel Z_c(D'F')) + \frac{Z_o}{2} \quad (6.1)$$

where $Z_o$ represents the characteristic impedance of the transmission line, $Z_c(CD)$ and $Z_c(BD')$ represent the open circuit impedance provided by points CD and BD’ respectively, $Z_L(BD)$ and $Z_L(B'D')$ are the impedance provided by the horizontal part of coupling strip inductance, $Z_c(DF)$ and $Z_c(D'F')$ are the impedance provided by vertical portion of coupling strip, DF and D’F’ respectively and $Z_L$ is the impedance of electric monopole. In the resonant process, the horizontal part of coupling strip and electric monopole behave like an inductor while magnetic monopole, vertical portions of feeding structure, and shorted wall behave like a capacitor. The schematic of proposed ME monopole antenna along with its equivalent circuit is shown in Figure 6.4.
To calculate the input impedance $Z_{in}$, the impedance of each part can be expressed as:

\[
\begin{align*}
Z_L & = j\omega L \frac{1}{C} \\
Z_c(CD) & = -jZ_{oc}\cot\beta l_{CD} \\
Z_c(BD') & = -jZ_{oc}\cot\beta l_{BD'} \\
Z_L(BD) & = j\omega L_{BD} \\
Z_L(B'D') & = j\omega L_{B'D'} \\
Z_c(DF) & = 1/j\omega C_{DF} \\
Z_c(D'F') & = 1/j\omega C_{D'F'}
\end{align*}
\]

Here $L$ and $C$ represent the inductance and capacitance respectively, whereas $l$ represents the electrical length. On the basis of equation (1), it can be observed that the input impedance is mainly affected by the parameters of the horizontal length and vertical height of electric dipole, the horizontal length and vertical length of the coupling strip.

Figure: 6.4a Schematic of proposed ME monopole antenna  
6.4b Equivalent circuit of ME monopole antenna
The input impedance for the proposed ME monopole antenna, has been derived using equation (1), and the real and imaginary part of input impedance are calculated and plotted using MATLAB. It has been found that the real part of input impedance varies from 26.9ohm to 37.7ohm and imaginary part varies from 3.8ohm to 17.5ohm, for the given frequency range 4.5GHz – 8.5GHz, which is indicated by Figure 6.5. As the theoretical value of input impedance of any quarter wave monopole antenna is 37.5ohm, and the proposed antenna has shown the variation of real part of input impedance as: 32.5ohm at 4.5GHz, 37.7ohms at 6.5GHz and 30ohm at 8.5GHz, which are very close to the theoretical value.

Using equation (1), the reflection coefficient has also been calculated and plotted, as shown in Figure 6.6 and it has been observed that the reflection coefficient calculated using equation (1) varies from -13.4dB at 4.5GHz, peak value of -16.2dB at 6.5GHz and -13.09dB at 8.5GHz.

In the light of above results, it can be concluded that the proposed ME monopole antenna is working well within the given frequency range.

![Image](image.png)

Figure: 6.5 Real and imaginary parts of input impedance of proposed ME monopole antenna
6.5 Results and Discussion

The proposed ME monopole antenna has been designed and analyzed using MOM based full wave electromagnetic simulator IE3D. The antenna has been fabricated using 0.3mm thick copper sheet and in accordance with the actual antenna, the same thickness has been used for copper while performing simulations. Various antenna parameters like reflection coefficient, current distribution, radiation pattern and gain have been analyzed rigorously to get the optimum results.

Variation of reflection coefficient through simulations, measured reflection coefficient and reflection coefficient calculated using equation derived for $Z_{in}$, with frequency have been shown in Figure 6.6. From the figure, it is shown that the measured results match well with the simulated one within the acceptable limit and the proposed antenna delivers an impedance bandwidth of 61.5% in the frequency range 4.5GHz - 8.5GHz.

Another important antenna parameter is gain and variation of simulated and measured gain with frequency has been represented in Figure 6.7, which clearly shows the peak gain of 7.4dBi is obtained. This high gain, as confirmed from simulated as well as measured result, is in contrast to standard electrical monopole antenna that provides low gain in the range of frequency operation.

One of the most desired characteristic of ME monopole antenna is to have identical E-plane and H-plane radiation pattern with omnidirectional radiation characteristics. These radiation characteristics of the proposed ME monopole antenna have been highlighted in Figure 6.8.

Cross polarization is another parameter which has to be analyzed to confirm the purity of the signal. Figure 6.9 represents the cross polarization radiation pattern of proposed monopole antenna and it is shown that the antenna possesses low cross polarization level at 5GHz, 6GHz and 7GHz. At 8GHz the cross polarization increases which may have resulted due to the presence of back radiations. However, these back radiations may be reduced if size of ground plane increases.
Figure: 6.6 Measured, simulated and formula based reflection coefficient of proposed antenna

Figure: 6.7 Measured and simulated gain of proposed antenna
Figure: 6.8 Measured and simulated E-plane and H-plane radiation patterns at: (a) 5GHz (b) 6GHz (c) 7GHz (d) 8GHz

Table: 6.2 Comparison of previously designed ME monopole antenna with the proposed antenna

<table>
<thead>
<tr>
<th>Reference No.</th>
<th>Planar/Non-Planar</th>
<th>Frequency Range</th>
<th>Impedance Bandwidth(IB) %</th>
<th>Gain (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>[149]</td>
<td>Planar</td>
<td>704 MHz - 1040 MHz</td>
<td>38.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.56 GHz – 2.46 GHz</td>
<td>44.7</td>
<td></td>
</tr>
<tr>
<td>Proposed Antenna</td>
<td>Non-Planar</td>
<td>4.5 GHz – 8.5 GHz</td>
<td>61.5</td>
<td>7.4</td>
</tr>
</tbody>
</table>
Figure: 6.9 Measured and simulated co-polarization and cross polarization radiation patterns in E-Plane at: (a) 5GHz (b) 6GHz (c) 7GHz (d) 8GHz

6.6 Effect of Height of Monopole Antenna

The height of antenna plays an important role while analyzing the study of antenna parameters like reflection coefficient, gain etc. Keeping this in view, the height of antenna has been changed to 17mm and 15mm, while considering 16mm as the optimum height. Figure 6.10 highlights the variation of reflection coefficient with frequency for different height of monopole antenna and it has been reflected that as the antenna height is reduced to 15mm, antenna starts showing the presence of dual-bands at 4.5GHz - 7.3GHz and
7.6GHz - 8.7GHz, which ultimately gives impedance bandwidth of 47.4% and 13.4% respectively. On the other hand, when the height of monopole antenna has been increased to 17mm, the antenna possesses the impedance bandwidth of 62.1% in the frequency range 4.1GHz - 7.8GHz.

The variation of gain with the different height of antenna has been shown in Figure 6.11. It has been reflected that as the height of antenna is decreased to 15mm, the peak gain of antenna is reduced to 6.6dBi and when the height of antenna has been increased to 17mm, it reduces to 6.9dBi. The antenna at the height of 16mm gives the peak gain of 7.4dBi, which is higher than results obtained at antenna height of 15mm and 17mm.

Hence it can be concluded that with reference to the optimized value of height of antenna, as the height of monopole antenna has been decreased, the peak gain of antenna is reduced with reduction in impedance bandwidth whereas when the height of antenna has been increased, higher impedance bandwidth with lower peak gain is obtained.

Figure: 6.10 Simulated reflection coefficient of proposed antenna at different height
6.7 Effect of Length of Feed of Monopole Antenna

The input impedance of monopole antenna is closely dependent on length of the feed line, as interpreted from equation (1). To analyze the impact of change in length of feed (L3 and L4) on antenna impedance bandwidth and gain, the length of feed has been changed to 7.5mm and 6.5mm, while maintaining 7mm as the optimum value.

Figure 6.12 represents the variation of reflection coefficient with frequency for different length of feed of monopole antenna. It has been clearly highlighted that as the length of feed is changed to 7.5mm, the antenna starts indicating the presence of dual bands at 4.1GHz - 6.6GHz and 6.8GHz - 8.1GHz providing an impedance bandwidth of 46.7% and 17.4% respectively. On the other hand, when the length of feed of monopole antenna has been changed to 6.5mm, the impedance bandwidth of 61.2% has been shown by the antenna in the frequency band 4.3GHz - 8.1GHz. This can be concluded that the impedance bandwidth of the antenna has decreased, when the length of feed is either decreased or increased from optimized value of 7mm.
Variation of gain with the change in length of feed is shown in Figure 6.13 and it has been observed that as the length of feed is changed to 6.5mm, the peak gain of 6.78dBi is obtained, while a peak gain of 6.8dBi is observed when the length of feed is changed to 7.5mm. The antenna with length of feed as 7mm provides a peak gain of 7.4dBi, which is higher than both the results obtained at feed length of 6.5mm and 7.5mm.

Hence, the above results can be summarized like- as the length of feed of monopole antenna is deviated from 7mm, the peak gain of antenna has been reduced with decrease in impedance bandwidth.

Figure 6.12  Simulated reflection coefficient of proposed antenna for different length of feed
6.8 Effect of Width of Ground Plane of Monopole Antenna

The size of ground plane is another important factor on which gain, impedance bandwidth and back lobe radiations of the antenna are closely dependent. To confirm its effect on ME monopole antenna, width of ground plane, GW, has been changed to 88mm and 108mm, while maintaining the length of ground plane, GL, as 65mm. The width of antenna has been optimized at 98mm.

In Figure 6.14, the variation of reflection coefficient with change in width of ground plane has been plotted. It has been observed that as the width of ground plane is decreased to 88mm, impedance bandwidth increases to 63.4% for the frequency range 4.2GHz - 8.1GHz, whereas, as the width of ground plane is increased to 108mm, the antenna shows the presence of dual-bands at 4.2GHz - 6.6GHz and 6.9GHz - 8.0GHz, which ultimately gives reduced impedance bandwidth of 44.4% and 14.7% respectively.

The impact of change in width of ground plane has been observed on gain of the monopole antenna, as highlighted in Figure 6.15. It has been proved that the peak gain of antenna has decreased from optimized value of 7.4dBi to 6.77dBi for width of ground plane as 88mm and 6.4dBi for width of ground plane as 108mm.
On the basis of above two results and with reference to the optimized value of width of ground plane, it can be summarized that as the width of ground plane is decreased, the impedance bandwidth increases with fall in peak gain whereas the impedance bandwidth as well as the peak gain of monopole antenna decreases, when the width of ground plane has been increased.

Figure: 6.14  Simulated reflection coefficient of proposed antenna for different width of ground plane

Figure: 6.15  Simulated gain of proposed antenna for different width of ground plane
6.9 Effect of Length of Ground Plane of Monopole Antenna

The next parametric analysis has been done to know the impact of length of ground plane on various antenna parameters. Hence, the length of ground plane, GL, has been changed to 60mm and 70mm while maintaining width of ground plane, GW, as 98mm. It is to be noted that the optimized value of length of ground plane is 65mm.

The impact of change in length of ground plane on reflection coefficient of the antenna has been shown in Figure 6.16. It has been clearly visualized that as the length of ground plane has been reduced to 60mm, affirm presence of dual-bands at 4.2GHz - 6.6GHz and 6.8GHz - 8.1GHz, has been shown by the antenna, hence reducing the impedance bandwidth to 44.4% and 17.4% respectively. But as the length of ground plane has been increased to 70mm, impedance bandwidth is also increased to 63.4% for frequency range 4.2GHz - 8.1GHz.

The effect of change in length of ground plane on gain is shown by Figure 6.17. It has been observed that as the length of ground plane is deviated from the optimized value, the peak gain of antenna has been dropped to 6.47dBi and 6.74dBi for length of ground plane as 60mm and 70mm respectively. The proposed antenna has shown the peak gain of 7.4dBi, by maintaining the length of ground plane as 65mm.

So it can be concluded that though impedance bandwidth is proportional to the length of ground plane, the peak gain falls for both the results.
Figure 6.16 Simulated reflection coefficient of proposed antenna for different length of ground plane

Figure 6.17 Simulated gain of proposed antenna for different length of ground plane

6.10 Conclusion

A simple non-planar ME monopole antenna with novel feed design has been designed and fabricated. The measured and simulation results indicate that it possesses 61.5% wide impedance bandwidth, stable omnidirectional radiation pattern with almost identical E-plane
and H-plane radiation patterns and provides a peak gain of 7.4dBi in the frequency range 4.5GHz - 8.5GHz. Due to its good electrical and radiation characteristics, the antenna has wide potential to operate in C-band to overcome the challenges of multi-frequency applications.