A Compact Microstrip Patch Antenna for LTE Applications

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Abstract

A compact multiband antennas for Long Term Evolution (LTE) applications is a challenge. Both the frequencies of new wireless technologies and new frequency bands must be covered. The lower end of the 0.7 – 3.5 GHz band is especially difficult to handle for miniaturized terminal devices. A single layer, line-feed rectangular microstrip patch antenna is small enough for the LTE handsets. Our project proposes size reduction and bandwidth enhancement through adapted feeding techniques. By means of slits the return loss and gain can be optimized with the aid of HFSS (High Frequency Structure Simulator).
## Contents

1 Background ................................................. 5  
   1.1 Objective ............................................ 5  
   1.2 Methodology ........................................... 5  
   1.3 Breakdown of report ................................. 5  

2 The microstrip patch antenna ......................... 6  
   2.1 Introduction .......................................... 6  
   2.2 Structural configuration .............................. 6  
   2.3 Formulas for the rectangular patch antenna ...... 7  
   2.4 Feeding techniques ................................... 7  
      2.4.1 Microstrip transmission-line feed ............... 8  
      2.4.2 Aperture coupling feed ............................ 8  
      2.4.3 Coaxial probe feed ................................. 9  
      2.4.4 Proximity coupling feed ........................... 9  
   2.5 Advantages: ........................................... 10  
   2.6 Disadvantages: ....................................... 10  
   2.7 Applications .......................................... 10  

3 Long term evolution ...................................... 11  
   3.1 Introduction .......................................... 11  
   3.2 Major requirements for LTE ......................... 12  
   3.3 Motivation of LTE ..................................... 12  

4 Literature review ......................................... 13  
   4.1 Compact antenna with port decoupling for LTE .... 13  
   4.2 Internal mobile antenna for LTE/WiMax/WLAN ....... 13  
   4.3 Compact dual-band monopole antenna for LTE ....... 13  

5 Design specifications ...................................... 14  
   5.1 Substrate .............................................. 14  
   5.2 Line-feed rectangular patch on a grounded substrate at 1 GHz 14  
   5.3 Feed transmission line ................................. 14  
   5.4 Design ............................................... 14  
   5.5 Results ............................................... 15  
      5.5.1 Return loss ....................................... 15  
      5.5.2 Radiation pattern at 1 GHz ....................... 16  
   5.6 Problem statement ..................................... 17
6 Results and analysis
6.1 Step 1 ................................................................. 18
6.2 Step 2 ................................................................. 20
6.3 Step 3 ................................................................. 21
6.4 Step 4 ................................................................. 22
6.5 Step 5 ................................................................. 23
6.6 Step 6 ................................................................. 24

7 Conclusion.......................................................... 28
Chapter 1

1 Background

The antenna is a necessary component of every wireless communication system and provides a means for transmitting and receiving electromagnetic waves [1]. Recent developments in wireless communication have increased the demand for multiband antennas that can operate at multiple frequencies with sufficient bandwidth. The microstrip patch antenna has a wide range of applications in wireless or satellite communication due to reduction in size, price and power consumption. In this project we study a single layer, line-feed, rectangular patch antenna with multiband capability. It is versatile enough to cover many LTE bands as well as DCS, PCS, UMTS, WiMAX, Bluetooth and WLAN.

1.1 Objective

We wish to address the generic compact antenna problem. Other objectives are:

- To design and simulate a dual band microstrip patch antenna for LTE applications.
- To design a compact antenna for smart phones.
- A comparison of performance involving the standard antenna parameters.

1.2 Methodology

The software that we used for simulation is Ansoft HFSS version 12. Starting with a microstrip patch, various techniques have been applied to meet frequency and size requirements.

1.3 Breakdown of report

This report has six chapters beginning with a brief introduction. Chapter 2 presents the microstrip patch antenna, its physical description, theory and feeding methods. Chapter 3 discusses the LTE and parameters for its applications. Chapter 4 covers some of the background literature. Chapter 5 explores the design specification in relation to calculated results and chapter 6 presents the results for the proposed design.
Chapter 2

2 The microstrip patch antenna

2.1 Introduction

The patch antennas received considerable attention in the 1970s, although the idea was explored already in 1953 and documented in 1955 [1]. Practical implementation started in the 1970s when suitable substrate materials became available. The microstrip patch antennas are low profile and easy to fabricate using modern printed circuit technology. They are mostly used to enhance the bandwidth in mobile, radio and wireless communication systems [1].

2.2 Structural configuration

The microstrip patch antenna consists of a metallic patch on one side of a dielectric substrate. The value of the relative permeability ($\epsilon_r$) depends on the materials which can be copper, silver, gold, aluminium. A substrate FR4 epoxy with a dielectric constant in the range $2.2 \leq \epsilon_r \leq 12$ is used. The patch can be rectangular, circular, elliptical, triangular or any other shape. For a rectangular patch, the length L of the element is usually $\frac{\lambda}{3} < L < \frac{\lambda}{2}$. The length, height and width of the patch and its substrate are given by standard formulas. The patch can be fed by means of a number of techniques that are discussed below.

![Microstrip patch antenna](image.png)

Figure 1: Microstrip patch antenna.
2.3 Formulas for the rectangular patch antenna

The width $W$ of the rectangular patch is given in terms of the speed of light $c$ and the frequency $f_o$ [1] by,

$$W = \frac{c}{2f_o\sqrt{\epsilon_r+1}}.$$  \hspace{1cm} (1)

Eq. 2 is used to calculate the effective length of the rectangular patch,

$$L = \frac{c}{2f_o\sqrt{\epsilon_{eff}}} - 2\Delta L.$$  \hspace{1cm} (2)

There is a fringing effect described by $\Delta L$,

$$\Delta L = 0.412h \frac{\epsilon_{eff} + 3(w \frac{h}{w} + 0.264)}{\epsilon_{eff} - 0.258(w \frac{h}{w} + 0.8)}.$$  \hspace{1cm} (3)

The value of the effective dielectric constant $\epsilon_{eff}$ is given by,

$$\epsilon_{eff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}(1 + 12\frac{h}{w})^{\frac{1}{2}}.$$  \hspace{1cm} (4)

In the above formula, $h$ is the height of the dielectric substrate, $\epsilon_r$ is the relative dielectric constant for the substrate and $\epsilon_{eff}$ is the effective dielectric constant. Eq. 5 is used to calculate the length of the radiating patch,

$$L_{eff} = L + 2\Delta L.$$  \hspace{1cm} (5)

2.4 Feeding techniques

The following feeding techniques are used for patch antennas,

- Microstrip transmission-line feed
- Aperture coupling feed
- Coaxial probe feed
- Proximity coupling feed

These methods can be contacting or non-contacting. Contacting methods involve direct contact between the transmission line and the radiating surface. The non-contacting methods use electromagnetic field coupling to transfer the power to the patch [2].
2.4.1 Microstrip transmission-line feed

A microstrip feed line is a strip that is much narrower than the patch. This feed is very easy to fabricate and easily matched by controlling the inset position [1]. The feed is connected to one side of the patch. The transmission-line and the patch are made from the same material.

![Microstrip Feed Line](image)

Figure 2: Patch with feed line.

2.4.2 Aperture coupling feed

Aperture coupling is more difficult to fabricate and leads to narrow bandwidth. The geometry consists of two substrates separated by a ground plane. The bottom side of the substrate is fed by a transmission-line and the energy is coupled to the patch through a slot [1]. The substrate on top has a low dielectric constant while the bottom substrate is a high $\varepsilon_r$ material with a non-contacting feed. By controlling the length of the slot or the width of the transmission-line, matching is performed.
2.4.3 Coaxial probe feed

The coaxial probe feed has a narrow bandwidth. It consists of two conductors. The outer conductor is connected with the ground plane while the inner conductor is connected to the radiating patch. Coaxial probe feed is easy to fabricate and match. It is very difficult to model for thick substrates.

![Coaxial probe feed](image)

Figure 3: Coaxial probe feed.

2.4.4 Proximity coupling feed

In proximity coupling, the microstrip line is placed between two substrates. The upper substrate has a radiating patch on top. It is easy to model but difficult to fabricate. The bandwidth of the proximity coupling feed is very large. This coupling is capacitive and has low spurious radiation.

![Proximity coupling feed](image)

Figure 4: Patch with proximity coupling feed.
2.5 **Advantages:**

- Reduction in size: Printed circuits are thin and thus require less volume than waveguides or coaxial lines.
- Large scale fabrication possible.

2.6 **Disadvantages:**

- Low gain and efficiency.
- Large ohmic loss in large feed networks.

2.7 **Applications**

Nowadays, microstrip patch antennas are used in many government and commercial sector applications. Since the antennas are small they can be used in satellites and other high performance applications. They are also practical to use in mobile applications, radars and security systems [3].
Chapter 3

3 Long term evolution

3.1 Introduction

Long term evolution is the latest step in the telecom development. The expansion of LTE is to a large extent due to the success of the high speed packet access and the evergrowing need for capacity. In terms of generations LTE counts as the fourth generation [4] as illustrated by Figure 5.

Figure 5: Telecom systems [5].
3.2 Major requirements for LTE

LTE defines a new high speed access method for mobile communication systems. Flexibility and interoperability with current technology are combined with the following features,

- Peak data rates of 100 Mbps for downlink and 50 Mbps for the uplink.
- Improved spectrum efficiency.
- The system transmits and receives at the same time using full duplex.

3.3 Motivation of LTE

For operators, and when compared to previous standards, LTE offers improved performance as well as reduced capital and operating costs. Many manufacturers design prototype antennas of varying sizes and our work relates to some of these prototypes and the following LTE bands,

<table>
<thead>
<tr>
<th>LTE band number</th>
<th>Allocation (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>880 – 915</td>
</tr>
<tr>
<td>11</td>
<td>1427.9 – 1452.9</td>
</tr>
<tr>
<td>22</td>
<td>3410 – 3500</td>
</tr>
<tr>
<td>34</td>
<td>2010 – 2025</td>
</tr>
<tr>
<td>36</td>
<td>1930 – 1990</td>
</tr>
<tr>
<td>38</td>
<td>2570 – 2620</td>
</tr>
<tr>
<td>39</td>
<td>1880 – 1920</td>
</tr>
</tbody>
</table>

Table 1: LTE Bands [4].
Chapter 4

4 Literature review

The following three designs have been useful references in our work on compact LTE antennas.

4.1 Compact antenna with port decoupling for LTE

A compact dual-element antenna has been designed [6] for LTE applications. The proposed antenna consists of two printed meander-line monopoles that are placed edge-to-edge for good impedance matching and better return loss. It is operating at the resonant frequency 0.71 GHz. The length, width and height of the antenna is 110 mm, 50 mm and 1 mm, respectively. The antenna is too long to fit into ultra thin PDA’s or small mobile handsets.

4.2 Internal mobile antenna for LTE/WiMax/WLAN

An internal antenna for LTE was designed [7] for multiple frequency bands. A metal branch near the feeding point and an FR4 substrate was useful for the WLAN band. The ground plane was extended to improve matching for low frequencies. The overall size was reduced to 100 by 40 by 5 mm.

4.3 Compact dual-band monopole antenna for LTE

A monopole antenna was designed for LTE phones. A duroid substrate and a meandering monopole was used for the 0.7 GHz band and the 2.5 GHz band [8]. The relative permittivity of the dielectric is 2.2 and the thickness is 0.762 mm. The antenna consists of a main meandered monopole and a connected parasitic element to extend the frequency band upward. For that reason, two antennas are positioned close by on the same Printed Circuit Board (PCB). To increase the bandwidth, a neutralization technique is implemented. The total size of the antenna is 120 × 50 mm². The size of the antenna is very large and it can not be fitted into a small PDA-mobile phone.

Based on these examples we tried to design a compact patch antenna. The main problem is of course to keep the size of the antenna within bounds when the resonating frequency is reduced.
Chapter 5

5 Design specifications

5.1 Substrate
We are using FR4 epoxy as a substrate. Data can be found in Refs. [9] [10].

5.2 Line-feed rectangular patch on a grounded substrate at 1 GHz
The dimensions of a simple rectangular patch on a grounded substrate were obtained from the formulas in chapter 2. We consider a simple line-feed rectangular patch at 1 GHz and a substrate with \( \epsilon_r = 4.4 \) and height 1.6 mm. One obtains a width \( W = 91.28 \) mm and a value \( \epsilon_{eff} = 4.245 \).

The final length of the patch is then \( L = 71.31 \) mm. At 1.95 GHz the corresponding values are \( W = 46.81 \) mm and \( L = 36.36 \) mm.

5.3 Feed transmission line
Similarly, the dimensions of the transmission-line can be obtained by the formulas in chapter 2 for \( f = 1 \) GHz, \( \epsilon_r = 4.4 \), \( H = 1.6 \) mm and \( Z_0 = 50 \) Ω. This requires a line with \( L = 27.39 \) mm and \( W = 3.05 \) mm.
In the same way, for the frequency \( f = 1.94 \) GHz, one obtains \( L = 14.05 \) mm and \( W = 3.05 \) mm.

5.4 Design
A 1.6 mm FR4 epoxy substrate with copper coating on both sides is easily available. The simple antenna shown in Figure 6 was simulated in HFSS for an operating frequency of 1 GHz.
5.5 Results

5.5.1 Return loss

The computed return loss is shown in Figure 7. The main resonance at 1.15 GHz appears and in addition there is also a band with low loss above 2 GHz, indicating a certain multiband capacity. The minimum return loss is $-27.6$ dB. The unphysical maximum at 1.9 GHz may be caused by some resonance effect that the software has problems with. In chapter 6 we have tried to remove this problem.
5.5.2 Radiation pattern at 1 GHz

Figure 8 shows the radiated power in elevation diagrams for $\phi = 0^\circ$ and $\phi = 90^\circ$. There is a well defined main lobe at this comparatively low frequency.
5.6 Problem statement

These figures describe a simple patch with a rather poor impedance matching. Especially for frequencies below 1 GHz, the size of the antenna is a real problem and this antenna can not be used in conventional mobile phones. LTE frequency bands were discussed in chapter 3 and range from 0.7 to 3.5 GHz. It is difficult to handle such a wide band with a single antenna. Two methods are,

- A multiband antenna operating at selective narrow bands
- A wide band antenna that covers all the LTE bands

Chapter 4 presented three examples, designed for selected bands, as references for our work. These antennas are too large and nor do they cover all the LTE bands. In order to handle both these aspects, also for real time applications, we have designed a patch antenna through a procedure of gradual improvement.
Chapter 6

6 Results and analysis

This chapter tackles the design problems encountered in chapter 5. Our final design is compact and covers the LTE bands.

6.1 Step 1

Starting with new dimensions, we consider an antenna operating at 1.95 GHz, corresponding to the centrally placed LTE bands. The equations of chapter 2 are applied to the smaller antenna shown in Figure 9.

Figure 9: Dimensions of the antenna.

The dimensions are L= 36.3 mm and W= 46.8 mm for operation at 1.95 GHz in the LTE band 36 [1] [11]. The width of the feed line (input port) can be varied to obtain impedance matching.
Figure 10 shows that a width of 1.22 mm produces good matching to 50 Ω.

![Figure 10: Impedance matching vs frequency.](image)

Figure 11 shows that the antenna is resonating at 2.2 GHz but the return loss is not good enough and more work is needed.

![Figure 11: Return loss vs frequency.](image)
6.2 Step 2

It has been demonstrated that by adding a narrow slit close to the radiating edges, as shown in Figure 12, dual frequency operation can obtained [12]. A suitable operating frequency is given by the minimum in the return loss, as shown in Figure 13.

Figure 12: The microstrip antenna with a narrow slit.

By introducing slit 1, the surface current distribution at the center of the radiating patch is greatly enhanced, causing the minimum at 1.1 GHz. The slit appears to produce deeper minima (−19.4 dB). The bandwidth is very narrow, however, and only a single LTE band (11 or 8) can be covered.

Figure 13: Return loss after adding slit 1.
6.3 Step 3

Another possibility is to modify the ground plane [1][13][14], as shown in Figure 14. The ground plane has been modified by reducing its length to 12.25 mm to increase the bandwidth. The surface current is shown to the right.

![Figure 14: Antenna with modified ground plane.](image)

By reducing the length of the remaining plane, in steps from 30 to 7 mm, the return loss can be improved significantly.

![Figure 15: Return loss for a modified ground plane.](image)
Figure 15 shows that for a length $L_m = 15$ mm, there is a multiband response. Adjusting the length to 12.25 mm yields an optimum since further reduction (7 mm) has a negative effect.

6.4 Step 4

The conversion of a non-radiating patch edge to a radiating surface is expanded by adding slit 2 [12]. The slit is positioned to maintain the operating frequency while reducing the return loss. A parametric study with two lengths of the second slit is shown in Figure 16.

![Figure 16: Return loss when slit 2 has been added.](image)

Good results are obtained with a second slit of length 10.2 mm. For longer slits the performance near 0.7 GHz is not so good. This design covers the LTE bands with a return loss below 6 dB.
6.5 Step 5

It turns out that the tuning of the antenna can be maintained when the size of the antenna is reduced. This makes it possible to stretch the minimum so that a wider band is covered.

Figure 17: Size reduction and comparison.

Figure 17 shows the size of the antenna when the length scale is reduced. Figure 18 shows the corresponding return loss and illustrates how the minimum can be expanded.

Figure 18: Return loss comparison graph.
The new dimensions of the antenna are shown in Figure 19. The antenna is now small enough for the applications.

![Figure 19: Dimensions of the antenna after scaling.](image)

### 6.6 Step 6

A rectangular patch can be described by a transmission line model. The input resistance is then given by,

\[
R_{in} = \frac{1}{2(G_1 + G_{12})}
\]

(6)

The (+) sign is used for the odd symmetry modes and the (−) sign is used for the even symmetry modes. An inset feed technique can be used to improve the return loss further [1] [14].
Figure 20 shows an inset $y_0$. As $y_0$ increases, the input impedance decreases monotonically down to zero for $y_0 = L/2$.

$$R_{in}(y_0) = \frac{1}{2(G_1 + G_{12})} \cos^2 \left( \frac{\pi}{L} y_0 \right)$$

(7)

where

$$G_1 = \frac{I_1}{120\pi^2}$$

(8)

$$I_1 = \int_0^{\pi} \left[ \frac{\sin \left( \frac{k_0 W \cos \theta}{2} \right)}{\cos \theta} \right]^2 \sin^3 \theta d\theta$$

(9)

$$G_{12} = \int_0^{\pi} \left[ \frac{\sin \left( \frac{k_0 W \cos \theta}{2} \right)}{\cos \theta} \right]^2 J_0(k_0 L \sin \theta) \sin^3 \theta d\theta$$

(10)
$J_0$ is the Bessel function of the first kind of order zero. The inset affects the input resistance significantly. A parametric simulation provides a suitable value for $y_0$.

![Figure 21: Final inset distance and current distribution.](image)

Figures 21 and 22 show that inset feeding shifts the resonant frequency, but above all that there is a major reduction in return loss.

![Figure 22: Return loss in relation to inset distance.](image)
The best choice ($y_0 = 1.974 \text{ mm}$) is shown in Figure 23. The resonant frequency is shifted by about $0.9 \text{ GHz}$.

Figure 23: Return loss for the final design.

A similar analysis has been carried out for multiple LTE bands [14] but we believe that our antenna covers a larger bandwidth. The final design, based on 6 improvement steps, has a bandwidth of $3.38 \text{ GHz}$ (below $-6 \text{ dB}$) and hence covers the LTE bands considered here.
7 Conclusion

A compact microstrip patch antenna for LTE applications is proposed. This antenna is flexible and can operate at various LTE bands with high radiation efficiency. Introducing slits improves the radiation properties in terms of return loss, impedance and gain. The antenna is sufficiently small to be installed in ultra thin PDA’s and small handsets. This antenna is designed for future mobile communication systems with LTE specifications.
References


[5] [http://mobiledevdesign.com/tutorials/MDD-LTE-next-3G-Figure01-1016.jpg](http://mobiledevdesign.com/tutorials/MDD-LTE-next-3G-Figure01-1016.jpg).


