Passive Front End for LTE TDD Transceiver

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ABSTRACT
In this paper, a passive front end for a 3GPP Long Term Evolution (LTE) TDD transceiver comprising a microstrip antenna and filter is presented. The proposed antenna and filter operates in the LTE band 36 (TDD) which extends from 1930MHz to 1990MHz. A patch antenna and Hairpin filter is fabricated with a total area of 43x36mm^2 for the antenna and 38.6x32.16mm^2 for the filter. The proposed devices are fabricated using FR-4 material substrate and the measuring results show good agreement with the simulation results. The fabricated antenna has 2.67dBi directivity, 1.242dB gain, a minimum return loss of -31.85dB at resonant frequency 1950MHz and 150.3 MHz bandwidth at 6dB return loss, while the filter has -3dB BW of 90MHZ, a center frequency of 1950MHz and a fractional bandwidth of 4.615%.

Keywords
LTE, TDD, band 36, Patch antenna, Hairpin filter, FR-4 material.

1. INTRODUCTION
The evolution of wireless technology has grown dramatically. In the future, it is estimated that the need to access the internet will increase along with ever increasing human mobility. The presence of service for higher data rate will be the solution to answer the needs. In order to overcome this issue, LTE (Long Term Evolution technology) was launched [1].LTE will be the step towards the fourth generation (4G) originated from radio technology which is designed to improve network capacity and speed. LTE provides downlink capacity of at least300 Mbps and uplink capacity of at least 75Mbps.

LTE supports both frequency division duplex (FDD) and time-division duplex (TDD). FDD spectrum requires pair bands, one of the uplink and one for the downlink, and the separation must be sufficient to enable the roll-off of the antenna filtering to give sufficient attenuation of the transmitted signal within the receive band. While TDD requires a single band as uplink and downlink are on the same frequency but time separated [2]. As a result, there are different LTE band allocations for TDD and FDD. In some cases these bands may overlap. The different LTE frequency bands are allocated numbers. Currently the LTE bands between 1 & 22 are for paired spectrum, i.e. FDD, and LTE bands between 33 & 41 are for unpaired spectrum, i.e. TDD.As well as a wide range of system bandwidths in order to operate in a large number of different frequency bands allocated from 0.7 to 2.7 GHz. In addition, LTE standard supports a large number of channel bandwidths that vary from 1.4 MHz to 20MHz [3]. This paper present the design and implementation of an LTE passive front end comprising a transmitting patch antenna and band pass filter for LTE band 36 extending from 1930MHz to 1990MHz for TDD mode of transmission.

The paper is organized as follows; section 2 presents the design procedure of the proposed patch antenna, section 3 presents the design procedure of the proposed band pass filter, section 4 discusses simulation and measurements for antenna, section 5discusses simulation and measurements for filter finally, section 6 is for conclusion

2. LTE ANTENNA DESIGN
Micro-strip antennas are widely used because they can be printed directly onto a circuit board. Since the Micro-strip antenna requires few materials, it is low cost, easy to be manufactured and light weight. These characteristics make Micro-strip antennas ideal for use in cell phones and other small electronic systems [4].

The most common type of Micro-strip antenna is the patch antenna which consists of a radiating patch. The radiating patch and the feed lines are usually photo etched on the dielectric and a substrate which has a ground plate [5] as shown in Fig.1.The patch is of length L, width Wand thickness h sitting on top of a substrate

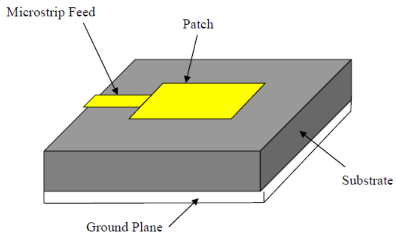


Fig.1: Structure of a Micro-strip Line feed antenna

The width of the patch element (W) is given by

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon r+1)}{2}}} \qquad (1)$$

Substituting c=300 Km/s, ε_r = 4.4, f_o = 1.95GHz, then W =46.81mmthe effective dielectric constant (ε_{reff}) depending on the same geometry (W, h) but is surrounded by a homogeneous dielectric of effective permittivity ε_{reff}. Whose value is determined by evaluating the capacitance of the fringing field.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon r+1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \qquad (2)$$

Substituting ε_r = 4.4, and h =1.6mm (for used substrate), W =46.81mm, then ε_{reff} = 4.1315

The effective length (L_{eff}) is given

$$L_{eff} = \frac{c}{2f_o\sqrt{\varepsilon_{reff}}} \qquad (3)$$

Substituting c = 300Km/s, ε_{reff} = 4.1315and f_o=1.95GHz, then L_{eff} = 37.844

The length extension (ΔL) is given by:

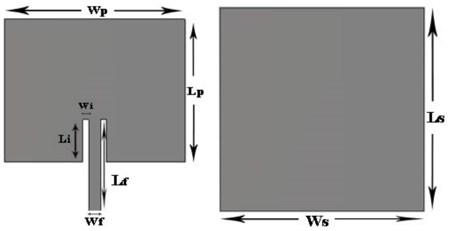
$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{W}{h}+0.8\right)} \qquad (4)$$

Substituting ε_{reff} = 4.1315, W =46.81mm and h=1.6mm, then ΔL= 0.640mm

The actual length (L) of patch is obtained by:

$$L = L_{eff} - 2\Delta L \quad (5)$$

Substituting ΔL=0.640mm, and L_{eff} = 37.844, then L=36.56mm



(a) (b)

Fig.2: Antenna Design (a) Top view and (b) Bottom view

Fig.2 (a) and (b) shows the top and bottom views respectively, for the design of the rectangular patch antenna using the help of CST simulator. The dimensions of the antenna are listed in Table1

Table1. Antenna parameter's size

Parameter	Size (mm)	Parameter	Size (mm)
L_s	55	L_f	22.737
W_s	55	W_f	2.86
L_p	36.56	L_i	10.487
W_p	48.81	W_i	1.5

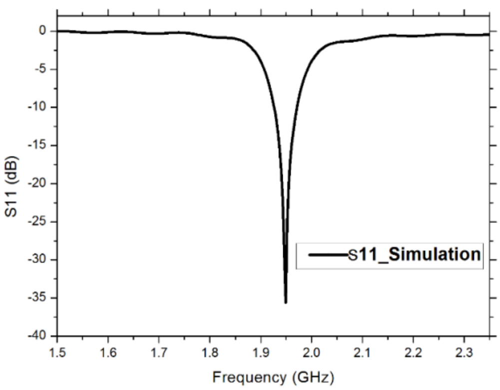
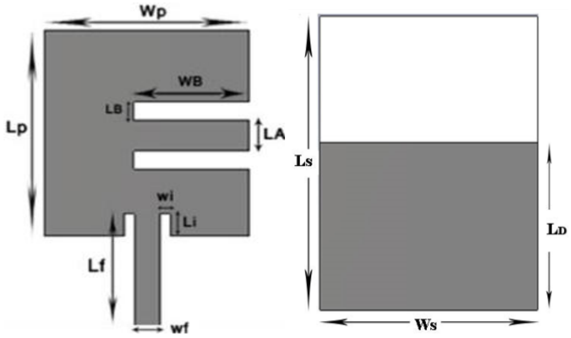


Fig.3: Return Losses vs. Frequency (in GHz)

Fig.3 shows the return loss results from CST simulator for the designed antenna at resonant frequency 1950 MHz The proposed antenna achieves the desired characteristics with minimum return loss of -35.4 dB and with BW =75MHZ but with dimensions of 55x55mm^2 which is considered large area for PCB design.

A modification in the shape of the patch was done to optimize the area and adjust the bandwidth. An E shaped patch antenna is formed [6] to achieve the design targets.



(a) (b)

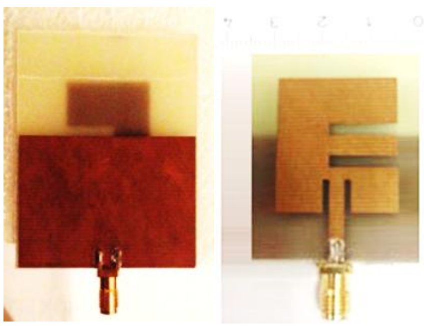
Fig.4: Antenna Design (a) Top view(b) Bottom view

Fig.4 (a) and (b) show the top and bottom views for the design of the proposed antenna whose dimensions are determined with the help of CST simulator and listed in Table 2.

Table2. Antenna parameter's size

Parameter	Size (mm)	Parameter	Size (mm)
Ls	43	LD	28
Ws	36	Li	6.6
Lp	27.5	Wi	1.25
Wp	24	WB	13.57
Lf	18.5	LB	2.45
Wf	2.97	LA	4.05

Two insets with W_i and L_i as shown in Fig. 4(a) are cut in the patch to match the impedance of the feed line to the patch (50 Ohm) without the need for any additional matching element and minimize the return loss. Also a defect in the ground plane (DGS) [7] shown in Fig.4 (b) with an area 28 xs35mm^2 is made to achieve the required bandwidth of the antenna. According to these modifications the bandwidth increased by 50% and the area decreased by almost 51%. The antenna is then fabricated and its photographs from the front and back are shown in Fig. 5 (a) and (b)



(a) (b)

Fig.5: Antenna photography (a) Top view (b) Bottom view

3. LTE FILTER DESIGN

The Hairpin Tapped line input resonator filter is one of the most popular microstrip filters configurations used in the lower microwave frequencies. It is easy to be manufactured as it has open-circuited ends that require no grounding [8]. Its form is derived from the edge-coupled resonator filter by folding back the ends of the resonators into a "U" shape. This reduces the length and improves the aspect ratio of the microstrip significantly as compared to that of the edge-coupled configuration.

3.1 Chebyshev Filter

For the design purposes, a third order low pass prototype Chebyshev with a pass band ripple of 0.1dB is chosen to satisfy the requirements of LTE front end. Element values for Chebyshev lowpass prototype filters for passband ripple of 0.1dB can be calculated with the following rules [9].

$$g_0=1 \qquad (6)$$

$$g_1=\frac{2}{\gamma}\sin\left(\frac{\pi}{2n}\right) \qquad (7)$$

$$g_i=\frac{1}{g_{i-1}}\frac{4\sin\left[\frac{(2i-1)\pi}{2n}\right]\sin\left[\frac{(2i-3)\pi}{2n}\right]}{\gamma^2+\sin\left[\frac{(i-1)\pi}{n}\right]} \text{for} i=2,3,\ldots n \qquad (8)$$

$$g_{n+1}=\begin{Bmatrix} 1 & \text{for n odd} \\ \coth^2\left(\frac{\beta}{4}\right) & \text{for n even}\end{Bmatrix} \qquad (9)$$

Where β, and γ are calculated from (10), (11) respectively:

$$\beta=\ln\left(\coth\frac{L_{Ar}}{17/37}\right) \qquad (10)$$

$$\gamma=\sinh\left(\frac{\beta}{2n}\right) \qquad (11)$$

The parameters g_0, g_1, g_2 ………. g_{n+1} are the normalized low pass elements of the Chebyshev low pass filter approximation and n is the order of the filter.

The element values for n=3 are calculated in Table3.

Table3. Lowpass prototype elements values 3Thorder filter

Low-Pass Prototype Elements	Values
g_0	1
g_1	1.0316
g_2	1.1474
g_3	1.0316
g_4	1

The lowpass prototype element values obtained can be represented by the ladder network shown in Fig.6

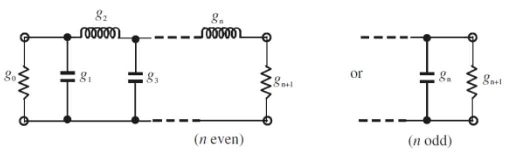


Fig.6: Lowpass prototype filters for all-pole filters with a ladder network structure

3.2 Transformation to Bandpass Filter

For basic conventional bandpass filter design, J-inverter concept is used to convert from low-pass filter to bandpass filter after obtaining the low pass prototype element values. Finally, the characteristic impedances and dimensions of the coupled lines can be attained after obtaining the low pass prototype element values.

An equivalent circuit for Hairpin Bandpass Filter is represented in Fig7 where each resonator can be modeled as a combination of an inductor and a capacitor

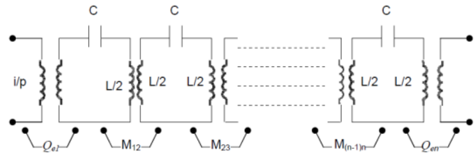


Fig.7: Equivalent circuit of the n-pole Hairpin Bandpass Filter

$M_{i,i+1}$ represents the mutual coupling coefficient between two resonators while $Q_{e1}$and Q_{en} represents the quality factors at the input and output.

The following set of equations describes the design process. The parameters computed are shown in Table 4. Coupling coefficient determines the space required between adjacent Hairpins [10].

$$\text{FBW}=\frac{\omega_2-\omega_1}{\omega_0} \qquad (12)$$

$$\omega_0=\sqrt{\omega_1\omega_2} \qquad (13)$$

$$Q_{e1}=\frac{(g_0 g_1)}{\text{FBW}} \qquad (14)$$

$$Q_{en}=\frac{(g_n\, g_{n+1})}{\text{FBW}} \qquad (15)$$

$$M_{i,i+1}=\frac{\text{FWB}}{\sqrt{g_i\, g_{i+1}}} \quad , \quad \text{for i=1 to n-1} \qquad (16)$$

Where FBW is the fractional bandwidth,ω_0 is the center frequency,$\omega_1$is the lower cut off frequency, $\omega_2$is the higher cut off frequency and g_0, g_1, g_2 ……g_{n+1} are the normalized low pass elements of the desired low pass filter approximation.

The quality factors and the mutual coupling coefficient of the filter are shown in Table4.

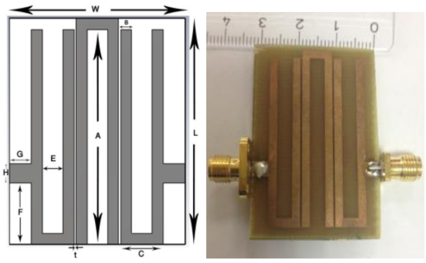
Table4. Quality factors and mutual coupling coefficients

Q factor and Coupling Coefficient	Values
Q_1	3.438
Q_2	3.438
$M_{1,2}$	0.270
$M_{2,3}$	0.270

The length of the U-shape resonator is half wavelength long. The guided wavelength can be calculated as:

$$\lambda_g=\frac{300}{f(\text{GHZ})\sqrt{\varepsilon_{re}}} \qquad (17)$$

The calculated length of U-shape resonator is 36.6mm, which is$\lambda/2$; the width of the resonator is 2 mm to match the 50 ohm line. The separation is chosen to be 0.38 mm.After obtaining all the parameters required for designing a three pole Hairpin filter, the filter is designed and simulated using CST simulator program.



(a) **(b)**

Fig.8: Filter Design (a) Top view (b) Filter photography

The configuration of designed Filter using CST simulator is depicted in Fig. 8 (a), the photograph of its fabricated version is shown in Fig. 8 (b) and its geometrical dimensions are given in Table5.

Table5. Filter parameter's size

Parameter	Size (mm)	Parameter	Size (mm)
L	38.6	E	3.8
W	32.16	H	3.2
A	36.6	G	4
B	2	F	11.2
C	7.8	t	0.38

4. ANTENNA SIMULATION AND MEASUREMENTS

The simulation of the antenna is carried out using CST simulator. Micro-strip Line Feed technique is used, where in this type of feed technique a conducting strip is connected directly to the edge of the micro-strip patch. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure [11]. The operating frequency of this design is 1950MHz with a return loss -31.85dB. The gain obtained at this frequency is 1.242dB, Directivity =2.670dBi and the BW=150.3 MHz from 1880.3 MHz to 2030 MHz at return loss -6 dB

4.1 Return loss and Bandwidth

Fig. 9 demonstrates the return loss (S-Parameter) value, as a result of antenna simulation and antenna measurement. From the antenna simulation the antenna operates between 1903.3 MHz and 2011.1MHz the Bandwidth obtained from the simulation was 107.7 MHz at return loss -6 dB with minimum return loss -28.58 dB this antenna covers LTE TDD frequency band 36.

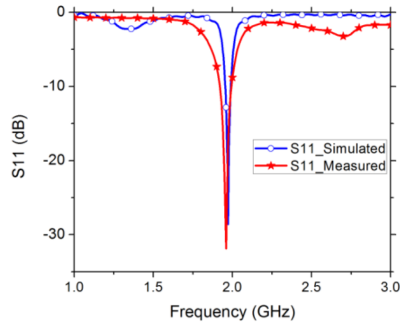


Fig.9: Comparison between the simulation and measured results for the antenna

Measurement results plotted on the same figure for sake of comparison shows that the antenna operates between 1880.3 MHz to 2030 MHz, so the bandwidth is 150.3 MHz at return loss of -6 dB and minimum return loss of -31.85dB. The measured bandwidth is larger than the simulated one this antenna covers bands33 (1990MHz-1920MHz), 34(2010MHz-2025MHz), 36(1930MHz-1990MHz) andband37 (1910MHz1920MHz).Although the measured BW is larger than the required frequency band for LTE band 36; the whole passband can be controlled by filter BW.

4.2 3-D Radiation pattern

Three-D simulated radiation pattern for determining the Directivity of microstrip patch antenna is shown in Fig.10The inset indicates that the antenna Directivity =2.670 dBi.at 1950 MHz.

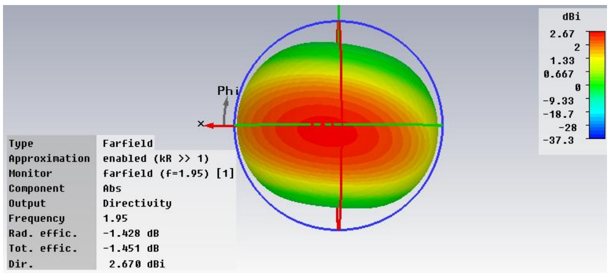


Fig.10: Directivity =2.670 dBi at 1.95 GHz center frequency

Fig.11 shows the 3-D radiation pattern of the antenna to estimate its gain. It is found that the Gain=1.242 dB at 1950 MHz frequency.

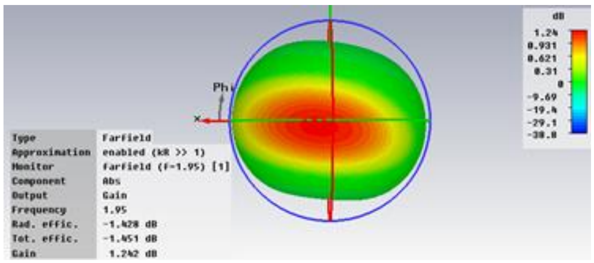
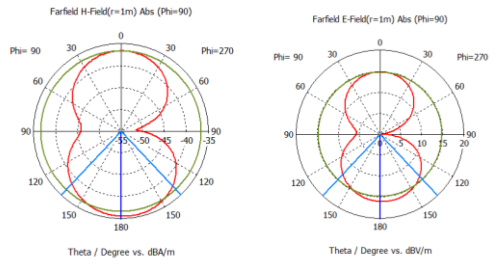


Fig.11: Gain =1.242 dB at 1.95GHz center frequency

Fig.12 shows the simulated radiation patterns of the proposed antenna on (a) H- plane and (b) E- plane. It shows that the antenna has strong back radiation because of the defected ground structure



(a) H-plane **(b) E-plane**

Fig.12: Radiation pattern of E plane and H plane at frequency 1950 MHz

5. FILTER SIMULATION AND MEASUREMENTS

The simulation of the filter design is done using CST simulator. The above given dimensions in Table5 are used to simulate the structure. The operating frequency of this design is 1950 MHz

The tapped line is chosen to have a characteristic impedance that matches to a terminating impedance Z0 = 50 ohms. Hence, the tapped line is 3.2 mm wide on the substrate. The layout of the final filter design with all the determined dimensions is illustrated in Fig.8(a). The input and output resonators are slightly shortened to compensate for the effect of the tapping line and the adjacent coupled resonator. The simulated performance of the filter is shown in Fig. 13.

From the measurements, the -3dB BW of the filter amounts to 90 MHZ and a center frequency of 1950MHz. Then the fractional bandwidth is about 4.615%.

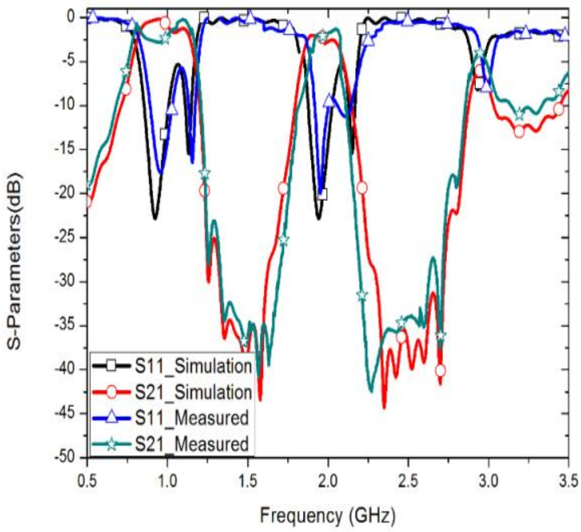


Fig.13: Comparison between the simulation and measured results for the Hairpin filter

The measured characteristics of the same filter are plotted also in Fig13 for sake of comparison. It is clear from the figure that there is satisfactory agreement between the simulated and measured results and the deviations are within the errors in measurement and fabrication and calculations.

6. CONCLUSIONS

In this paper, the design of a front end for a TDD LTE transceiver comprising a Micro-strip patch antenna and Hairpin resonator filter for band 36 covering frequencies from 1930 MHz to 1990MHz was carried out.

The design and simulation of antenna and filter have been achieved with the help of simulator CST program. FR-4 material is used as a substrate material with dielectric constant of ε_r=4.4, thickens h =1.6, and Loss tangent of 0.025to fabricate the front end. The shape of the conventional microstrip patch antenna. Was modified to minimize the size of antenna and increase the bandwidth. So the designs was optimized by using the design geometry of the E shape and by making a defect in the ground plane to maximize the bandwidth of the antenna and these goals were achieved by increasing the bandwidth 50% and decrease the area 51% compared to conventional microstrip patch antenna.

The antenna has the following characteristics: the operating frequency is 1950 MHz, the patch dimension is 27.5 mm x 24 mm x 1.6 mm, the Directivity is 2.67dBi, the Gain =1.242dB and the BW=150.3 MHz

The Design of bandpass filter with a tapped Hairpin resonator on FR4 laminates has been also presented in this paper. The resonator length was shown to have a significant effect on the center frequency. The designed filter has the following characteristics: Filter Size= 38.6x32.16mm^2, BW=90 MHz, center frequency 1950 MHz, and a fractional bandwidth of 4.615% with return loss of -20dB. These characteristics match the required specifications of the LTE transceivers.

So, it is proved in this work that a passive front end of an advanced wireless system can be successfully produced in university laboratories.

Future work design for Low noise amplifier, demodulator and synthesizer with characteristics match for LTE (TDD) band 36.Then combine the passive component (Antenna and Filter) with (Low noise amplifier, demodulator and synthesizer) to achieve a complete front end receiver for LTE TDD band 36 and measure the whole system.

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