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Smart Antenna for Future Wireless Communication

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Abstract
Long-Term Evolution (LTE) is one of the fourth generation wireless communication technologies with frequencies that vary from 400 MHz – 4 GHz. The proposed antenna array will operate at the center frequency of 3.5 GHz (LTE Band – 22). The microstrip has been selected for this application because of its compact size, narrow bandwidth, higher gain and easy fabrication. The antenna array is fabricated using FR4 epoxy substrate having dielectric constant of 4.4 and the input is given with inset feeding technique. In this paper, the rectangular patch antenna array and E-shaped patch array antenna are analyzed. E-Shaped patch is used instead of rectangular patch because of its vulnerability to interference when formed as an array. The analysis proved that the latter antenna array has better return loss, VSWR value, gain, front-to-back ratio and efficiency compared to the rectangular patch antenna array. The antennas are designed, simulated and analyzed by using ANSOFT HFSS V14.0 software.

Keywords: *LTE, antenna array, microstrip patch antenna, inset feed, E-shaped array, HFSS*

INTRODUCTION

In the recent years due to the rapid development of wireless technologies, the need for compact antenna has increased. The antenna designed for wireless communication has to exploit the resources properly. In order to cope up the advancements, wireless connections such as Global System for Mobile Communications (GSM), Wi-Fi, Long Term Evolution (LTE), Bluetooth, Global Positioning System (GPS) and Wireless Interoperability for Microwave Access (WiMAX) requires antenna with efficient design. In recent years, insatiable demand for wireless broadband arises due to advancement in wireless technology [1]. Wireless communications systems should provide high data rate services and should have a high quality [2]. The long term evolution (LTE) standard has attracted as 4G of mobile communications technology to provide better mobile broadband and multimedia services [3]. LTE is a standard for wireless communication which provides high speed data for mobile phones and data terminals. LTE communication equipment is being developed at different frequencies in various regions of the world. Frequency spectrum allocated for LTE ranges from 400 MHz to 4 GHz with bandwidths from 1.4 to 20 MHz [4].

Multiple-input multiple-output (MIMO) operation of the LTE system is becoming essential to improve data reliability, capacity of channel and network coverage in multipath environments using multiple antennas without additional power [3]. A well-known technique to improve the performance of wireless communications systems using MIMO is antenna diversity. It reduces multipath induced fading and cross-channel interference. High level of isolation between antenna elements is required in MIMO antenna systems but the space limitations mean that antennas must be placed close to each other [2]. A MIMO communication system uses antenna arrays at the transmitter and the receiver. A good MIMO antenna should have low mutual coupling between the antenna elements in the array [5]. For closely spaced elements, some amount of the radiated energy will be directly absorbed into other elements and some energy will be delivered through the common ground plane. The performance of the MIMO antenna can be degraded if the energy leaks into the other elements instead of being radiated to them [6].

The antenna designed for base station consists of an antenna array to increase the capacity of the system. This led to a great demand for designing antennas with multiband operation, low specific absorption rate (SAR), light weight, and low profile [7]. Microstrip patch antennas have been chosen for increasing number of wireless communication systems because they have simple structures, low profile, light weight, broadside radiation pattern and it is easy to form array [8]. The inset feeding technique is selected since it has the advantage of being simple to implement and the behavior of the patch antenna can be studied easily and the properties of the patch can be controlled by changing the inset gap and the inset length. The impedance control can be obtained with inset feeding.

In this paper, the rectangular patch antenna is designed using FR4 substrate to operate at 3.5 GHz. The analysis of the antenna shows that it has low gain and efficiency.

The rectangular patch antenna is a modified with E-shaped patch to broaden the impedance bandwidth of a basic patch antenna. The proposed E-shaped patch exhibits the advantage of the simplicity which requires only the length and width of the slot to be determined [9]. Hence E-shaped antenna with inset feed is designed for the same frequency. The E-shaped antenna has been selected for LTE application since it has less interference when it is used to form an array [10]. The analysis of E-shaped antenna has been done and it is compared with the rectangular microstrip patch antenna. The comparison reveals that the latter antenna exhibit higher efficiency and Front-to-Back ratio (FBR). Then the Wilkinson power divider has been designed and antenna array is designed with both rectangular patch and E-shaped patch and the results are compared.

MICROSTRIP PATCH ANTENNA

A microstrip antenna is the simplest antenna which consists of radiating patch on one side and ground plane on another side. The different shapes of microstrip antenna are square, circular, rectangular and elliptical and any shapes can be possible for various applications. Among different feeding techniques, inset feed is preferred because the impedance matching can be easily achieved by varying inset gap and inset length. The top view of the microstrip patch antenna. The advantage of microstrip patch antenna are low fabrication cost, conformal structures are possible, small size, light weight, easy to integrate with MIC, allow dual and triple frequency operation, low profile and higher gain. Though it has several advantages, it has some disadvantage such as narrow bandwidth, lower efficiency and low power handling capability

ANTENNA DESIGN

The geometry of the rectangular patch is shown in the Figure 2. It is composed of the rectangular ground plane and the dielectric substrate with relative permittivity of 4.4 and loss tangent of 0.02. The transmission line model is used as the analysis method. Inset feeding technique is used and the substrate material is FR4 epoxy with thickness of h=1.6 mm. the operating frequency is selected as 3.5 GHz. The length and width of the patch is obtained from the Eqs. (1) and (2) [11–13].

$$W = \frac{c}{2f_0\sqrt{\left(\frac{\varepsilon_r+1}{2}\right)}} \quad (1)$$

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

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+12\frac{h}{W}}}\right) \quad (3)$$

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

Where,

c = Velocity of Light

ε_r = Dielectric constant of the substrate

f = Antenna operating frequency

W = Width of the patch

L = Length of the patch

h = Height of substrate

Δl = Normalized extension of length of the patch

SINGLE ANTENNA ELEMENT

Patch as a radiator was etched on the top portion of one side of an FR4 substrate. The dimensions of the patch is 19.862 (L) x 26.082 (W) mm^2 whereas the ground plane with a size of 29.462 x 35.682 $mm^2$was printed on the other side of the substrate. A 50Ω microstrip line of width W_L and length L_L was then adopted for feeding the patch. The layout of the microstrip antenna with inset feed is shown in the Figure 1.

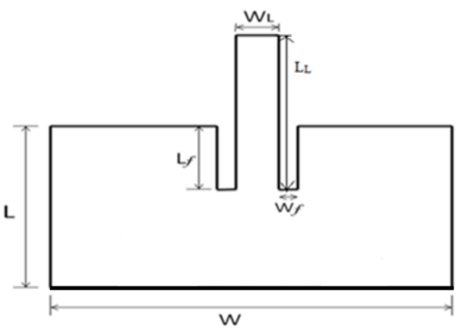

Fig. 1: *Design of Rectangular Patch Antenna.*

For improving the performance of the antenna, two slots of dimensions of L_s x W_s, are cut at the top of the patch of the above antenna to form the E-shape. The resonating frequency of E-shaped antenna is 3.5 GHz. The advantage of preferring E-shape is it has less vulnerable to interference when several antenna elements are placed adjacent to each other to form an array in multiple antenna system. The layout of the E-shaped patch antenna with inset feed is shown in the Figure 2.

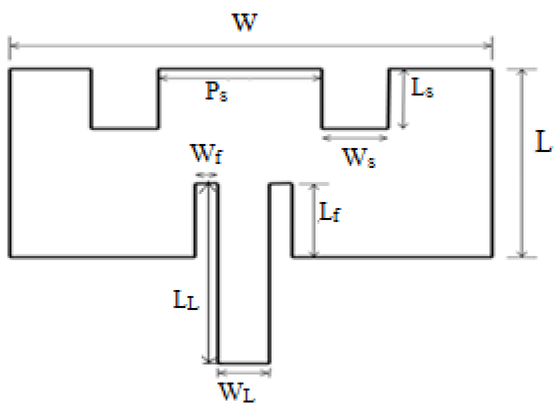

Fig. 2: *Design of the E-shaped Patch Antenna.*

By simply embedding two slots into a rectangular patch, improvement in the antenna gain and front-to-back ratio is achieved. Since the proposed antenna has two slots, the size of the patch gets reduced. The dimensions of the antenna calculated from the design equation are shown in the Table 1.

***Table 1:** Dimensions of the Designed Antenna.*

Parameter	Length (mm)
Patch Width (w)	26.082
Patch Length (l)	19.862
Feed Width (w_f)	1.5
Feed Line Length (l_l)	10
Feed Line Width (w_l)	4
Feed Length (l_f)	5.2
Slot Width (w_s)	5
Slot Length (l_s)	5
Width b/w Slots (p_s)	8.041
Height (h)	1.6

RESULT AND DISCUSSION OF SINGLE ELEMENT

The inset feed rectangular patch antenna and E-shaped patch antenna is compared in terms of return loss, VSWR, radiation pattern and gain. The analysis of both antenna shows that the E-shaped antenna has better performance when compared to the normal inset feed patch antenna. The comparison is shown in Table 2.

From the above comparison Table, it is shown that the E- shaped patch antenna has better return loss, VSWR, directivity, gain and front-to- back ratio. The analysis shows that the rectangular patch antenna is bi-directional and the E-shaped antenna is uni-directional. The uni-directional property is important in order to form array in multiple antenna systems.

***Table 2:** Comparison of Parameters of the Rectangular Patch and the E-Shaped Patch Antenna.*

Parameters	Rectangular Patch	E-Shaped Patch
Frequency (GHz)	3.5	3.5
Return Loss (dB)	-15.5355	-18.5172
VSWR (dB)	1.4015	1.2691
Bandwidth (%)	6.52	12.23
Max U (W/Sr)	0.000198	0.000218
Peak Directivity	0.03827	0.04614
Peak Gain	0.02527	0.02698
Front-to-Back Ratio	1.73628	5.16013
Directionality	Bi-directional	Uni-directional

POWER DIVIDER FOR ARRAY

Power dividers are the important component in many microwave circuits such as high power parallel power amplifiers and high gain antenna arrays. It is a passive component and used to distribute the power among different paths. The two main categories of power divider are resistive and reactive. The power divider must have properties such as high isolation between output ports, low insertion loss and low isolation loss. Wilkinson Power Divider (WPD) belongs to reactive power divider and has the advantage of matching all ports theoretically and output ports are isolated from one another. The designed WPD is a three port network and used to split the input into two equal phase signals. It uses quarter wave transformer to match the ports. The length and width of the transmission line is calculated from the known values of frequency and characteristic impedance.

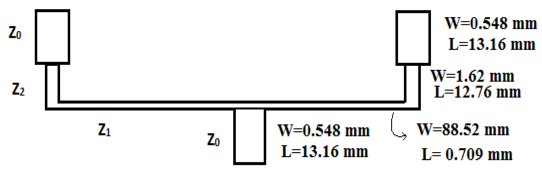

Fig. 3: *Design of Wilkinson Power Divider.*

The value of impedance is calculated from the following equations:

$Z_0 = 50$ ohm

$Z_1 = 2\ Z_0 = 100$ ohm

$Z_2 = \sqrt{(Z_0 * Z_1)} = 70.7$ ohm

The designed power divider is simulated using HFSS and the results are obtained. The return loss obtained for the designed power divider is -18.5779 dB.

ANALYSIS OF DISTANCE OF SEPARATION BETWEEN ANTENNA ELEMENTS

The antenna elements in the array are placed in such a way that the distance between them improves the performance of the array. So, the distance between the elements is varied by placing them at lambda, lambda/2 and lambda/4.

Table 3: *Contribution of Spacing between the Antenna Elements.*

Parameters	**Separation Between Antenna Elements**		
	Lambda	**Lambda/ 2**	**Lambda/ 4**
Frequency (GHz)	3.5	3.5	3.5
Return Loss (dB)	-18.126	-11.831	-13.805
VSWR	1.2833	1.6886	1.5127
Max U (W/Sr)	0.00954	0.00762	0.01079
Peak Directivity	0.40635	0.37526	0.42552
Peak Gain	0.17484	0.13480	0.18414
Radiation Efficiency (%)	39.69	35.92	43.27

The above analysis Table shows that the lambda/4 distance exhibits better performance when compared to the other two distances. So, the distance between the antenna elements is preferred as lambda/4.

RESULT AND DISCUSSION OF ANTENNA ARRAY

The antenna array is formed with rectangular patch and E-shaped patch antennas with two antenna elements. Each output of the power divider is connected to the single antenna elements. Antenna array is a set of antenna elements that can be series fed or corporate fed. The corporate feed is selected because it has the advantage of low cost, reliability, good performance and the resulting PCB will be thin. The antenna array increases the directivity and gain of the singe antenna element.

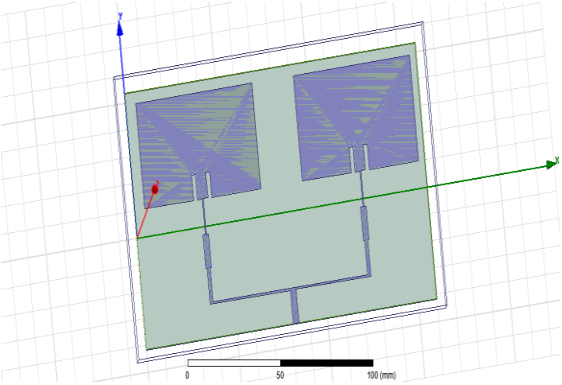

Fig. 4: *Design of Rectangular Patch Antenna Array with Two Elements.*

The Figure 4 shows the design of the rectangular patch array using the designed antenna and the Wilkinson power divider. The power divider divides the input into two and feed the two rectangular patch elements. The power divider is designed to operate in the same frequency as the antenna at 3.5 GHz.

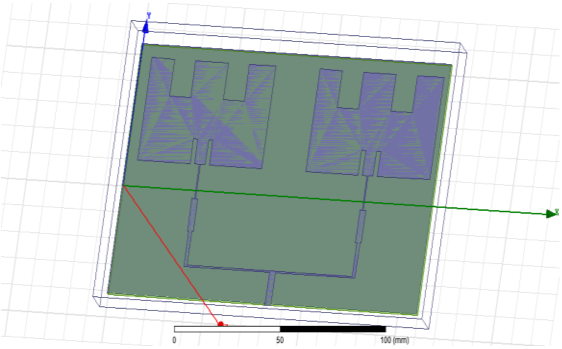

Fig. 5: *Design of E-shaped Patch Antenna Array with Two Elements.*

The Figure 5 depicts the designed E-shaped patch antenna array with the same power Wilkinson power divider designed for the frequency of 3.5 GHz. In order to improve the performance of the rectangular patch array, two slots with same dimension is cut on the patch to make it E-shaped antenna array to reduce the interference.

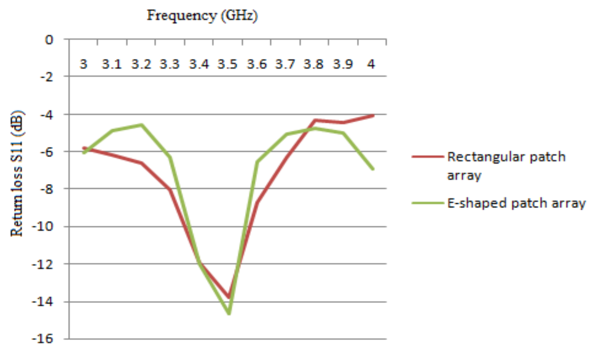

Fig. 6: *Comparison of Return loss Curves of Rectangular Patch and E-Shaped Patch Array.*

From the above graph, the comparison of return loss curve of the rectangular patch array and the E-shaped patch antenna array is done. The return loss of the antenna should be less than -10 dB. The higher the return loss, the less power will be lost due to mismatch. The analysis reveals that the E-shaped patch antenna array has less return loss than the rectangular patch array. The below comparison Table reveals that the E-shaped patch array exhibits less return loss and less VSWR value than the rectangular patch. The directivity, gain, radiation efficiency and front-to-back ratio of E-shaped array is improved compared to the conventional rectangular patch array.

Table 4: *Comparison of Two Antenna Array.*

Parameters	Rectangular Patch Array	E-Shaped Patch Array
Frequency (GHz)	3.5	3.5
Return Loss (dB)	-13.8054	-14.6674
VSWR	1.5127	1.4533
Max U (W/Sr)	0.0107972	0.0210925
Peak Directivity	0.425517	0.784098
Peak Gain	0.184139	0.353099
Radiation Efficiency (%)	43.27	45.03
Front-to-Back Ratio	2.48628	5.87566

CONCLUSION

In this paper, single antenna element is designed with rectangular patch and E-shaped patch. The result shows that the E-shaped patch performs better than rectangular patch antenna. The antennas are designed at the center frequency of 3.5 GHz. In order to improve the gain and directivity of the single element, antenna array is designed with two patch elements and Wilkinson power divider. The distance between the antenna elements is analyzed and selected as lambda/4. Then, the array is formed with both patch antennas. The gain and directivity of rectangular patch is improved in E-shaped patch array and efficiency is also increased to about 45%. In the future, the number of antenna elements will be increased.

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