Ultra-wide band microstrip antenna for 4G applications

Mohamed Fathy Abo sree1, 2, Muhammad Aly Ibrahim2, W. Swelam3, Mohamed H. Abd El-Azeem1 and Hadia El Hennawy2

1Arab Academy For science and Technology Maritime Technology, Department of Electronics and Communication, Cairo Branch AASTMT, Egypt
2Ain Shams University, Faculty of Engineering, Cairo, Egypt.
3Egyptian Armed Forces

eng_m_fathey@hotmail.com , mohamed.fathy@aast.edu ,
Muhammadalyibrahim@hotmail.com , wswelam@gmail.com ,
mhabdazeem@hotmail.com , helhennawy@ieee.org

Abstract. Presently, there is an expanded activity for ultra-wideband (UWB) technology for use in a few present and future applications. UWB got an exceptional attention, particularly after the approval of utilizing the unlicensed band beginning from 3.1 to 10.6 GHz for commercial use. A compact ultra-wide band microstrip antenna is introduced in this paper. The antenna consists of dual elements each having a size of 24X24 mm$^2$, while the total size is 58X24 mm$^2$. A decoupling circuit is added to the design; afterwards the spacing between the elements is adjusted. The first element covers the range between 3.29 and 6.9 GHZ using the digital ground and the second antenna covers the frequency range from 8.76 GHz to 13.27 GHz using defective ground. This type of antenna is designed to be used for 4G applications. The antenna’s structure and the parametric study, including the reflection coefficients, gain, coupling and decoupling, will be discussed further in this work. In addition to that comparison of similar UWB antennas is done.

1. Introduction
According to the major demand of high data rate in the wireless communication technology such as 3G and 4G; communication systems were created to improve these rates, and enhance the wireless communication [1].

The 3G system can cover a data rate of 5.8 Mbps for the uplink and 14 Mbps for the downlink. Also, the 3G system is allocated in the frequency band between 1.8GHz and 2.5GHz; 3G system applications and services include mobile internet access, mobile TV services and video call services [2-3].

Besides that, the 4G system can cover high data rates that reach 100Mbps for the mobile or moving user and 1Gbps for the stationary user. In addition to that, the 4G communication system is allocated in the frequency band from 2GHz to 8GHz. Where 4G systems offer the user high performance and high capacity; examples for the 4G applications are tele-medicine applications, tele-geoprocessing applications and educational applications [4].

The 3G/4G antennas are smart antennas; microstrip antennas are considered as an example for smart antennas, which are characterized by their low profile. That can be applicable to planar and non-
planar arrays, due to their low cost, ease of fabrication, high performance; and according to the selected patch shape they are versatile from the point of view of resonance frequency, polarization and field pattern. According to these specifications microstrip antennas can be used in aircrafts, spacecraft, missiles and satellite applications and... etc. Microstrip antennas consist of conductor plates separated from each other by a dielectric with specific permittivity and specific height [5].

Our design is made up of multiple antennas that are put together to work simultaneously at different ranges. These antennas are placed for transmitting and receiving data. Adding more antennas increases quality, reliability, throughput between transmitter and receiver [6].

Increasing the diversity is one of the primary reasons of using multiple antennas. Diversity is done by placing two antennas at a certain distance from each other, and because of the difference in physical location, each receives a slightly different version of the signal sent by the transmitter. The receiver compares between the received signals and gives out the best form of signal [6-8].

Difference created between the transmitter and receiver can increase reliability of the link between them; and this is good for noisy channels, it also can increase the used range between them [8-9].

For increasing the data rate we ask for spatial multiplexing, it can increase the capacity of the system. The source is divided into independent streams called spatial streams; in this case the throughput is doubled [9-12].

In this paper we introduce a microstrip antenna composed of two single elements as the first element covers the bandwidth from 3.29 GHz to 6.9 GHz and the second element covers the bandwidth between 8.76 GHz and 13.27 GHz. Also, there is a decoupling circuit implemented between the two elements’ grounds to reduce the coupling effect between them.

2. Antenna Structure and Design

The antenna introduced in our work is composed of two single microstrip antennas of different frequency bands, implemented on FR-4 dielectric of permittivity $\varepsilon_r = 4.4$ and dielectric height 1.6 mm. The first antenna covers a band from 3.29 GHz to 6.9 GHz as the type of the ground which is designed to help in achieving this band is called a Digital Ground. The following diagrams show the geometric dimensions of the first antenna. Where figure 1 represents the top view and figure 2 shows the bottom view of the antenna and its ground’s structure.

The second antenna covers a band between 8.76 GHz and 13.27 GHz, where the type of the ground designed to help in achieving this band is called a Defective Ground [13-14]. Figure 2 shows the geometric dimensions of the second antenna.
Then the two antennas are placed together on one FR-4 substrate of 58x24 mm2 to implement one microstrip antenna. Coupling effect occurs in the design of this antenna between the two single elements, and to reduce the coupling effect we used two techniques explained in the following paragraph.

Firstly, the spacing between the two single elements is increased as illustrated in figure 3. Secondly, a digital decoupling circuit is implemented between the two elements’ grounds; figure 4 shows the total dimensions of the antenna.

The following three tables demonstrate the different dimensions of the Microstrip antenna, expressed in millimetres:

| Layer   | Variable and Dimension | 1st antenna  |
|---------|------------------------|--------------|
| Substrate | Lsub 24 | Wsub 24 | Rp1 7 |
| Patch   | Wf 3.01 | Lf 10 | |
|          | Rs 2 | Ls 2 | |
| Ground  | S1 3 | S2 3 | S3 7 |
|          | S4 8 | S5 10 | Lg1 6 |
|          | Rg1 5.7 | Wg1 10 | Lg2 5.5 |
Table 2 Dimensions of 2nd antenna

| Layer  | Variable and Dimension |
|--------|------------------------|
| Substrate | Lsub=24 mm | Wsub=24mm |
| Patch   | Lf=10mm    | Wf=3.01 mm |
| Ground  | Rg2=9mm    | S6=5mm    |
|         | S7=10.4mm  | S8=10.4 mm |

Table 3 Decoupling Circuit Dimensions

| Layer  | Variable and Dimension |
|--------|------------------------|
| Substrate | Lsub1 24 | Wsub1 58 |
| Patch   | d1 15  |
| Ground  | R1 3   | R2 3   | Ld1 4 |
|         | Ld2 4   | Ld3 7  | Ld4 8 |
|         | Ld5 5   | d2 9   | d3 8.5 |
|         | d4 4    | d5 2.5 | d6 9.5 |
|         | d7 12   | d8 13.25 | d9 4.5 |
|         | d10 1.5 | d11 2.5 | d12 10.25 |
|         | d13 3   |

3. Antenna Results

This section will present the fabricated Microstrip antenna on a FR-4 substrate with dimensions 58X24 mm²; the following shows the real fabricated antenna. Where figure 6 shows the front view of the fabricated antenna. While the second figure 7, is a representation of the backside view of the fabricated antenna.

![Figure 6](image1.png)  
**Figure 6** The front view of the antenna

![Figure 7](image2.png)  
**Figure 7** The back view of the antenna

3.1. S-Parameter

At first, a comparison between the bandwidths of the two elements of the antenna is represented; simulation results and measurement results are illustrated. Where figure 8 shows the comparison between the measured and simulated results based on the S(1,1) factor, that reach a level below the (-15 dB) in the measured, compared to almost (-30 dB) in the simulated. While figure 9 shows the comparison based on the S(2,2), as it decays below the (-15 dB) for the measures.
The difference between the simulated and measured results is basically due to the theoretical results using waveguide port on the software tool simulation; while in the practical antenna an SMA connector was used to be able to measure the s-parameter of the antenna. The SMA connector had a large effect on the s-parameter because the antenna has a small size therefore the SMA connector was able to make an observed difference between the simulated and measured results.

Secondly, we compare the coupling effect between the two elements of the antenna which is simulated and measured, where figure 10 and figure 11 represent the comparison between the coupling effect which is simulated using the software and the practical coupling effect.

Finally, the overall s-parameter is shown and to explain the purpose of this antenna design, and to prove that the antenna elements are separated in the frequency domain. Thus figures 12 and 13 represent the overall s-parameter. Where figure 12 shows the simulated results, and figure 13 shows the practically measured results.
3.2. VSWR
In this part, a comparison between the simulated and measured VSWR results will take place; figure 14 represents the difference between simulated and measured VSWR results. The result's graph demonstrates a curve tending to reach the value of 1 within the bandwidth interval.

3.3. Gain
For the Gain, figures 15 and 16 represent the outcome between the simulated and the measured gain of the antenna. Where the measured results show a peak gain around the 6 dB at some intervals on port 1 shown in figure 15. While the maximum gain of the measured antenna at port 2, exceeds 8 dB as demonstrated in figure 16.
3.4. Total Efficiency of Antenna
The Total Efficiency is represented in fig. 10, it displays the simulated and measured. From the figure, it's noticed that the efficiency can reach levels above 60% and 70%.

![Figure 17 Total efficiency simulated and measured at port1](image1)

![Figure 18 Total efficiency simulated and measured at port2](image2)

3.5. Radiation Pattern
Also, the radiation patterns at both E-plane and H-plane are demonstrated in six different frequencies. The pattern is divided into three frequencies for the first element as they are located at the first band (S11). The other three frequencies are for the second element, that are located in the second band (S22). The following graphs including figure 19, 20, 21 and 22 illustrates the radiation patterns at these six different frequencies.

![Figure 19 E-Plane Radiation patterns from port1](image3)

![Figure 20 H-Plane Radiation patterns from port1](image4)
4. Comparison
In this part we will be comparing our suggested design with other designs and other papers, that similarly are designed to operate within the UWB. The comparison will be based on the dimension, minimum value of return loss (S11) reached, the total bandwidth achieved in GHz and the gain in dB. This comparison is represented at the next table:

| Ref. | Dimensions       | Return Loss (min. db) | Bandwidth (total) | Gain (dB) |
|------|------------------|-----------------------|-------------------|-----------|
| This Work | 58 x 24 mm² | -18 | 8.1 GHz | 8 |
| [15]  | 30 x 35 mm²    | -30 | 8.2 GHz | 6 |
| [16]  | 30 x 17 mm²    | -35 | 4.15 GHz | 4 |
| [17]  | 29.4 x 29.4 mm² | -30 | 9.2 GHz | 5.5 |
| [18]  | 32.42 x 27 mm² | -45 | 7.19 GHz | 5.4 |

From the table above, the proposed antenna design was able to achieve the highest gain value compared to the other papers. While it was also among the highest reachable bandwidth with a range exceeding the 8 GHz.

5. Conclusion
The Microstrip antenna designed in this paper is implemented on a 58x24mm2 FR-4 substrate, and composed of two elements. Each element covers a specific bandwidth so the two elements of the antenna are separated in the frequency domain; also, a decoupling circuit was designed between the two elements to minimize the coupling effect as possible. The antenna was then fabricated and measured to compare the results with the simulation. A total bandwidth of approximately 8.2 GHz was achievable and the minimum value of the return loss measured was around the -18 dB.

The future work for this design will include further enhancements to reach better values concerning the return loss, while maintaining the large bandwidth offered, and also attain the high results of the gain.
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