A Novel Linear Array Antenna Based on UWB Slot Antenna

Faten Ben Ghenaya, Ridha Ghayoula and Ali Gharsallah

Unit of Research in High Frequency Electronic Circuits and Systems, Faculty of Mathematical, Physical and Natural Sciences of Tunis, Tunis El Manar University, Campus Universitaire Tunis-El Manar-2092, Tunis, Tunisia

Abstract: This paper introduces the novel Ultra-Wide Band (UWB) antennas for UWB applications. We used two different structures, the first is fed by micro-strip line and the second is a compact coplanar waveguide fed planar slot antenna. These designs are a small on planar antenna. The substrate used is FR4 that have the characteristics following: Permittivity $\varepsilon_r = 4.4$ Impulse Radio Ultra Wide Band systems (IR-UWB). The frequency central is 5.6 GHz and shows good characteristics for IR-UWB. The radiation pattern and gain are simulated and we compared between the different results we have obtained.

Keywords: Wireless Communications, UWB Antenna, Linear Antenna Array

Introduction

In the Internet development, wireless communications with mobile vehicles becomes a new challenge because most computers and almost all “mobile” devices (such as mobile phones) have means for connection to one or more types of wireless networks such as WiFi, Bluetooth or infrared (Sabattier, 2008). So, the necessity of high data rates wireless communication becomes more and more urgent and various solutions have been brought forward. As a solution, we choose the UWB antenna because she makes it possible to attain speeds of several hundreds of megabits per second, while retaining a limited cost and complexity (Blefari-Melazzi et al., 2002).

Currently, a plurality of antenna structures have been designed to satisfy the strong demand of wideband antennas and more miniaturization techniques and band broadening have been developed. Many technologies were reported to broaden the bandwidth; The stacked patch antennas with aperture coupled feed can provide wider bandwidth, to cover GSM1800 and UMTS in, the Microstrip stacked patches for dual-polarization have been proposed, patch elements fed with two probes with a relatively broad bandwidth have been introduced, Genetic algorithm was used to design microstrip patches operating at GSM1800 up to UMTS and for simple structure and stable performance needs, through metal dipole antenna is an usual choice.

In this article, we offer two new Ultra Wide-Band antennas for UWB applications and for communicate with mobile vehicles, we are interested exclusively on the base station and as an application, we proposed the implementation of these antennas near propose to design high gain antennas to maximize their range and minimize their number (Ahmed and Sebak, 2008).

As first proposed antenna consists of a rectangular patch with two stages and a partial plan field (Choi et al., 2004; Vuong et al., 2006).

In the rectangle, we added 2 slots to obtain high bandwidth and higher gain in the normal direction of the plane of the antenna. The inquests based on experiments and simulations are conducted. The simulation is performed using the commercially available simulation software CST Microwave Studio (CSTMS, 2008). The second antenna is a Compact Coplanar Waveguide (CPW) fed planar slot antenna (William and Nakkeeran, 2010a). This antenna possesses the above said characteristics with simple structure, less dispersion, less radiation loss and easy integration of Monolithic Microwave Integration Circuits (MMIC) (Simons, 2004). This antenna is fed by a coplanar line with a rectangular slot to ensure high bandwidth and higher gain in the normal direction of the plane of the antenna. In the second part of the article, we presented the antenna networks and as example we utilize simulation of linear antenna array. This article is organized as follows: In section 2, we presented the UWB antenna, section 3 presented the two structures proposed and simulation, section 4 presented the linear Array and the simulation results and, finally, section 5 makes conclusions.
Table 1. The frequency band for these applications

| Frequency Band | Applications |
|----------------|-------------|
| 24 and 77 GHz  | applications related to vehicle |
| < 1 GHz        | GPR radar and radar |
| 1.99-10.6 GHz  | Medical applications (imaging) |
| 3.1-10.6 GHz   | Wireless communications systems and applications related to the localization |

**Ultra Wide Band Antenna**

The techniques of Ultra Wide Band (UWB) were paid the most attention to multiple advantages, such as higher data rates, operational safety, low interference existing systems and immunity to the cancellation of the increase in multiple communications.

The definition of Ultra Broadband given by the FCC (Federal Communication commission) in February 2002 is as follows. A signal is Ultra Wide Band if its bandwidth and a Vivaldi antenna and the transient responses of a rectangular slot to ensure high bandwidth and a higher gain in the normal direction of the plane of the antenna (William and Nakkeeran, 2010b).

This antenna has been printed on a FR4 epoxy substrate with thickness $h = 1.6$ mm and permittivity ($\varepsilon_r = 4.4$, $\tan \delta = 0.0009$).

The proposed antennas have been printed on a FR4 epoxy substrate with permittivity ($\varepsilon_r = 4.4$, $\tan \delta = 0.0009$) and thickness $h = 1.6$ mm.

The size of this antenna with two slots in Fig. 1 is around $35$ mm ($L_{sub} \times 30$ mm ($W_{sub}$).

The antenna is printed in the front of substrate FR4 with the compact dimensions of $15 \times 14.5$ mm$^2$ and is feed by a $50$ Ω microstrip line printed on a partial ground plane.

The dimensions of the slot and of the ground plane are ($11 \times 0.5$ mm$^2$) and ($30 \times 11.5$ mm$^2$) respectively in this study. The parameters of the antenna are the following: $L_p = 14.5$, $W_p = 15$, $L_{sl} = 5$, $W_{sl} = 0.5$, $L_{st1} = 1$, $W_{st1} = 1.5$, $L_{st2} = 1.5$, $W_{st2} = 1.5$, $W_c = 1$, $L_r = 12.5$ and $W_r = 3.2$ mm.

We use commercially available simulation CST Microwave Studio to realize the antenna. The return loss (Fig. 2) and radiation pattern (Fig. 3) of the UWB antenna with two slots are shown.

**Second Configuration: The Triangular Slot Antenna**

Figure 4 presents a UWB patch antenna in the form of rectangle fed by a Coplanar Waveguide (CPW) in a rectangular slot to ensure high bandwidth and a higher gain in the normal direction of the plane of the antenna (William and Nakkeeran, 2010b).

This antenna has been printed on a FR4 epoxy substrate with thickness $h = 1.6$ mm and permittivity ($\varepsilon_r = 4.4$, $\tan \delta = 0.0009$).

Figure 4 shows the dimensions of the antenna proposed who are: The length ($L$) and width ($W$) of antenna are $28 \times 21$ mm, the length ($L_r$) and width ($W_r$) of the slot are $13.5 \times 14$ mm, the feed gap distance ($d$) is $1.1$ mm, the height of the tuning stub ($H$) is $5.4$ mm and the length of the slot in the tuning stub ($L_s$) is $18$ mm.

The $50$ Ω characteristic impedance CPW feed is designed with fixed feed line width of 2.4 and 0.5 mm ground gap.

**Different Characteristics for the 2 Antennas**

As summary, the antennas have the following characteristics, in order to more easily in power before their advantages and disadvantages.

Figure 7 represents the return loss of the two antennas: UWB antenna with two slots and the triangular slot antenna.

Table 2 summarizes the different characteristics for the two antennas.

In Fig. 8, we have shown the input impedance of the UWB antenna with two slots over the bandwidth of 5 to 8 GHz. The graph shows input impedance fluctuates throughout the bandwidth of 5 to 8 GHz. the imaginary part of the impedance between 20 Ω and about $-40$ Ω gold the real part of the impedance varies between 70 and 20 Ω about.
Fig. 1. Geometry of the UWB antenna with two slots

Fig. 2. Return loss of the UWB antenna with two slots
Fig. 3. Radiation pattern of the UWB antenna with two slots in 3d

Fig. 4. Geometry of the triangular slot antenna
Fig. 5. Return loss of the triangular slot antenna

Fig. 6. Radiation pattern of the triangular slot antenna
In Fig. 7 we have show the return loss of the UWB antenna with two slots and the triangular slot antenna. The graph shows return loss fluctuating across the entire bandwidth from 3.1 to 10.6 GHz. The real part of return loss varies between -15 dB and about -30 dB, whereas the imaginary part varies between -20 dB and about -50 dB.

In Fig. 8 we have show the input impedance of the triangular slot antenna over the bandwidth between 5 and 8 GHz. The graph shows input impedance fluctuating across the entire bandwidth from 5 to 8 GHz. The real part of impedance varies between 110 Ω and about 30 Ω, whereas the imaginary part varies between 40 Ω and about -50 Ω.
Fig. 9. Simulated real and imaginary input impedance

Fig. 10. Linear antennas array

| Table 2. Different characteristics for the 2 antennas |
|------------------------------------------------------|
|                                                      |
| The UWB antenna with two slots | The triangular slot antenna |
| Size | (35×30) mm² | (35×30) mm² |
| Band-width (GHz) | 3.750 | 2.012 |
| Input Impedance (Ω) | 50.53 | 49.56 |
| Gain (dB) | 3.642 | 3.771 |
| Directivity (dBi) | 3.472 | 3.471 |
| Angular width at 3 dB in the E plane | 75.6° | 96° |
| Radiation pattern | Stable and symmetrical in the E plane | Stable and symmetrical in the E plane |
| Polarization | Vertical | Vertical |
Antenna Array

An antenna array is a set of antennas separate and have a fed synchronously antennas. That is to say a phase difference between the two current pairs of antennas is fixed (Kin and Rahmat-Saïmu, 2013). In our paper, we are interested in the linear array. Linear array geometry is most frequently used in the design of antenna arrays. This is a set of N elementary sources arranged according to a given axis and spaced in pairs by the distance d (Fig. 10) (Singh et al., 2013).

In the azimuth plane, the far-field radiation function is following axis Ox, as we already know from Equation 1.

The angular distribution of the field is independent of the distance $r$. For a typical antenna element, the far electric field is:

$$E_n(r) = ja \mu \frac{e^{-j \beta r}}{4\pi r} f_n(\theta, \phi)$$  \hspace{1cm} (1)

The angular-dependent vector $f_n(\theta, \phi)$ gives the directional characteristics of the $n$th element electric field (Vuong et al., 2007; William and Nakkeeran, 2010b):

$$f_n(\theta, \phi) = I_n e^{-j \beta r}$$ \hspace{1cm} (2)

$$f(\theta, \phi) = \text{Called the 'pattern function' of the element}$$

$I_n$ = The complex excitation of the $n$th element of the array

$$E(r) = ja \mu \frac{e^{-j \beta r}}{4\pi r} f(\theta, \phi) \sum_{n=1}^{N} I_n e^{j \beta r_n \cos \zeta_n}$$ \hspace{1cm} (3)

Where:

- $r$ = The distance of the observation point from the origin
- $\beta = \frac{2\pi}{\lambda}$ = The free space wave number
- $\omega$ = The angular frequency
- $\mu$ = The magnetic permeability of the space
- $r_n$, $\theta_n$ and $\phi_n$ = The spherical coordinates of a convenient reference point of the $n$th element and $\cos \zeta_n = \sin \theta \sin \theta_n \cos(\varphi - \phi_n) + \cos \theta \cos \theta_n$

The Results for N Antennas

We used $n$ antenna elements and we have put along the axis Ox.

The N elements linearly are spaced by a distance $d_1$ for the UWB antenna with two slots and $d_2$ for the triangle slot antenna.

| N   | The UWB antenna with two slots | The triangular slot antenna |
|-----|--------------------------------|-----------------------------|
| 1   | 3.602                          | 3.768                       |
| 2   | 7.015                          | 7.246                       |
| 4   | 13.620                         | 10.400                      |
| 8   | 14.830                         | 14.530                      |
| 16  | 18.250                         | 16.590                      |
| 20  | 19.252                         | 18.420                      |

|                | The UWB antenna with two slots | The triangular slot antenna |
|----------------|--------------------------------|-----------------------------|
| Size (mm$^3$)  | 630*30*1.92                    | 495*30*1.76                 |
| Band-width (GHz)| 3.75                           | 2.012                       |
| Gain (dB)      | 18.25                          | 16.59                       |
| Angular width at 3 dB in the vertical plane (°) | 74.3 | 73.8 |
| Angular width at 3 dB in the horizontal plane (°) | 5.6  | 7.9  |
| Side lobe level (dB) | -6.5                         | -2.5                        |

In the (Table 3), all results of simulations of the linear array of two antennas are summarized.

$d_1 = 40$, $d_2 = 31$ mm, we saw that the gain increase with increasing numbers of antennas.

Comparison between the two Structures

To satisfy the UWB that requires strong antenna gain, we studied two types of structure in a linear antenna array.

Table 4 illustrates the main characteristics of these two solutions.

After the table, we saw the results obtained for the two structures are nearly equal, except that the first antenna gets a wideband and a higher gain.

Conclusion

In this study, we presented two novels UWB slot antenna with minimum size and better impedance matching. The first configuration of the proposed UWB antenna is a rectangular patch with two slots and two stages and a partial ground plane. The second antenna consists of coplanar fed slot antenna Compact Planar Waveguide (CPW). Due to its very wide bandwidth, these antennas can be considered as a potential candidate for cost effective UWB applications. But in many applications such as communication long distance, it is necessary to design highly directional antennas, so with a high gain.

Hence, we are set these antennas in array to increase the gain and the linear array is chosen for our application.
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Author’s Contributions

Faten Ben Ghenaya: Conception, design and writing of computer programs for the novel Ultra-Wide Band (UWB) antennas for UWB applications.

Ridha Ghayoula: Coordination of the realization of this work.

Ali Gharsallah: Organization of the plan of this study.

Ethics

This work is new and presents unpublished material. All authors have examined and agreed the manuscript. We confirm that no ethical issues concerned.

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