Design and Analysis of an Antenna for Ultra-Wideband System

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***Abstract*—In this paper requirements for the Ultra-wideband antenna and differences between narrow-band and ultra-wideband antennas for wireless system are discussed. Also a novel printed loop antenna with introducing an L shape portion to its arm is presented. The antenna offers excellent performance for lower-band frequency of UWB system, ranging from 3.1 GHz to 5.1 GHz. The antenna exhibits a 10 dB return loss bandwidth over the entire frequency band. The antenna is designed on FR4 substrate and fed with 50 ohms coupled tapered transmission line. It is found that the lower frequency band depends on the L portion of the loop antenna; however the upper frequency limit was decided by the taper transmission line. Though with very simple geometry, the results are satisfactory.**

***Index Terms*—Antenna design, broadband wireless communication, ultra-wideband antenna.**

I. Introduction

THE Ultra-wideband (UWB) system covers the frequency range from 3.1-10.6 GHz, which based on narrow pulses to transmit data at extremely low power, and looks like random noise to most conventional radio systems. The UWB technology offers several advantages over conventional communications systems. For instance, there is no carrier frequency. Instead, UWB emits timed "pulses" of electromagnetic energy. Therefore transmitter and receiver hardwares can be made very simple, which is necessary for the portable devices. There is a wide range of applications for UWB technology, which includes wireless communication systems, position and tracking, sensing and imaging, and radar.

Antenna plays an essential task in UWB system, which is different from narrowband system. UWB systems transmit extremely narrow pulses on the order of 1 ns or less resulting in bandwidths in excess of 1 GHz or more. However, the design and fabrication of high-performance transmitting/receiving antennas often present significant challenges in the implementation of these systems. The challenge lies in the development of an antenna, capable of handling these high-speed pulse trains. The design of a UWB antenna is very difficult, because the fractional bandwidth is actually big, and antenna must cover multiple-octave bandwidths in order to transmit pulses that are of the order of a nanosecond in duration.

Since data may be contained in the shape of the UWB pulse, antenna pulse distortion must be kept to a minimum. From a system design perspective, the impulse response of the antenna is of particular interest, because it has the ability to alter or shape the transmitted or received pulses. In practice, attempt must be made to limit the amplitude and group delay distortion below certain threshold that will ensure reliable system performance.

The purpose of the current study is to establish guidance for the UWB antenna designers, make notes on the necessary parameters of UWB antennas, and provide an example of UWB antenna.

II. Antennas for Wireless System

There are several different types of wireless antenna [1], divided into two main groups: directional and omni-directional, which might be used in narrowband or wideband systems.

Directional antenna is suitable for long distance communications as they have focused beam with high gain, while omni-directional antenna covers a wide area with reasonable gain. Hence, omni-directional antenna is suitable for short distance and indoor environments, such as office or room.

Wireless antennas may be classified into two separate classes, narrowband and wideband. The narrowband class demonstrates tremendous smallness for a given operating bandwidth. The wideband class possesses extreme bandwidth capability, capable of covering multiple octaves.

Both classes achieve performance very near to the theoretical Chu-Harrington limit [2], indicating that they are as small as possible for the exhibited bandwidth. The Chu-Harrington graph is a theoretical limit concerning the volumetric size of an antenna element to its quality factor or bandwidth of operation. This relationship gives the antenna designer an approximation of a switch between size and desired bandwidth.

There are many issues involved in designing of UWB systems, such as antenna design, channel model, and interference. UWB antennas must cover an extremely wideband of 3.1-10.6 GHz (lower band 3.1-5.1 GHz, upper band 5.85-10.6 GHz) for the indoor and handheld applications, have electrically small size, and high efficiency. In addition, they are required to have a non-dispersive characteristic in time and frequency domain, providing narrow pulse duration to enhance a high data throughput. Antennas in the frequency domain are typically characterized by radiation pattern, directivity, impedance matching, and bandwidth [3]. However, there are certain requirements for the antennas in the wireless system regardless of ultra-wideband or narrowband same as regulatory issues, antenna gain, antenna efficiency, and group delay of antenna.

III. Antenna Gain

The required gain is decided by link budget, which is calculated by taking into account the required channel quality. As mentioned above a directional antenna will provide high gain in narrow field with large size radiator, while an omni-directional antenna has low gain in wide field with small size of radiator. It should be kept in mind the regulatory issues, when high gain directional antenna is in use, because the peak radiated emission limit must meet the regulatory limit. Therefore, transmit power must be decreased, when using a high gain directional antenna. In view of the fact that regulatory limits are defined in terms of Effective Isotropic Radiated Power (EIRP), system designer should try to keep EIRP as much as possible constant and close to the regulatory limit. The EIRP is

$$EIRP(f) = P_{TX}(f)G_{TX}(f) \qquad (1)$$

where $P_{TX}(f)$ is the transmitting antenna power and $G_{TX}(f)$ is the transmitting antenna gain.

IV. Antenna Size And Gain

Wireless systems needs antennas with small geometrical dimensions. An antenna is said small when its geometrical size is small compare to the operating wavelength and can be fit into a radiansphere of $\lambda/2\pi$ [4], [5]. Particular consideration should be taken in the time of small antennas design, as small antennas are inefficient by nature and have high quality factor.

The electrical size of a small omni-directional antenna may in point of fact be considerably larger than the physical area of antenna. This follows from the ability of electromagnetic waves to couple to objects within about $\lambda/2\pi$ [6]. Therefore, even a small physical size antenna can receive or transmit electromagnetic radiation.

V. Antenna Size And Bandwidth

The Chu-Harrington limit [2] has investigated basic limits on antenna size, efficiency, and bandwidth and re-examined by McLean [5]. This limit is related to the quality factor of small antenna, which is inverse fractional bandwidth of antenna too. That means, small antenna provides narrow bandwidth, due to high quality factor.

Generally the antenna bandwidth is limited by size relative to the wavelength. But, a small antenna could be made wideband by reducing its internal reflections at its discontinuities. Due to finite size of antenna, it is impossible to make an antenna without discontinuities. It is possible to make an antenna as wideband as possible by constructing a gradual transition between the metal surface of the antenna and free space. This can be done in different approach, such as antenna shape, surface resistance or reactance [7], [8].

VI. Group Delay

An antenna in UWB system can be analyzed as a filter by means of magnitude and phase responses. When a signal passes through a filter, it experiences both amplitude and phase distortion, depending on the characteristics of the filter. By representing the receiver/transmitter antenna as a filter, we can determine its phase linearity within the frequency band of interest by looking at its group delay.

Group delay is the measure of a signal transition time through a device. It is classically defined as the negative derivative of phase versus frequency given by

$$GroupDelay = -\frac{d\theta(\omega)}{d\omega} \qquad (2)$$

The phase response and group delay are related to the antenna gain response. The group delay variation induced by the radiation pattern of the antenna appears to be a very important parameter in the overall receiver system performance, since it can bring relatively large timing errors. An antenna gain plot without null, means a linear phase response, hence a constant group delay.

VII. L-Loop Antenna

Based on the above explanation a planar antenna namely L-Loop antenna (patent applied for) is designed. The proposed design is described in detail, and simulation results of the antenna are presented. The simulation results have been obtained from Method of Moments (MoM). The structure of L-loop antenna is illustrated in Fig. 1. To have a linearly polarized radiation the total length of outer limits of the square loop antenna should be in one wavelength [3]. Designing the antenna for 3.1 GHz will give the wavelength of λ_0 = 96.77 mm. The present antenna composed of a single metallic layer and printed on a side of a FR4 substrate with dielectric constant of ε_r = 4.4, loss tangent of $\tan\theta$ = 0.02, and thickness of 1 mm. A coupled tapered transmission line is printed in the same side with similar metallic layer. A copper of 0.018 mm thickness has been used as a metallic layer. As shown in Fig. 1 the size of the proposed antenna is 24 x 25 x 1 mm, which is quite appropriate for wireless system. The rectangular loop has 98 mm length, which is fairly close to one wavelength of designed antenna. In this work we used taper transmission line for impedance matching, and we modified the shape of conventional loop antenna with introducing an L portion to its arms, as shown in Fig. 1, to reduce the antenna's internal reflections at its discontinuities and make gradual transition

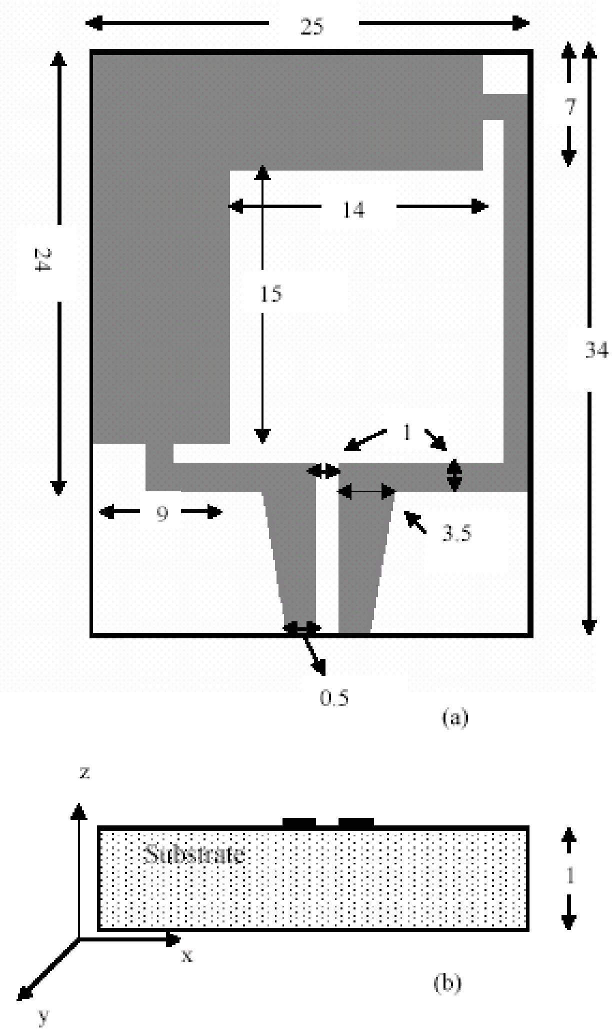


Fig. 1. a) Top view, b) Side view of the antenna structure (Unit: mm).

between the metal surface of the antenna and free space.
The tapered transmission lines have shown good impedance matching over a wide range of frequency [9]-[14]. The geometry of the taper is chosen to minimize the reflection and optimize impedance matching and bandwidth. Moreover, the use of taper in the antenna structure can make more magnitude of pulse due to more radiation near to the feed point.

The achieved impedance bandwidth is in the order of 2 GHz (3.1-5.1 GHz) for VSWR ≤ 1.6, as illustrated in Fig. 2. The antenna gain is illustrated in Fig. 3. It is observed that the designed antenna achieved almost more than 1.4 dBi gain in the entire frequency. Fig. 3 shows that the designed antenna gain variation is less then 0.8 dBi in the total frequency band. For UWB antenna, the most difficult part is to maintain the stability of the radiation pattern across the frequency band. The proposed antenna radiation patterns at 3.1, 4.1, and 5.1 GHz for $\varphi = 0^o$ and $\varphi = 90^o$ are illustrated in Fig. 4. It can be seen that antenna almost achieved radiation pattern stability across the frequency band.

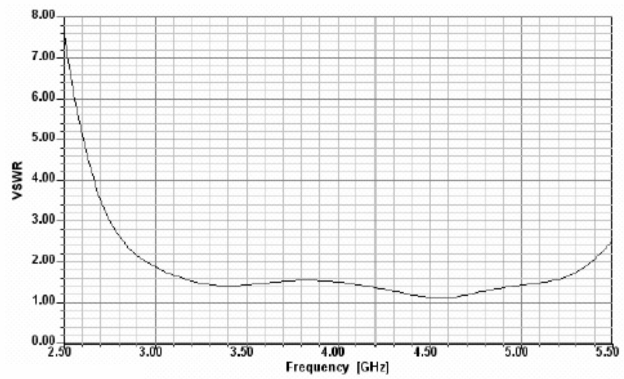


Fig. 2. VSWR of proposed antenna.

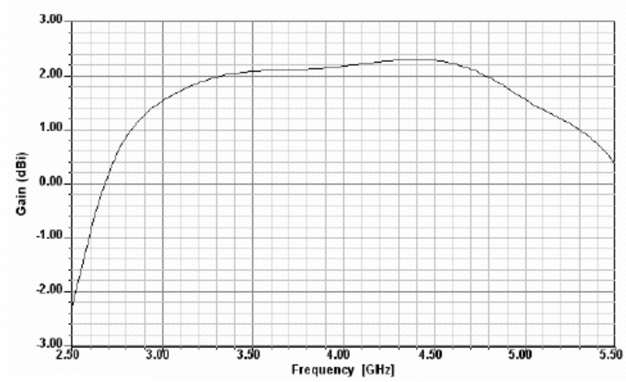
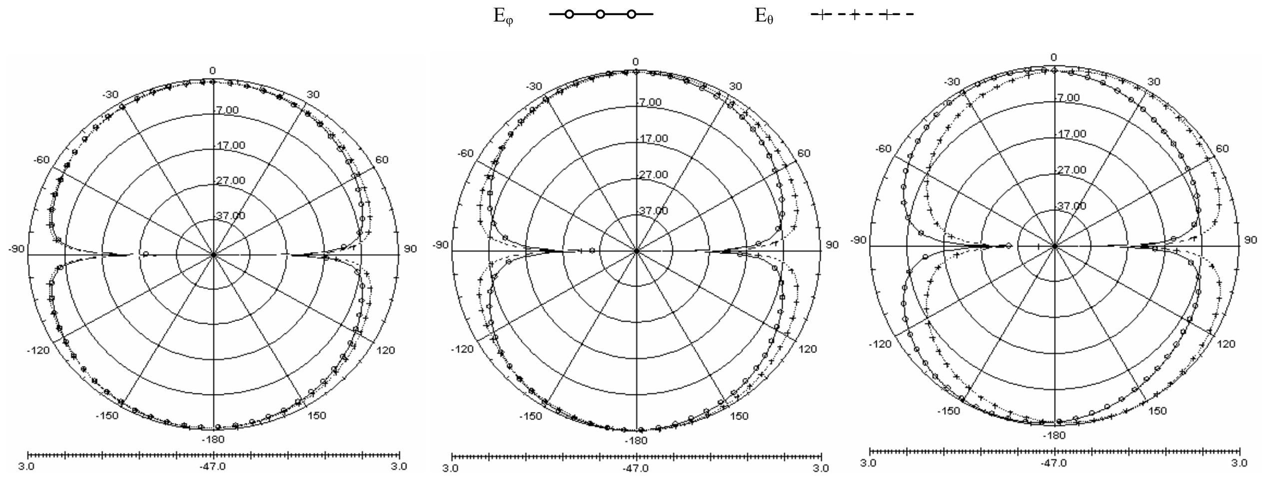


Fig. 3. Gain of proposed antenna.

VIII. CONCLUSION

A main aim of this study was to understand the important aspects of UWB antenna design and how they are related to the system performance. UWB antennas should be designed with specification of flat amplitude and linear face response over the desired bandwidth. For UWB system antenna is the significant part of the system. Its characteristics have an effect on the overall system performance.

An UWB L-Loop antenna was presented in this work. It was demonstrated that by introducing an L pattern to the printed rectangular loop antenna an impedance bandwidth of 2 GHz can be achieved. The proposed antenna has excellent performance for lower band of the UWB system and has the attractive features of small size, low-cost, and easy to design.



a) b) c)

Fig. 4. Radiation patterns of proposed antenna at a) 3.1 GHz, b) 4.1 GHz, and c) 5.1 GHz.

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