Ultra-Wideband Monopole Antenna with Modified Ground Plane

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Introduction

Ultra-Wideband (UWB) technology has drawn great attention since its emergence at the beginning of the new millennium, and the monopole microstrip antenna with a truncated ground plane has proved to be a good UWB antenna choice as shown in [1-3]. A different shape of microstrip monopole antenna is introduced to cover most of the UWB systems with satisfactory characteristics that meet UWB technology requirements. An antenna system consisting of the proposed antennas is built to analyze the transmission and the reception characteristics.

Although the transfer function of the UWB antenna system was investigated in [1] using a first-order Rayleigh pulse as a transmitted signal, it was evident that the power spectrum density (PSD) of the first-order Rayleigh pulse does not completely meet the FCC regulations [4] regarding UWB system spectral power. In [5], a modulated signal was used as transmitted signal. Although the modulated signal meets the FCC requirements regarding UWB spectral power for indoor applications, the modulated signal has a narrow 3-dB bandwidth.

In this paper, the fifth derivative Gaussian pulse is used as input signal to the proposed antenna system. The power spectral density of fifth derivative Gaussian pulse [6] fully meets FCC requirements. It also has a wider 3-dB bandwidth than that in [5]. The transfer function (S21) is measured at different distances and positions to guarantee good transmission and reception of the designed antenna under several realistic conditions. The received signals under these conditions exhibit good omnidirectional properties.

Antenna Design and Analysis

The proposed antenna is a monopole microstrip line fed antenna with truncated modified ground plane as shown in Fig. 1, where L=50mm, W=42mm, W1=2.6mm, L1=20.38mm, L2=12.67mm, L3=3mm, L4=4mm, S=1mm, S1=2mm, r=10mm. The antenna is fabricated on Rogers RT-5870 substrate of thickness of 1.57 mm, and relative permittivity of 2.33. The antenna is fed using microstrip feeding technique. The ground plane extends at bottom side of the substrate as shown in Fig. 1 to obtain a microstrip feed line with 50Ω impedance. The truncated ground plane is to compensate for the mismatch between the feed line and the top radiating patch. The wide bandwidth is achieved by overlapping two resonant frequency bands. For example in CST MW studio, the two resonances are centered at 4.1GHz and 7.4GHz. The measured 10 dB return loss bandwidth is from 3.5 to about 11 GHz; while in simulation (CST) is from 2.8 to more than 11 GHz as shown in Fig. 2.
Antenna System Measurements

The 10-dB bandwidth is not the end of the story when it comes to the UWB antenna design. Time domain characteristics for the antenna are required also. The UWB spectral mask for the proposed antenna system must meet FCC’s requirements as indicated in [4]. Therefore, an antenna system consisting of two of our proposed antenna and air as a wireless channel were built. The transfer function of the system is measured. Different positions, and distances between the transmitter and the receiver were considered when measuring. The positions are face to face, face to side, and side to side.

The idea of measuring the transfer function using different positions between the transmitter and the receiver is to mimic realistic circumstances of the proposed system. This will guarantee that the antenna system is operable under different conditions. The distances used in measuring the transfer function are 30 cm and 50 cm; these distances are chosen to guarantee that the reception will be at the far field region which is greater than the minimum far field distance \( r = \frac{2D^2}{\lambda} \) [7]. The 5\textsuperscript{th}-derivative of the Gaussian pulse with \( \sigma \) (standard deviation) = 51 ns is found to satisfy the FCC requirements for indoor transmission as illustrated in [6]. Therefore, this signal will be used as input signal \( x(t) \) to the proposed antenna system. The antenna system can be considered as linear time invariant (LTI) system. So the transfer function \( H(f) \) can be found by measuring \( S_{21} \). Since all passive antenna systems comply with the theory of linear, time-invariant (LTI) system, the received pulse can be found by \( Y(f) = H(f) \ast X(f) \) [8], where \( Y(f) \) is the Fourier transform of the received signal, \( X(t) \) is the Fourier transform of the transmitted signal, and \( H(f) \) is the transfer function in the frequency domain. Figs. 3-5 display the measured and the calculated magnitude of the transfer function where the separation distance between the transmitter and the receiver is 30 cm. The magnitude of \( S_{21} \) is calculated using Friis’ transmission equation which is given by [9]:

\[
P_r = |S_{21}|^2 P_t = \left( \frac{\lambda}{4\pi d} \right)^2 G_r G_t P_t
\]

Which relates transmitted power \( P_t \) to received power \( P_r \). The simulated gains of the receiving and the transmitting antennas are used for \( G_r \) and \( G_i \) respectively, and \( d \) is the separation between the antennas. In Fig. 3-5, the magnitudes of the transfer functions in the three different cases have good agreement with the calculated magnitude of \( S_{21} \) along the operating UWB bandwidth (3.1-10.6) GHz. However, there is a deep null for face to face, and face to side positions at 9.4 GHz and 9.2 GHz, respectively due to the low gain along the z-axis at these frequencies, while the calculated results show the deep null at 9.7 GHz. In Fig 6, the time delay varies slightly along the operating UWB bandwidth, except from 9 to 10 GHz. It is noticed that the system has good transfer function properties regardless of the position of the transmitting, and the receiving antennas.

To ensure the reliability of the system, the power spectrum density (PSD) of the received signals are obtained for the three different setups at separation distances
30cm and 50 cm as displayed in Figs 7 and 8, respectively. The PSD of the received signal is obtained by taking the inverse Fourier transform of the transfer function and convolving it with the input signal, then getting the PSD of the result of convolution. The pulse used at the transmitter is the fifth derivative Gaussian pulse since it meets the FCC requirements for indoor systems regarding the PSD as shown in [6]. It is seen that the PSDs in Fig. 7 still comply with the FCC requirement for transmitted power as expected. The normalized power spectrum densities in Fig 8 comply with FCC mask over the UWB spectrum 3.1-10.6 GHz.

Conclusion

In this paper, we propose a new design of a planar UWB antenna with modified ground plane. Most of UWB for unlicensed use is covered 3.5-11 GHz. The antenna parameters are examined and analyzed. There is good agreement between the measured results and the FCC regulations regarding the power limitations for UWB systems. An antenna system consisting of our proposed antenna is built. The transfer function for the antenna system is measured under different positions and at different distances to ensure the functionality of the antenna under some realistic conditions. The fifth derivative of the Gaussian pulse is presented as an input signal for the system to meet FCC’s spectral requirements.

References

Fig. 1. Antenna Geometry.

Fig. 2. Return losses of the proposed antenna.

Fig. 3. Face to face $|S21|$ at 30 cm.

Fig. 4. Side to side $|S21|$ at 30 cm.

Fig. 5. Side to side $|S21|$ at 30 cm

Fig. 6. Group time delays at 30 cm

Fig. 7. Normal PSDs of the received signals at 30 cm

Fig. 8. Normal PSDs of the received signals at 50 cm