LINK BUDGET EVALUATION FOR ULTRA WIDE BAND IMPULSE RADIO TRANSMISSION

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1. Introduction

Ultra Wide Band (UWB) is a powerful technology, which has been recently introduced for wireless communication systems and especially for short-range indoor applications. UWB is defined as any signal, which occupies a bandwidth larger than 500 MHz, or has a fractional bandwidth larger than 0.20 [1]. Due to its large bandwidth, UWB may offer many advantages over conventional narrowband and wideband communication systems. One of the principal technologies of UWB communication systems is based on the transmission of very narrow pulses with a relatively low average power (also indicated as impulse radio IR).

The design of an UWB communication system requires a good understanding of the link budget for determining the coverage of the system. Indeed, several results have been reported on UWB channel measurements and modeling and accordingly, models for UWB path loss are proposed [2]-[5]. However, none of these references has investigated the link budget with an impulse transmission regarding the characteristics of the transmitted signal. Moreover, the received power depends on the gain of transmit and receive antennas, which are frequency dependent. This means that the UWB link budget cannot be directly determined in the time domain. In this work, a link budget model for an UWB system is evaluated taking into account the characteristics of the antennas as well as of the generator pulse shape. A set of UWB time domain measurements has been performed at different distances between the transmit and receive antennas to verify the model.

2. Link budget calculation

The electric field radiated by the transmit antenna E^{rad} can be expressed as follows [6]:

$$E^{rad}(f) = \frac{jV_g(f)\eta_0}{Z_g(f)+Z_A^T(f)} F_0 \frac{e^{-j\beta R}}{4\pi R} \tag{1}$$

where V_g, Z_g and Z^T_A are the generator voltage and the impedances of the generator and the transmit antenna, respectively. The following parameters are used: f is the frequency, $\beta = 2\pi/\lambda$ is the free space wave number where λ is the wavelength, $\eta_0 = 120\pi$ is the free space impedance, F_0 is the antenna field factor and R is the distance. If the transmit and receive antennas are assumed to be identical, the field factor can be expressed as [7]:

$$F_0 = \beta H_e \tag{2}$$

where H_e is the effective height of the antenna. The open-circuit voltage induced at the receive antenna output is proportional to the incident electric field E^{inc} and the effective height of the antenna. If we assume that $E^{inc} = E^{rad}$, the voltage at the load V_L can be expressed as:

$$V_L(f) = I_L(f)Z_L(f) = E^{inc} H_e \frac{Z_L(f)}{Z_A^R(f) + Z_L(f)} \tag{3}$$

where I_L, Z^R_A and Z_L are the current through the load, the impedance of the receive antenna and the load, respectively. Inserting (1) and (2) in (3) we get:

$$V_L(f) = \frac{Z_L(f)}{\left(Z_g(f) + Z_A^T(f)\right)\left(Z_A^R(f) + Z_L(f)\right)} jV_g(f)\beta H_e^2 \eta_0 \frac{e^{-j\beta R}}{4\pi R} \tag{4}$$

According to (4), the voltage at the load can be determined if the parameter H_e is well known since other parameters are given (i.e. known form the design). From (4) we find for the received power spectral density:

$$\frac{1}{2}\frac{\left|V_L(f)\right|^2}{\left|Z_L(f)\right|} = \frac{1}{2}\frac{\left|V_g(f)\right|^2}{\left|Z_g(f)\right|} \frac{\left|Z_L(f)\right|\left|Z_g(f)\right|}{\left|Z_g(f) + Z_A^T(f)\right|^2 \left|Z_A^R(f) + Z_L(f)\right|^2} \frac{\beta^2 H_e^4 \eta_0^2}{\left(4\pi R\right)^2} \tag{5}$$

Using $P_r(f) = \frac{1}{2}\frac{\left|V_L(f)\right|^2}{\left|Z_L(f)\right|}$ and $P_t(f) = \frac{1}{2}\frac{\left|V_g(f)\right|^2}{\left|Z_g(f)\right|}$, equation (5) can be expressed as:

$$P_r(f) = P_t(f) \frac{\left|Z_L(f)\right|\left|Z_g(f)\right|}{\left|Z_g(f) + Z_A^T(f)\right|^2 \left|Z_A^R(f) + Z_L(f)\right|^2} \frac{\beta^2 H_e^4 \eta_0^2}{\left(4\pi R\right)^2} \tag{6}$$

where P_t and P_r are the transmit and receive power spectral densities, respectively. The effective height of the antenna can be expressed in terms of the antenna gain and input impedance:

$$H_e^4 = \frac{\left|Z_g(f) + Z_A^T(f)\right|^2 \left|Z_A^R(f) + Z_L(f)\right|^2}{\left|Z_L(f)\right|\left|Z_g(f)\right|} \frac{\lambda^4}{(2\pi)^2 \eta_0^2} G_t(f) G_r(f) \tag{7}$$

where G_r and G_t are receive and transmit antenna gain, respectively. Substituting (7) in (4), we get the following expression for the link budget based on signal amplitudes:

$$\left|V_L(f)\right| = \left[\frac{c}{4\pi}\frac{\sqrt{G_t(f)G_r(f)}}{f}\left|V_g(f)\right|\right]\frac{1}{R} \tag{8}$$

where c is the speed of light. According to (8), the link budget expression is based on the received voltage rather than the received power. Such an approach is more appropriate for a system operating in time domain. Calculation of link budget based on the peak-voltage can avoid the noise level problem caused by averaging of signal over a large time window.

3. Simulation and measurement results

From (8), the maximum received voltage as function of the distance between transmit and receive antenna can be determined in the following way. From the input voltage $v_g(t)$, $V_g(f)$ is determined by taking its Fourier Transform (FT). The gain of the antenna is known. Then, $V_L(f)$ can be calculated from (8), and v_L (t) is determined by the Inverse FT. In order to validate the results, a set of measurements has been performed at different distances using a time domain setup. In the measurements, the maximum distance was considered to be 4 m and the spacing between two successive measurements was 0.25 m. At the transmit and receive sites two identical, vertically polarized, omni-directional bi-conical antennas were used. The antennas were placed 1.5 m above the floor. The antenna gain was determined using time domain as well as frequency domain measurements. The measurement results of the antenna gain as a function of frequency are depicted in Figure 1. From this Figure we see that nearly similar gain results are obtained from the time domain and frequency domain measurements. Some discrepancies at low frequencies are due to insufficient performance of the absorber materials used within the anechoic chamber (the absorber material is specified for frequencies above 2 GHz). Since the antenna practically does not radiate any energy at very low frequencies, the gain is assumed to be zero in the frequency range 0-100 MHz. The pulse used for the time domain measurements is shown in Figure 2. The half-pulse width (i.e. pulse width at half of the maximum amplitude) is of about 200 ps providing a spectrum until 6 GHz when averaging is used. Figure 3 shows the measurement and simulation results of the maximum received voltage as a function of the separation distance between the transmit and receive antennas. Form this Figure it can be observed that the received voltage decreases inversely proportional to the separation distance and the simulation results match very well the measurement results.

The effect of the generator pulse waveform on the UWB link budget with IR transmission is investigated using a number of Gaussian pulses with different widths and equal total transmit energy (see Figure 4 and 5). The results for a system with a dynamic range of about 40 dB (i.e. a signal part below 40 dB from the maximum value is padded to zero) are shown in Figure 6. From this Figure it can be concluded that the received voltage increases when the pulse width decreases. This can be explained by the fact that when the pulse width is larger, the more energy is concentrated at lower frequency. However, the antenna does not perform efficiently at these lower frequencies, which means that less power is transmitted through the channel and consequently less power is received.

4. Conclusions

In this paper, a link budget model for UWB impulse radio transmission, which includes the influence of the generator pulse waveform and magnitude as well as antenna characteristics, such as gain and input impedance, is developed and evaluated. To verify the model, time domain measurements were performed at different separation distances. The measured peak-to-peak voltage as a function of the distance agrees well the simulation results. The developed model has been used to evaluate the impact of the pulse width on the link budget. It has been shown that the received voltage increases when the pulse width decreases (for the same total pulse energy). This model can be used for the design and evaluation performance of an UWB communication system.

References

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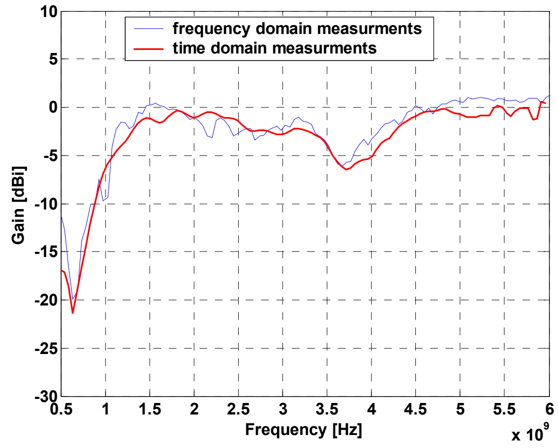

Figure 1: Antenna gain as function of the frequency.

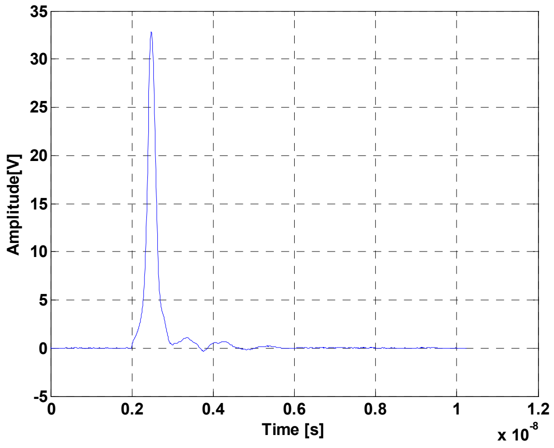

Figure 2: Generator output.

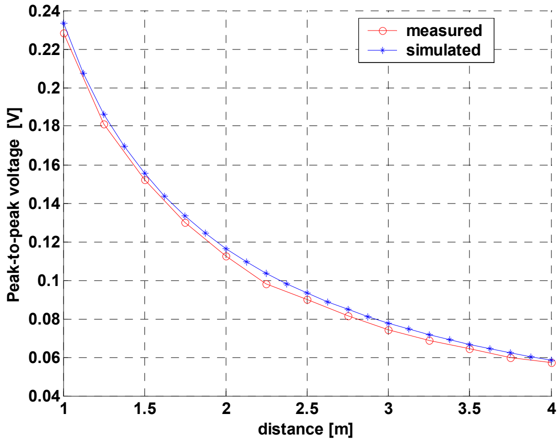

Figure 3: Measured and simulated maximum received voltage as function of the distance.

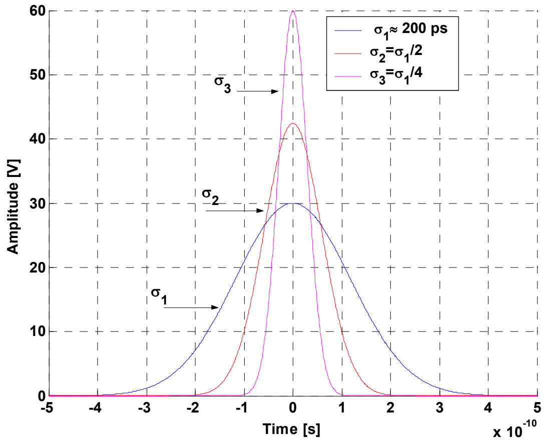

Figure 4: Gaussian pulses with different widths and equal total energy.

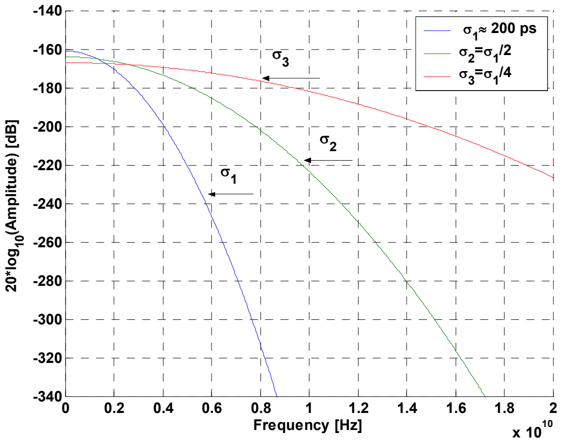

Figure 5: The spectrum of the Gaussian pulses with different widths.

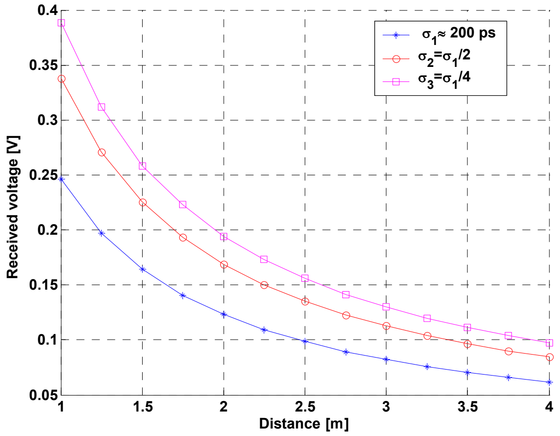

Figure 6: Received peak-to-peak voltage as function of the distance for different Gaussian pulse widths.