Novel Waveform Distortion Parameter for Ultra Wideband Impulse Radio Systems

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Abstract

Study of waveform distortion is necessary for designing optimum ultra wideband impulse radio (UWB-IR) systems because the distortion of waveform degrades the performance of correlation receiver. In this paper, the novel quantitative parameter of waveform distortion that is peak to average loss ratio is proposed and derived in the closed form formula for UWB-IR transmissions. The peak to average loss ratio is defined as the ratio between peak power loss and average power loss from transmitter (Tx) to receiver (Rx). The free space and ground reflection channels are considered. The results obtained from proposed formula are compared with measurement. This proposed parameter is useful to define the quantity of waveform distortion in UWB-IR systems.

Keywords : ultra wideband impulse radio (UWB-IR), waveform distortion

1 Introduction

For ultra wideband impulse radio (UWB-IR) transmission, very high peak short pulse with very low duty cycle allow to obtain the ultra low power consumption. The peak power loss and average power loss from transmitter (Tx) and receiver (Rx) are equal for the distortionless condition. However, the distortion of UWB-IR waveform due to frequency and time dispersion of channel cases the difference. Therefore, the ratio between peak power loss and average power loss from Tx to Rx can be defined as the quantity of waveform distortion.

In this paper, the novel quantitative parameter that is peak to average loss ratio is proposed and derived in the closed form formula for UWB-IR transmissions. The peak to average loss ratio is defined as the ratio between peak power loss and average power loss from Tx to receiver Rx. The free space and ground reflection channels are considered. The measurement was done for the ground reflection channel. The results obtained from proposed formula are shown and compared with measurement.

2 Peak to Average Loss Ratio

For deriving the peak to average loss ratio, the transmitted waveform is defined as rectangular passband waveform [1]. The expression of this waveform in time domain v_{t} and its spectral density V_{t} are

$$v_{\mathrm{t}}(t) = \frac{1}{f_{\mathrm{b}}}[f_{\mathrm{H}}\mathrm{sinc}(2f_{\mathrm{H}}t) - f_{\mathrm{L}}\mathrm{sinc}(2f_{\mathrm{L}}t)], \quad (1)$$

$$V_{\mathrm{t}}(f) \quad = \quad \begin{cases} \frac{1}{2f_{\mathrm{b}}} & ||f|-f_{\mathrm{c}}| \le \frac{f_{\mathrm{b}}}{2} \\ 0 & ||f|-f_{\mathrm{c}}| > \frac{f_{\mathrm{b}}}{2} \end{cases}, \tag{2}$$

where t is the time, f is the frequency, f_{c} is the center frequency, f_{b} is the spectral bandwidth, $f_{\mathrm{L}} = f_{\mathrm{c}} - f_{\mathrm{b}}/2$ is the lowest frequency, $f_{\mathrm{H}} = f_{\mathrm{c}} + f_{\mathrm{b}}/2$ is the highest frequency and $\mathrm{sinc}(x) = \sin(\pi x)/(\pi x)$.

The spectral density of received waveform V_{r} is calculated by using multiplication between frequency transfer function of channel H_{c} and V_{t}. Subsequently, the received waveform in time domain v_{r} is calculated by using inverse Fourier transform of its spectral density, which can be respectively written as

$$V_{\mathrm{r}}(f) \quad = \quad H_{\mathrm{c}}(f) \cdot V_{\mathrm{t}}(f), \tag{3}$$

$$v_{\mathrm{r}}(t) \quad = \quad \int_{-\infty}^{\infty} V_{\mathrm{r}}(f) \cdot e^{j2\pi f t} \mathrm{d}f. \tag{4}$$

In this paper, the Tx and Rx antennas are assumed to be isotropic antennas and H_{c} is considered for free space and ground reflection channels.

The peak to average loss ratio PAR in dB is defined as the ratio between peak power loss and average power loss from Tx to Rx, which can be written as

$$PAR = 10\log\left\{\frac{\max[v_{\mathrm{t}}^2(t)]}{\max[v_{\mathrm{r}}^2(t)]} \cdot \frac{\int_{-\infty}^{\infty}|V_{\mathrm{r}}(f)|^2\mathrm{d}f}{\int_{-\infty}^{\infty}|V_{\mathrm{t}}(f)|^2\mathrm{d}f}\right\}. \tag{5}$$

This proposed definition is used to derive the closed form formula for free space and ground reflection channels.

2.1 Free Space Channel

The extension of Friis' transmission formula [2] is used to characterize the UWB-IR free space channel. The frequency transfer function of free space channel $H_{\mathrm{c,f}}$ can be written as

$$H_{\mathrm{c,f}}(f) = \frac{c}{4\pi|f|d} e^{-j2\pi f d/c}, \tag{6}$$

where c is the velocity of light and d is the distance from Tx to Rx.

From definition of peak to average loss ratio in Eq. (5), the closed form formula of peak to average loss ratio for free space channel PAR_{f} can be derived as

$$PAR_{\mathrm{f}} = 20\log\left[\frac{f_{\mathrm{b}}}{\sqrt{f_{\mathrm{H}} f_{\mathrm{L}}}\ln\left(\frac{f_{\mathrm{H}}}{f_{\mathrm{L}}}\right)}\right]. \tag{7}$$

2.2 Ground Reflection Channel

The frequency transfer function of ground reflection channel $H_{\mathrm{c,g}}$ is the addition between frequency transfer function of direct and reflection paths, and can be written as

$$H_{\mathrm{c,g}}(f) = \frac{c}{4\pi|f|d'} e^{-j2\pi f d'/c} + \Gamma \frac{c}{4\pi|f|d''} e^{-j2\pi f d''/c}, \tag{8}$$

where Γ is the reflection coefficient of ground $d' = \sqrt{(h_{\mathrm{t}} - h_{\mathrm{r}})^2 + d^2}$ and $d'' = \sqrt{(h_{\mathrm{t}} + h_{\mathrm{r}})^2 + d^2}$ are distances of direct and reflection paths, h_{t} and h_{r} are the heights of Tx and Rx antennas, respectively.

From definition of peak to average loss ratio in Eq. (5), the closed form formula of peak to average loss ratio for ground reflection channel PAR_{g} can be derived as

$$PAR_{\mathrm{g}} = 10\log\left\{\frac{f_{\mathrm{b}}^2(d''^2+\Gamma^2 d'^2) - 2\Gamma f_{\mathrm{L}} f_{\mathrm{H}} f_{\mathrm{b}} d' d''\left[\mathrm{Cd}\left(\frac{2\pi\Delta d}{c}\right) + \frac{2\pi\Delta d}{c}\mathrm{Sid}\left(\frac{2\pi\Delta d}{c}\right)\right]}{f_{\mathrm{L}} f_{\mathrm{H}}\left[d''\ln\left(\frac{f_{\mathrm{H}}}{f_{\mathrm{L}}}\right) + \Gamma d' \mathrm{Cid}\left(\frac{2\pi\Delta d}{c}\right)\right]^2}\right\}, \tag{9}$$

where $\Delta d = d'' - d'$ is the different distance between direct and reflection paths, $\mathrm{Cid}(x) = \mathrm{Ci}(xf_{\mathrm{H}}) - \mathrm{Ci}(xf_{\mathrm{L}})$, $\mathrm{Sid}(x) = \mathrm{Si}(xf_{\mathrm{H}}) - \mathrm{Si}(xf_{\mathrm{L}})$, $\mathrm{Cd}(x) = \frac{1}{f_{\mathrm{H}}}\cos(xf_{\mathrm{H}}) - \frac{1}{f_{\mathrm{L}}}\cos(xf_{\mathrm{L}})$, $\mathrm{Ci}(x) = -\int_x^\infty \frac{1}{\tau}\cos(\tau)\mathrm{d}\tau$, and $\mathrm{Si}(x) = \int_0^x \frac{1}{\tau}\sin(\tau)\mathrm{d}\tau$ are cosine integral and sine integral functions.

3 Measurement

The measurement equipment, setup and parameters are the same as in [3]. The frequency transfer function of ground reflection channel was measured using a vector network analyzer (VNA). The measurement was done in the open area that is the soccer field of King Mongkuts Institute of Technology Ladkrabang (KMITL), Thailand. The metallic plate was laid on the ground between Tx and Rx antennas for the perfect reflection condition ($\Gamma = -1$). The measurement setup is shown in Fig. 1.

The biconical antennas were used as Tx and Rx antennas. Both Tx and Rx antennas were fixed at the height of $h_{\mathrm{t}} = h_{\mathrm{r}} = 0.75$ m with horizontal polarization for focusing the signal from direct and ground reflection paths. The measurement distance d was ranged from 1 to 5 m with 0.25 m distance increment step. The frequency transfer functions of Tx and Rx antennas were evaluated by using three-antenna method [4] and were used to remove from the measurement frequency transfer functions of the ground reflection channels. The center frequency of waveform f_{c} is fixed at 4.1 GHz. The two cases of signal bandwidths are investigated, that are $f_{\mathrm{b}} = 0.5$ and 1.4 GHz. Therefore, the lowest frequencies f_{L} are equal to 3.85 and 3.40 GHz, while the highest frequencies f_{H} are equal to 4.35 and 4.80 GHz for fist and second cases, respectively.

4 Results

For free space channel, parameters f_{c} is fixed at 6.85 GHz and f_{b} is varied from 500 MHz to 7.5 GHz. Figure 2 shows the peak to average loss ratio for free space channel. At narrow bandwidth, the peak to average loss ratio is approached to zero. In other word, there is slight distortion of narrow bandwidth waveform for free space channel. The maximum peak

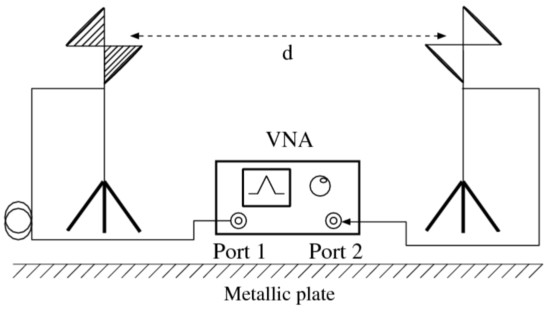

Figure 1: Measurement setup.

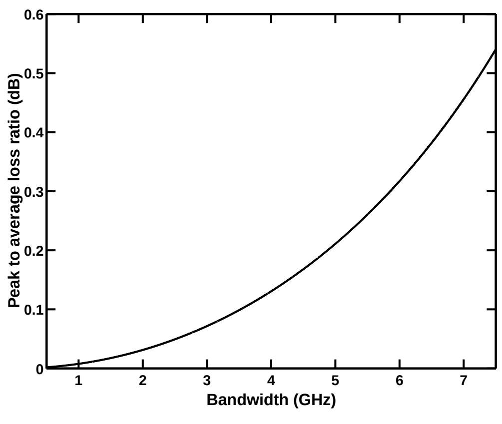

Figure 2: Peak to average loss ratio along 500 MHz to 7.5 GHz bandwidth for free space channel.

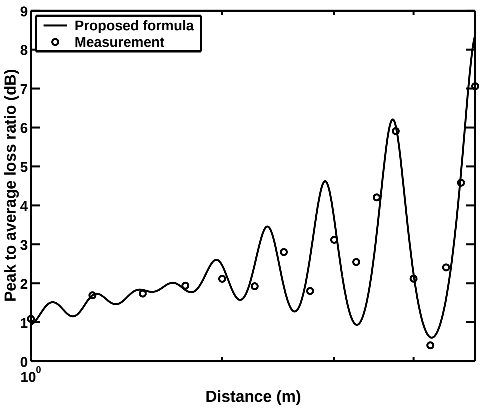

Figure 3: Comparison between peak to average loss ratio from proposed formula and measurement with 500 MHz bandwidth.

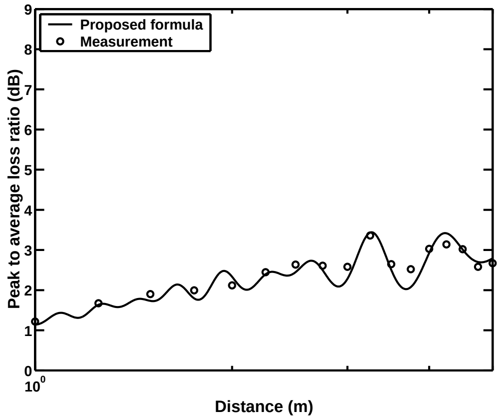

Figure 4: Comparison between peak to average loss ratio from proposed formula and measurement with 1.4 GHz bandwidth.

to average loss ratio is 0.54 dB at 7.5 GHz bandwidth. The distortion of waveform is caused by frequency dispersion. That is the magnitude of frequency transfer function of free space channel is not constant along frequency.

For ground reflection channel, the analyzed parameters are the same as measurement. Figures 3 and 4 show the comparison between peak to average loss ratio from proposed formula and measurement with 500 MHz and 1.4 GHz bandwidths, respectively. Unlike with free space channel, the peak to average loss ratio of wide bandwidth is less than that of narrow bandwidth because the main waveform distortion causes from time dispersion or multipath fading. Therefore, the UWB-IR systems are robust to multipath fading more than narrowband systems. The distortion of waveform is also dependent on distance.

5 Conclusions

In this paper, the novel quantitative parameter that is peak to average loss ratio is proposed and derived in the closed form formula for UWB-IR transmissions. From the results, the proposed formula corresponds with measurement. For free space channel, the waveform distortion is caused by frequency dispersion and is higher when bandwidth is increased. On the other hand, the waveform distortion is caused by time dispersion and is lower when bandwidth is increased for ground reflection channel. In addition, the waveform distortion is dependent on distance and is much more than free space channel. This proposed parameter is useful to define the quantity of waveform distortion in UWB-IR systems.

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