

## In-Band Interference Power Caused by Different Kinds of UWB Signals at UMTS/WCDMA Frequency Bands

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**Abstract:** *This paper studies in-band interference caused by different kind of ultra wideband signals in UMTS frequency bands as a function of UWB pulse width. UWB frequency spectra are produced by using several types of narrow pulse waveforms. Due to the extremely wide bandwidth these signals will spread over the frequency bands allocated to other RF-systems. Study revealed that one can reduce interfering UWB power by using different waveforms and pulse widths to avoid UMTS frequencies without any additional filtering. The simulations did not make significant difference between time hopping and direct sequence concepts when interference was calculated at UMTS bands.*

### INTRODUCTION

Ultra wideband (UWB) technology is one possible solution for short range indoor communication applications. UWB systems spread the transmitted signal power over an extremely large frequency band, and the power spectral density of the signal is very low. A simple waveform to generate ultra wideband spectrum is a narrow Gaussian pulse, and some of its modifications. The bandwidth of a Gaussian pulse is inversely proportional to the pulse width; the narrower the pulse the wider the spectrum.

Due to the wide bandwidth of the transmitted signal, UWB signal energy will spread over the frequency bands allocated to the other radio systems, like GPS, cellular phones, broadcasting, etc. Currently in the USA, the FCC is making regulations for UWB applications. In Europe this regulatory work has also been started by CEPT and ETSI. Some results of the interference tests between UWB transceiver and other radio systems have been published, e.g., in [1],[2],[3]. The difference between this study and the previously published UWB interference papers is that we consider different pulse waveforms under the same system assumptions. This allows one to compare the disturbance caused by different kinds of UWB pulse waveforms as a function of pulse width. The idea of the paper is to approach the issue from the victim receiver's point of view without caring about the performance of the UWB system.

Four pulse waveforms to generate UWB signal are studied. All the waveforms are modifications of a Gaussian pulse. The first waveform is the simplest one, a Gaussian pulse with length  $T_p$  [4]. The second one is composed using two Gaussian pulses, both having length  $T_p$  and reversed amplitudes with time gap  $T_w$  between the pulses. That is called Gaussian doublet [5]. Also, the 2<sup>nd</sup> and the 3<sup>rd</sup> derivatives of a Gaussian pulse are studied. The latter waveforms resemble the wavelet presented in [6]. Some other waveforms to generate UWB signal are presented, e.g., in [7] and [8] but they are not considered in this paper.

The victim system in this study is UMTS/WCDMA<sup>1</sup>. There are two different modes in UMTS; FDD<sup>2</sup> and TDD<sup>3</sup>. FDD uplink is between 1.92 ... 1.98 GHz and FDD downlink is between 2.11 ... 2.17 GHz. TDD bands are between 1.9 ... 1.92 GHz and 2.01 ... 2.025 GHz. The victim receiver RF bandwidth used in the calculations is 3.84 MHz that comes from the chip rate of UMTS/WCDMA [9].

### SYSTEM MODEL

#### A. Time domain presentation

Time domain presentations for the four narrow pulse waveforms to generate UWB signals used in this study are shown in Figure 1. The effect of the transmitter UWB antenna is modelled as a differentiation operation [10], so the time domain waveform in the radio channel is the first derivative of the generated pulse waveform. The radiated waveform in the channel is plotted using dashed thin line in Figure 1.

In Figure 1 the pulse width  $T_p$  of each pulse is equal ( $T_p = 0.5$  ns). The data modulation technique used in the study is baseband bi-phase modulation. In time hopping mode (TH-UWB) the modulated information signal  $s(t)$  for the  $m^{\text{th}}$  user can be presented as

$$s^{(m)}(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^N w(t - kT_d - jT_f - (c_w)_j^{(m)} T_c) d_k^{(m)}, \quad (1a)$$

and in direct sequence mode (DS-UWB)

$$s^{(m)}(t) = \sum_{k=-\infty}^{\infty} \sum_{j=1}^N w(t - kT_d - jT_c) (c_p)_j^{(m)} d_k^{(m)}, \quad (1b)$$

where  $d_k$  is the  $k^{\text{th}}$  data bit,  $(c_p)_j$  is the  $j^{\text{th}}$  chip of PR code and  $(c_w)_j$  is the  $j^{\text{th}}$  code phase defined by the pseudo random code and  $w(t)$  is the pulse waveform.  $N$  presents pulses within one data bit,  $T_c$  is chip length and  $T_f$  is pulse repetition interval. Data length  $T_d = NT_c$  in DS and  $T_d =$

<sup>1</sup> UMTS/WCDMA = Universal Mobile Telecommunications System/  
Wideband Code Division Multiple Access

<sup>2</sup> FDD = Frequency Division Duplex

<sup>3</sup> TDD = Time Division Duplex

$NT_p$  in TH. In DS-UWB  $T_c = T_p$ . Both the data and the code are bipolar ( $d(t) \in \{-1,1\}$ ,  $c(t) \in \{-1,1\}$ ).

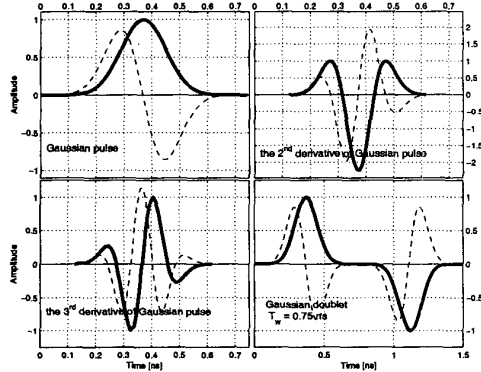


Figure 1. Pulse waveforms used in the study; solid thick line is generated pulse, dashed thin line presents the pulse waveform in a channel ( $T_p = 0.5$  ns).

### B. Frequency domain presentation

The normalized spectrum in the channel of a single pulse waveform is presented in Figure 2. The pulse waveform in the channel is the 1<sup>st</sup> derivative of a generated pulse waveform from Figure 1 (dashed line). The envelope of the spectrum is defined by the pulse waveform and the pulse width  $T_p$ . The pulse separation  $T_w$  inside a Gaussian doublet generates spectral nulls with spacing

$$f_{null} = 1/T_w \quad (2)$$

The effect of  $T_w$  can also be seen from Figure 2, where the spectra of a Gaussian doublet are shown using  $T_w = 1$  ns and  $T_w = 2$  ns.

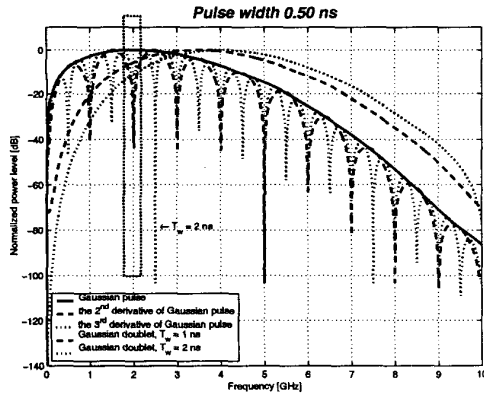


Figure 2. Normalized power spectral densities using different pulse waveforms, pulse width  $T_p = 0.5$  ns.

Figure 2 gives rough estimates for the interference caused by different pulse waveforms having  $T_p = 0.5$  ns and  $T_w = 1$  or  $T_w = 2$  ns. Considering UMTS frequencies, shown by a dotted rectangle in the figure, one can notice that about 2 GHz, Gaussian pulse has the highest

power spectral density whereas the Gaussian doublet has a minimum level due to the spectral null.

Both the Gaussian pulse and the Gaussian doublet have center frequencies<sup>4</sup>  $f_c$  inversely proportional to the pulse width,  $f_c \approx 1/T_p$ . -10 dB bandwidth is about twice the center frequency. The 2<sup>nd</sup> derivative of the Gaussian pulse (the 3<sup>rd</sup> derivative in a channel) has the center frequency  $f_c \approx 1.73/T_p$  and  $B_{-10dB} \approx 2.1/T_p$ . The 3<sup>rd</sup> derivative of the Gaussian pulse has  $f_c \approx 2/T_p$  and  $B_{-10dB} \approx f_c$ . In all cases the spectrum is asymmetric about  $f_c$ .

### C. Interference calculation

In this study, both the time hopping and the direct sequence spread spectrum systems are considered. When calculating the powers of UWB signals, the number of pulses used to transmit one data symbol are fixed to  $N = 31$ , and the transmitted power over one data symbol (length  $T_d$ ) is 1 mW. This results pulse power  $P_p = 32.3 \mu\text{W}$ . Also, the number of transmitted symbols remains the same during all calculations. The antenna gains, system losses as well as propagation loss are ignored in the calculations. Due to the given assumptions the data rates  $R_d$  of TH and DS systems are different. TH concept introduces silent periods into the transmission yielding  $R_{d,TH} < R_{d,DS}$ .

The in-band interference power  $P_i$  is calculated using the amplitude spectrum samples over the victim receiver's IF bandwidth, i.e.,

$$P_i = \sum_{f \in B_{IF}} |S_i(f)|^2 \quad (3)$$

The interference power represents the UWB signal power in the channel and not in the victim receivers RF/IF-end because the receiver parts are not included in the calculations (ideal probe in a channel is assumed).

### UWB SYSTEM USING TIME HOPPING

Time hopping concept is generally used in, so called, impulse radio concept [4], where consecutive pulses are transmitted using pulse repetition interval  $T_p$  and pseudo random (PR) time hopping code governs the nominal transmission instant. Randomised transmission time instants smooth the spectrum by deducting spectral lines, as can be seen in Figure 3. If  $T_j >$  delay spread of the channel intersymbol interference can be avoided in UWB system. Length of the pseudo random time hopping code is independent on the number of transmitted pulses per data symbol. In TH system the duty cycle  $< 100\%$ . The data rate  $R_d$  in TH can be defined by

$$R_d = 1/T_d = 1/NT_p \quad (4)$$

In multiuser TH case, each user has a unique PR code to define the nominal transmission instants so the users in the system can also be separated.

<sup>4</sup> The center frequency  $f_c$  is defined here to be the frequency with the maximum power level.

The effect of PR time hopping code is presented in Figure 3. Fixed pulse repetition interval generates strong spectral lines, clearly visible in the upper plot. Introducing the PR TH-code, the spectral lines are diminished, as can be seen in the lower plot. The spectrum is smoothed further if pulse position modulation (PPM) is used as a data modulation [4]. In Figure 3 transmission instant is equally distributed over the frame  $T_f$ .

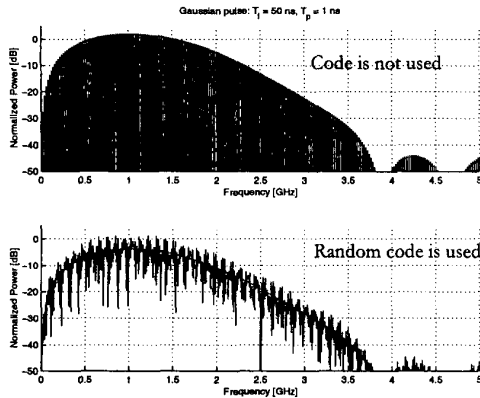


Figure 3. The effect of pseudo random time hopping in a Gaussian pulse train. The upper plot shows normalised power spectral density without pseudo random time hopping code. The lower plot shows the same pulse train when the code has been applied. Reference curve is a spectrum of a single pulse.

#### UWB SYSTEM USING DIRECT SEQUENCE

Alternative way to generate UWB transmission is to utilize direct sequence (DS) spread spectrum concept with chip waveforms from Figure 1. In this study we have used maximum length sequence with a length of 31 chips and 100% duty cycle. If the code length is the same as the symbol interval the data rate in DS-UWB system can be defined as

$$R_d = 1/T_d = 1/(NT_p), \quad (5)$$

where  $N$  is the PR code length used to transmit one data bit. The data rate is inversely proportional to the number of pulses used to transmit one data symbol, and also inversely proportional to the pulse repetition interval  $T_f$ . In DS-system  $T_f$  equals to  $T_p$ , and in a doublet  $T_f = T_p + T_p$ . Using doublet waveform  $R_d$  is always smaller compared to the other studied pulse waveforms with the same  $T_p$  due to the time gap  $T_g$  inside a doublet.

#### NUMERICAL RESULTS

Next, some numerical in-band interference power calculation results are presented for different pulse waveforms as a function of pulse width. All the calculations are made in a single user case.

The most interesting pulse widths are less than nanosecond due to the real life high data rate requirements. In the following results, the pulse lengths are limited to 3 ns,

since longer pulse widths would keep the main lobe of the UWB spectrum below the frequency band under interest in this study.

Figure 4 shows in-band interference within three UMTS/WCDMA bands caused by Gaussian pulses with different pulse widths. The results show that from the UMTS band's interference point of view, there is no significant difference between TH and DS concepts when the Gaussian pulse is used. The same is valid also when the other pulse waveforms are used.

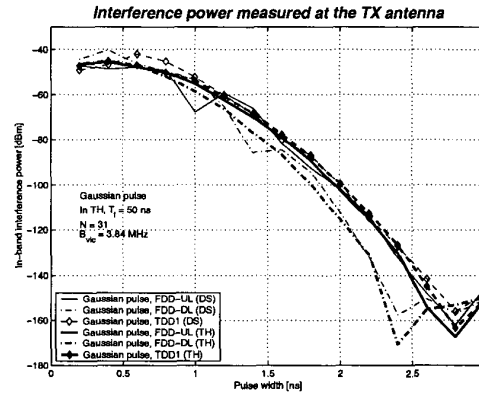


Figure 4. In-band interference power caused by Gaussian pulse in UMTS/WCDMA bands, as a function of pulse width.

Corresponding results for both FDD bands with four different pulse waveforms utilising DS-UWB concept are presented in Figure 5. The figure shows that the four waveforms having the same pulse widths are interfering differently at the frequency bands under interest. This behaviour can also be reasoned from Figure 2 where the spectra of the studied pulse waveforms are shown. The spectrum of the UWB signal depends on the pulse waveform as well as pulse width, as stated earlier.

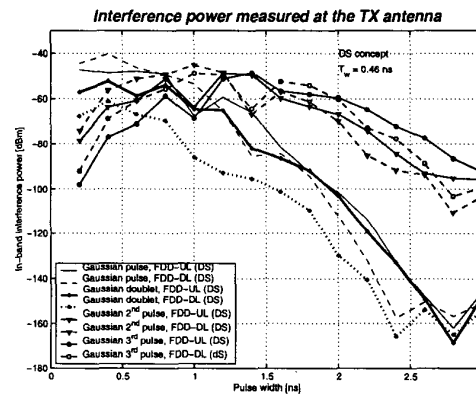


Figure 5. In-band interference power in FDD-UL and FDD-DL bands caused by four different pulse waveforms utilising DS concept.

When sub-nanosecond pulses need to be used to achieve high data rates, the best choice for the pulse

waveform will be higher derivatives of the Gaussian pulse, if interference in UMTS bands are considered. Increasing the pulse duration reduces interference in UMTS bands, because the energy is concentrated below the UMTS frequency bands. The interference can also be reduced by using the Gaussian doublet, where the spectral nulls can be generated at the certain frequencies.

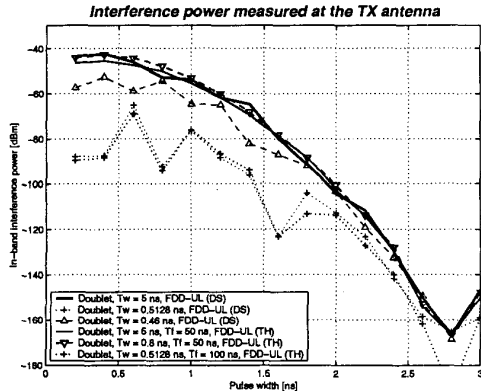


Figure 6. Interference caused by Gaussian doublets with different pulse separation  $T_b$ .

It is possible to do some spectral planning to avoid some restricted frequency bands by proper selection of the pulse width and the pulse separation in the doublet. Figure 6 shows effect of the pulse separation  $T_b$  of a Gaussian doublet on the interference. The dotted line in Figure 6 shows the result of an optimal  $T_b$  to generate a spectral null at the FDD-UL band. The effect can be noticed as a minimum total interference power of the presented cases. The Gaussian doublet brings two parameters for spectral planning but causes lower data rate due to the longer duration of a wavelet. Figure 6 shows that also the Gaussian doublets interfere in the same way in TH and DS modes, cf. Gaussian pulse in Figure 4.

The victim receiver sees a narrow portion of the total UWB spectrum. In other words, samples of the UWB signal is seen as samples of noise added noncoherently during the symbol integration time of a victim receiver. The variance of noise samples is described in the previous results. The total amount of interference depends on the integration time of the victim receiver. If the data rate is not critical one can use smaller duty cycle to reduce the interference. In real life case the propagation loss also reduces the UWB signal level and the amount of interference.

The interference of UWB signal can be reduced by lowering the transmission power which needs to be compensated with a higher pulse integration level at the receiver end costing lower data rate.

### CONCLUSIONS

In ultra wideband system design the pulse waveform and pulse width are the main parameters for spectral allocation,

and to minimise the interference level at the victim receivers. In UWB systems the power spectral density of the transmitted signal is very low. The interference against other systems can be reduced by applying the spectral nulls, e.g., by using two separate narrow pulses to form a doublet. The distance between consecutive nulls in the spectrum depends inversely on the pulse separation within a doublet. A generic Gaussian pulse generates the same spectrum envelope as a Gaussian doublet but the spectrum does not contain any deep nulls. Using the same pulse width as used with Gaussian pulse the spectra of the 2<sup>nd</sup> and the 3<sup>rd</sup> derivatives of the pulse moves toward higher frequencies. However, the latter pulse waveforms are more complex to generate than the former ones. Narrowing the pulses and applying more complex pulse waveforms one gets better results in the interference point of view. For low data rate applications the Gaussian doublet is suitable waveform if the pulse separation is optimised to generate spectral nulls in critical frequencies.

### ACKNOWLEDGEMENTS

This study has been financed by the National Technology Agency of Finland (Tekes), Nokia, Elektrobitt and the Finnish Defence Forces. Authors would like to thank the sponsors for their support.

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