ON THE UWB SYSTEM PERFORMANCE STUDIES IN AWGN CHANNEL WITH INTERFERENCE IN UMTS BAND

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ABSTRACT

This paper studies the performances of ultra wideband (UWB) systems in AWGN channel when the interference in UMTS/WCDMA band is present. The interfering band in the frequency division duplexing mode has been considered as a fully covered for both uplink or downlink cases. The interference is actually modelled as a sinc-pulse jamming having a spectrum in a predefined UMTS band. The uncoded UWB system performances are studied through the bit-error-rate as a function of signal-to-noise ratio as well as jamming-to-signal power ratio. Several modifications of a generic Gaussian pulse have been selected for the deeper study. The UWB systems are based on time hopping and direct sequence spread spectrum techniques, which utilizes a binary baseband pulse amplitude data modulation. The results showed that UWB system performance degradation is the highest when the interfering signal and the nominal center frequency of the UWB system are overlapping. UWB systems based on time hopping concept seem to outperform the corresponding direct sequence concepts. However, for high values of interfering power, the UWB performances are converging.

1. INTRODUCTION

This paper covers the ultra wideband (UWB) system performance studies in the AWGN channel. Introducing an additional interfering signal in the channel a degradation of the UWB system performances can be noticed. The interference source used in this study is the pulsed sinc-waveform having a spectrum in UMTS/WCDMA cellular phone band. The interfering signal cannot be assumed as a multi-user interference but as a narrowband jamming. This work follows our previous studies of the interference between UWB systems and other radio systems [1]-[2].

The UWB systems studied here utilize different kinds of Gaussian-based narrow pulse waveforms. The radiated waveforms selected for the further study are the first four derivatives of the generic Gaussian pulse. In the frequency domain the pulse shape and the pulse width of the transmitted pulse select the spectral allocation of the UWB signal. Using the studied waveforms the spectral allocation is the higher the higher order is the derivative of the transmitted pulse waveform.

The UWB systems utilize either time hopping (TH-UWB) or direct sequence (DS-UWB) technique. In both cases the transmitted data bit is spread over the multiple consecutive pulses. This corresponds to a pulse repetition coding and benefits the system by giving an additional processing gain. The data modulation scheme used in the study is baseband binary pulse amplitude modulation (BPAM).

For the UMTS/WCDMA system four different frequency bands and two operational modes have been allocated during the standardization process [3]. The jamming signal is located in the UMTS signal bands. When the system will be commercialized the frequency division duplexing (FDD) will be firstly utilized. The UMTS specification has also reservation for the system based on the time division duplex (TDD) mode that will be included in our further studies.

This paper is organized as follows. The Chapter 2 introduces the system and simulation models used in the study. Chapter 3 gives the simulations results and Chapter 4 gives the conclusions.

2. SYSTEM MODEL

In this Chapter the UWB system model and the interference (jamming) model are introduced.

2.1. UWB System Model

The studied UWB systems are based on time hopping (TH-UWB) and direct sequence (DS-UWB) spread spectrum techniques. In the former case a discontinuous transmission is utilized. The transmission instant is defined by a user dependent pseudo random code. In TH-UWB the pulse repetition interval is much longer than the pulse width [4]. The latter technique is like a conventional DS system but the pulse waveform is selected amongst the very narrow waveforms [5].

All the used waveforms are based on a generic Gaussian pulse (top-left in Fig. 1) whose waveform $w(t)$ is defined by [6]

$$w(t) = \frac{\exp\left(-0.5\left(\frac{t-m}{\sigma}\right)^2\right)}{\sigma\sqrt{2\pi}}, \tag{1}$$

where t = time, m = mean value and σ = standard deviation of the Gaussian distribution. The pulse width T_p in Eq. (1) is related to the standard deviation via $\sigma = T_p/2\pi$.

In the simulations the transmitting and receiving antennas are modeled as differentiation (derivative) operations [7]. In Fig. 1 the solid line represents the generated pulse waveform,

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and the dashed line is the waveform in the channel. All the plotted pulses have pulse width T_p = 1 ns. The generated waveforms are the Gaussian pulse and its first three derivatives. As can be seen from Fig. 2, the extra derivatives of the generated pulse waveform shift the transmitted spectra to the higher frequencies. All the spectra are also asymmetric about the nominal center frequency. Effectively high pass filtering is the same as derivation of the pulse.

The pseudo random code used in the study is a binary maximum length code. In a single-user case, as is the situation in our study, the pseudo random spreading code is used to smooth the spectrum to get rid of the line spectral components [4]. In multi-user case this code is also used for user separation. Because the data is also binary valued the pulse or its amplitude-reversed version is sent into the channel.

In Table 1 the rules of thumb for calculating the nominal center frequencies and -10 dB bandwidths, as well as the numerical values for the used pulse waveforms are given.

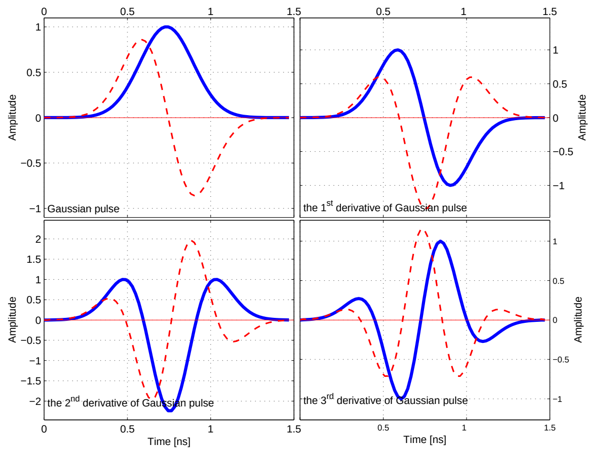

Fig. 1. The pulse waveforms used in the study. The solid lines represent the generated pulse waveforms and the dashed lines the radiated ones.

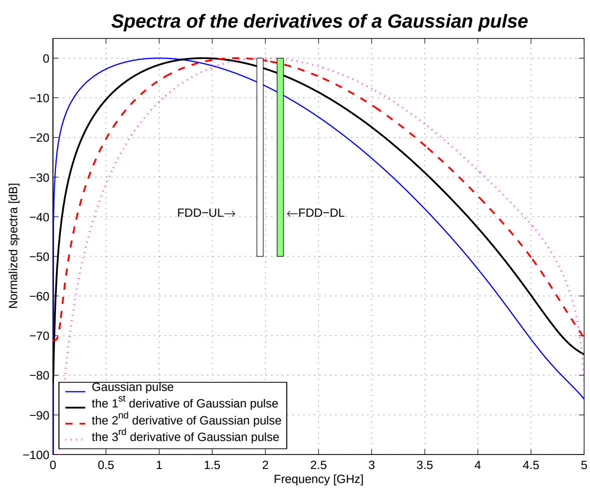

Fig. 2. Spectra of the pulse waveforms used in the study.

Table 1. Approximations for the nominal center frequencies and -10 dB bandwidths for the used pulse waveforms.

Radiated waveform	f_c	B_{-10dB}	Studied cases f_{max}	f_{min}
1st derivative	$1/T_p$	$2/T_p$	2	0,5
2nd derivative	$1.4/T_p$	$2.1/T_p$	2,8	0,7
3rd derivative	$1.73/T_p$	$2.1/T_p$	3,46	0,865
4th derivative	$2/T_p$	$2.13/T_p$	4	1
of a Gaussian pulse			GHz	GHz

Table 2. Data rates for the simulated pulse widths, PG = 20 dB.

T_p [ns]	0.5	1.0	1.5	2.0
R_d [Mbps]	20	10	6.67	5

Independently of the used pulse waveform, or UWB system concept, the corresponding pulse widths give the same data rate as presented in Table 2 for fixed processing gain. In our study PG = 20 dB is used.

2.2. Jamming Source

The jamming source in this study is the pulsed sinc-signal having its spectrum located in the UMTS/WCDMA cellular phone band. From the four different UMTS modes both FDD band were selected as jamming sources for the further study. In frequency domain FDD uplink (UL) band is allocated between 1.92 GHz and 1.98 GHz, and FDD downlink (DL) band is allocated between 2.11 GHz and 2.17 GHz. The total bandwidth for both FDD-UL and FDD-DL channels is 60 MHz. The RF bandwidth of the individual UMTS signal (physical channel bandwidth) is 3.84 MHz that comes from the chip rate used in UMTS/WCDMA [3].

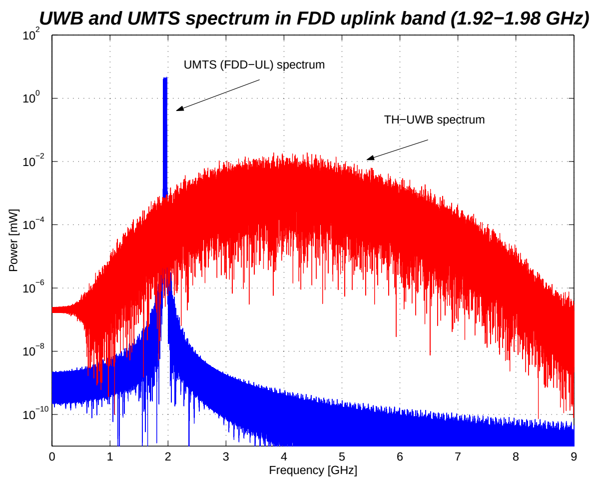

Fig. 3. Spectra of fully loaded UMTS FDD uplink band and UWB signal using the 3rd derivative of the Gaussian waveform.

In the simulations, the worst case interference scenarios were studied, that is, the whole UMTS band (uplink or downlink) was assumed to be jammed. Therefore the jamming signal is modelled using a windowed sinc wave in time domain having 60 MHz bandwidth in frequency domain. Because of a windowed sinc pulse shape in time domain, the jamming signal has almost a rectangular spectrum centred at the UMTS band under interest. The spectrum of the signal used to model UMTS FDD uplink jamming is presented in Fig. 3. During the study the radio channel is assumed to be AWGN channel.

The received signal $r(t)$ can then be modeled by

$$r^{(m)}(t) = s^{(m)}(t) + n(t) + J(t), \tag{2}$$

where $n(t)$ and $J(t)$ presents noise and jamming, respectively, and m represents the individual user. In our study $J(t)$ is the jamming coming from UMTS band, as noted in Fig. 3. For the single user case $m = 1$.

3. UWB PERFORMANCE EVALUATION

In this paper two different approaches have been considered for the performance evaluation of the UWB systems in the presence of interference located in the UMTS/WCDMA band. The first approach shows the bit error rate (BER) as a function of the signal-to-noise ratio (SNR) for different UWB pulses with fixed jamming signal level. The second one analyzes the bit error rate of the same systems when the signal-to-jamming power ratio changes but the SNR is fixed. All the cases have been studied in uncoded single-user systems.

The UWB system performance is referred to the theoretical upper bound performance limit for BPAM modulated signal in AWGN channel. The theoretical upper bound limit P_e can be calculated using formula [8]

$$P_e = Q\left(\sqrt{2\frac{E_b}{N_0}}\right), \tag{3}$$

where E_b = bit energy and N_0 = noise power spectral density.

3.1. Bit error rate versus signal-to-noise ratio

This section introduces the effect of the UMTS/WCDMA interference to the UWB system performance degradation. Bit error rate curves are presented for both TH-UWB and DS-UWB utilizing the waveforms from Fig. 1.

In Fig. 4 the effects of different UWB pulse waveforms are studied when the jamming spectrum is located at the FDD downlink band. The UWB pulse widths are fixed to T_p = 0.5 ns. The total jamming power is P_I = 10 dBm, meaning -10 dB signal-to-jamming power ratio. The jamming signal energy is evenly distributed inside the considered UMTS band. From results one can notice that TH-UWB outperforms DS-UWB despite of the used pulse waveform in selected T_p. The difference in UWB system performances among the used waveforms is based on the different spectrum location of the UWB signal related to the jamming signal. The higher derivative of the pulse is used the higher is the nominal center frequency of the UWB transmission. In this case, the 1st derivative with T_p = 0.5 ns generates a spectrum that overlaps the jamming spectrum. When the order of the derivative increases, the UWB spectrum is shifted to the higher frequencies and overtakes the FDD band. This means that the UWB system performance also improves.

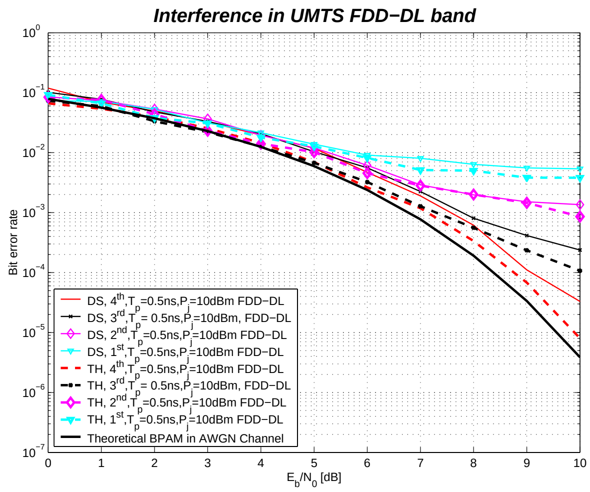

Fig. 4. UWB system performance degradation for different pulse waveforms when the jamming source is UMTS FDD-DL.

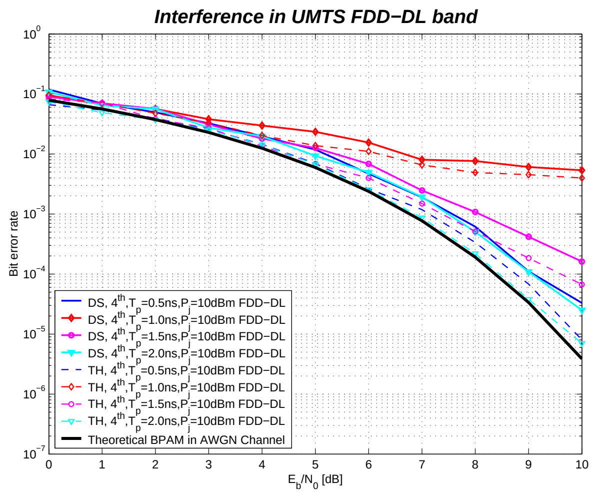

Fig. 5. BER for DS-UWB and TH-UWB systems utilizing the 4th derivative of the Gaussian pulse as a waveform with different pulse widths.

In the presence of jamming radio signal, the UWB system performance can be improved also by selecting a proper pulse width for a fixed waveform. The change of the pulse width shifts the spectrum in frequency domain. In Fig. 5 the waveform is the 4th derivative of the Gaussian pulse but the pulse width is changed. Both TH and DS concepts were studied.

If the curves from Fig. 5 are studied one can notice that independently of the used pulse width the TH-UWB performance is better than the corresponding performance of DS-UWB. Fig. 5 also shows that changing the pulse width the performance of the UWB system changes as well. This is also based on the changes in the spectral allocations. The results shown in Figs. 4 and 5 are consistent with the ones simulated with FDD-UL jamming.

Moreover, the same kind of UWB system performance degradation can be noticed with the presence of GSM interference (multitone jamming) studied in [1]. These results show also that the UWB system performances can be best decreased if the interfering or jamming signal is set at the nominal UWB center frequency.

3.2. Bit error rate versus jamming-to-signal ratio

In this section, the performances of different UWB systems are shown in terms of BER for different values of jamming-to-signal power ratio. The SNR is kept fixed at 8 dB.

Two different performance analyses have been carried out. Firstly, the simulation results will be shown for UWB systems using different derivatives of the Gaussian pulse. Secondly, several pulse widths will be taken into account and the results will be shown for a selected pulse type.

The results when the jamming has its spectrum in UMTS/ WCDMA FDD uplink band are shown in Figures 6a-b. Fig. 6a shows the performance curves for the 1st and the 3rd derivatives of a Gaussian pulse. Corresponding results for the 2nd and 4th pulses can be seen from Fig. 6b. In both cases, the pulse width is T_p = 1 ns. As it can be noticed, the 3rd derivative of the Gaussian pulse outperforms the first one in both the TH and DS cases. This is mainly due to the spectral allocation of the pulses. In the 3rd derivative case, in fact, the spectrum is shifted to higher frequencies, so that the negative influence of the UMTS transmission is less degrading the performance of the UWB system. Furthermore, the difference in performances between the 1st and 3rd pulse can be considered constant for different values of the jamming power, and is approximately 2 dB in both the TH-UWB and DS-UWB system cases.

The same trend can be exploited for the 2nd and the 4th pulse, shown in Fig. 6b, although here the difference between the performances of the different Gaussian pulses is much lower than 2 dB. Furthermore, in the DS-UWB case, the 2nd and the 4th derivatives of the Gaussian pulse show the same performances for any jamming-to-power ratio.

The BERs for the different UWB systems are summarized in Table 3 for a fixed SNR of 8 dB and a jamming-to-noise ratio of 10 dB.

Comparing directly TH and DS systems, it can be noticed that TH clearly outperforms DS-UWB for low values of jamming powers. While the jamming power is increasing, the performances of the different systems are getting closer since the curves are saturating, and the DS systems are performing as well as the TH ones. This can be noticed for jamming-to-signal power ratios starting approximately from 12 dB.

The performance results for the second approach are shown in Figures 7a-b for FDD-UL and FDD-DL, respectively. Here, different pulse widths have been considered performing the jamming-to-power ratio. The template pulse waveform is the 3rd derivative of the Gaussian pulse. It is clear how for a pulse length of 0.25 ns, in both UL and DL, the jamming in UMTS band does not affect the BER, since the spectrum of the UWB system is totally shifted above the UMTS band. In the other cases, instead, the performances are worsening while the jamming-to-signal power ratio is increasing. Generally, anyway, the TH-UWB systems are outperforming the DS ones, but when the jamming power gets higher, their performances get closer. It can be then concluded that interference (jamming) in UMTS band makes the DS- and TH-UWB systems perform the same when its band is within the UWB one, and its power gets higher.

Table 3. BER in DS-UWB and TH-UWB systems for different pulse waveforms with jamming having a spectrum at the UMTS FFD-UL band. The SNR is 8 dB and the jamming-to-signal power ratio is 10 dB.

	DS	***TH***
1st pulse	$4.5\ 10^{-3}$	$2.8\ 10^{-3}$
2nd pulse	$6.5\ 10^{-3}$	$5.5\ 10^{-3}$
3rd pulse	$6.7\ 10^{-3}$	$4.9\ 10^{-3}$
4th pulse	$6.6\ 10^{-3}$	$4.1\ 10^{-3}$

Finally, comparing Figures 7a and 7b reciprocally, one can notice how the behaviour of the curves related to the same pulse width does not differ too much, except for the performances of the 1.5 ns pulse, which are improving clearly in the FDD-DL case. The reason of this difference comes from the fact that when we consider high pass filtered versions of the Gaussian pulse, the slope of the UWB spectrum changes deeply. Then, if the jamming is located where the slope of the UWB spectrum is high, even a small shift of the jamming spectrum (i.e. from FDD-UL to FDD-DL, as it can be noticed from Figures 7a and 7b) can change remarkably the performances of the UWB system. The influence of the slope can be seen from Figure 2, where the UMTS FDD bands are plotted with the UWB spectra.

4. CONCLUSIONS

This paper studies the UWB system performance in AWGN channel when the pulsed jamming having a spectrum in the UMTS/WCDMA band is present. Time hopping and direct sequence based UWB systems have been studied using four different pulse waveforms. UWB transmission utilizes uncoded baseband binary pulse amplitude modulation schemes.

The performance analysis has been implemented to exploit UWB systems behaviour using different pulses and several pulse widths, as well as different jamming signals having their spectrum allocated in the UMTS FDD uplink or in the UMTS FDD downlink band.

Under these assumptions, the results showed that the UWB system suffers most if the jamming and the nominal center frequency of the UWB system are overlapping. Thus, the UWB performance depends on the pulse waveform and on the pulse width which defines the spectrum allocation in frequency domain.

The results showed also that as the jamming power is getting higher, the performances of DS and TH are getting more similar, while for low values of jamming power the TH system is always outperforming the DS system performance. However, even for a signal-to-jamming power ratio of -24 dB, UWB systems can maintain their BER below 0.05.

In the following work the UWB system performances will be studied with the multiband interference and jamming. Moreover, the effects of a real indoor radio channel will be taken into account in addition to the AWGN channel.

5. ACKNOWLEDGEMENTS

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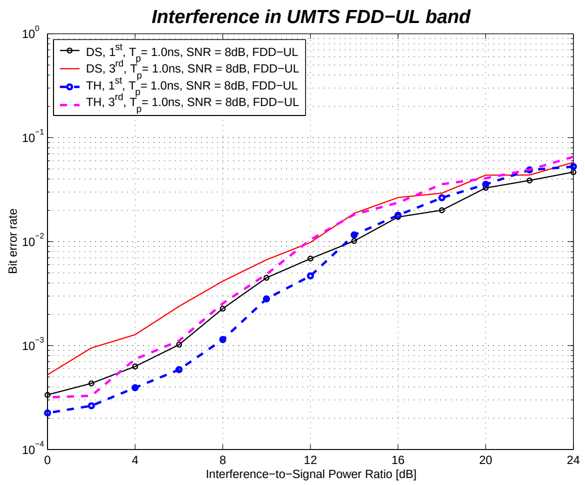

Fig. 6a. Bit error rate versus jamming-to-signal power ratio for the 1st and the 3rd pulses. SNR = 8 dB and the jamming is in FDD-UL band.

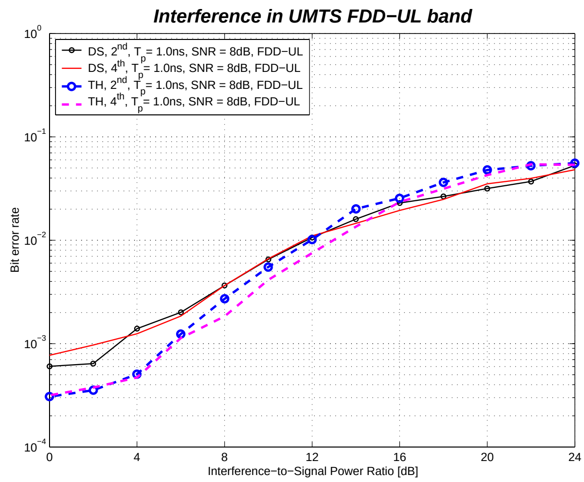

Fig. 6b. Bit error rate versus jamming-to-signal power ratio for the 2nd and the 4th pulses. SNR = 8 dB and the jamming is in FDD-UL band.

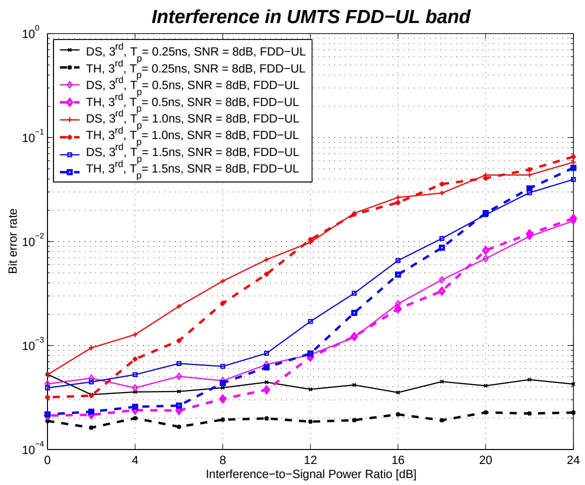

Fig. 7a. Bit error rate versus jamming-to-signal power ratio for different pulse widths. SNR = 8 dB and the jamming is in FDD-UL band. The UWB pulse waveform is the 3rd derivative of the Gaussian pulse.

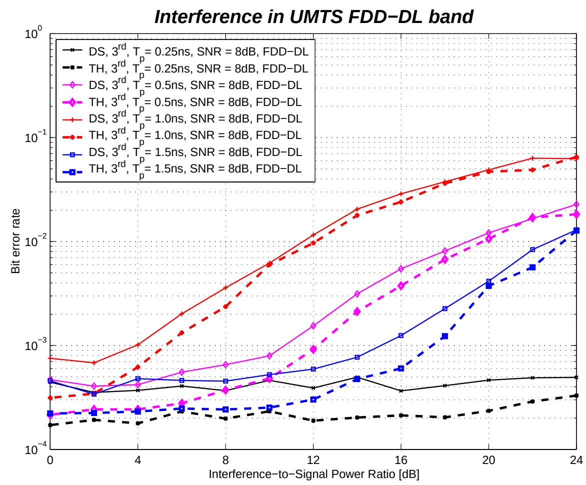

Fig. 7b. Bit error rate versus jamming-to-signal power ratio for different pulse widths. SNR = 8 dB and the jamming is in FDD-DL band. The UWB pulse waveform is the 3rd derivative of the Gaussian pulse.