RADIO FREQUENCY INTERFERENCE ISSUES IN IMPULSE RADIO MULTIPLE ACCESS COMMUNICATION SYSTEMS

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ABSTRACT

Impulse radio systems use very short pulses. Consequently, the spectrum of the transmitted signal spreads over several Gigahertz and overlaps with RF bands occupied by other communication systems. As a result, Radio Frequency Interference (RFI) affects the received signal.
In this paper, we present an analysis of the effects of RFI to a victim UWB receiver. Conditions for RFI cancellation for a large class of interfering signals are derived and it is shown that accurate frequency estimation of the interfering signal is necessary in order to provide interference cancellation.
Finally, the level of accuracy that guarantees that the theoretical results hold in practice is given.

1. INTRODUCTION

Impulse radio (IR) is a spread spectrum technique which uses very short duration pulses and pulse position modulation for transmitting information [1].
The transmitted signal is $s(t)=\sum_{i=-\infty}^{\infty}\sum_{j=0}^{N_s-1}g(t-jT_f-iT_b-b_i\delta)$, where $g(t)$ is the pulse of duration T_w, N_s is the number of pulses per bit and $T_b=N_s\cdot T_f$ is the bit duration. The sequence of b_i represents the information bits. Multiple access capability is achieved using time hopping codes [2], and in this case the transmitted signal is: $s(t)=\sum_{i=-\infty}^{\infty}\sum_{j=0}^{N_s-1}g(t-jT_f-c_jT_c-iT_b-b_i\delta)$. An additional shift of c_jT_c is provided by the hopping code, with $0\le c_j\le N_h$ and $N_h\cdot T_c\le T_f$. N_c is the code period and can be different from N_s.
The receiver performs the integral, in a bit time T_b, of the product between the received signal

$$s_{rec}(t)=\sum_{j=0}^{N_s-1}g(t-jT_f-c_jT_c-b_i\delta-iT_b)+n(t),$$

where *n(t)* includes the RFI and:

$$v(t)=\sum_{j=0}^{N_s-1}\left(g(t-jT_f-c_jT_c-iT_b)\right)-$$
$$-\sum_{j=0}^{N_s-1}\left(g(t-jT_f-c_jT_c-iT_b-\delta)\right)$$

In this paper, we address the topic of external interference (RFI) from a sinusoidal signal, a QAM modulated signal, many QAM modulated signals to a victim UWB receiver. General conditions of interference mitigation to a victim UWB receiver with pulse shape *g(t)* are derived in section 2. Section 3 reports, as a case study, the conditions of interference cancellation when the interfering signal is a sine wave and the UWB receiver has Gaussian pulse shape. Moreover, some considerations on the accuracy of the interfering signal estimation are given. Finally, section 4 contains the conclusions.

2. ANALYSIS OF RFI AND CONDITIONS OF CANCELLATION OF INTERFERENCE TO A VICTIM UWB RECEIVER

2.1 Interference from a sinusoidal signal to a victim UWB receiver

Here we consider a sinusoidal signal interfering to a victim UWB receiver.
Given that the received signal in a T_b interval is:

$$s_{rec}(t)=A\cdot\sum_{j=0}^{N_s-1}g(t-jT_f-c_jT_c-b\delta)+$$
$$+A_c\sin(2\pi f_c t)$$

The receiver output can be written as:

$$s_{out}=\int_{T_b}s_{rec}(t)\cdot v(t)dt=N_s\cdot A\cdot m_p+$$
$$+A_c\cdot\sum_{j=0}^{N_s-1}\left[\int_{j\cdot T_f}^{(j+1)\cdot T_f}\sin(2\pi f_c t)\cdot v(t)dt\right]$$

The interfering signal s_{int} at the receiver output is:

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$$s_{\text{int}} = A_c \cdot \sum_{j=0}^{N_s-1}\left[\int_0^{T_w} g(t)\sin\left(2\pi f_c\left(t + jT_f + c_jT_c\right)\right)dt\right] +$$

$$- A_c \cdot \sum_{j=0}^{N_s-1}\left[\int_0^{T_w} g(t)\sin\left(2\pi f_c\left(t + jT_f + c_jT_c + \delta\right)\right)dt\right]$$

$$s_{\text{int}} = -2A_c \sin(\pi f_c \delta) \cdot$$

$$\cdot \sum_{j=0}^{N_s-1}\left[\int_0^{T_w} g(t)\cos\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)dt\right],$$

depending upon pulse shape *g(t)*, pulse duration and δ.

In particular, a condition for $s_{\text{int}} = 0$ is:

$$\delta \cdot f_c = 2 \cdot k \quad k = 0,1,\ldots$$

The other condition for $s_{\text{int}} = 0$ is:

$$\sum_{j=0}^{N_s-1}\left[\int_0^{T_w} g(t)\cos\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)dt\right] = 0$$

not depending upon δ, but on the other UWB parameters.

2.2 Interference from a QAM modulated signal to a victim UWB receiver

Let $\{a_j\}$ and $\{b_j\}$ be the QAM phase and quadrature symbols of the interfering signal, with symbol rate $1/T_{\text{int}}$. Assuming that $\{a_j\}$ and $\{b_j\}$ cannot change in an interval T_f, the received signal in an interval T_b is:

$$s_{rec}(t) = A \cdot \sum_{j=0}^{N_s-1} g\left(t - jT_f - c_jT_c - b\delta\right) +$$

$$+ \sum_{j=0}^{N_s-1}\left(a_j \cos(2\pi f_c t) - b_j \sin(2\pi f_c t)\right)$$

The correlator output is:

$$s_{out} = \int_{T_b} s_{rec}(t) \cdot v(t)dt = N_s \cdot A \cdot m_p +$$

$$+ \sum_{j=0}^{N_s-1} a_j \cdot \int_{j \cdot T_f}^{(j+1) \cdot T_f} \cos(2\pi f_c(t_c)) \cdot v(t)dt -$$

$$- \sum_{j=0}^{N_s-1} b_j \cdot \int_{j \cdot T_f}^{(j+1) \cdot T_f} \sin(2\pi f_c(t_c)) \cdot v(t)dt$$

and the interfering signal is:

$$s_{\text{int}}(t) = \sum_{j=0}^{N_s-1} a_j\left[\int_0^{T_w} \cos\left(2\pi f_c\left(t + jT_f + c_jT_c\right)\right)g(t)dt\right] +$$

$$- \sum_{j=0}^{N_s-1} a_j\left[\int_0^{T_w} \cos\left(2\pi f_c\left(t + jT_f + c_jT_c + \delta\right)\right)g(t)dt\right] +$$

$$- \sum_{j=1}^{N_s} b_j\left[\int_0^{T_w} \sin\left(2\pi f_c\left(t + jT_f + c_jT_c\right)\right)g(t)dt\right] +$$

$$- \sum_{j=1}^{N_s} b_j\left[\int_0^{T_w} \sin\left(2\pi f_c\left(t + jT_f + c_jT_c + \delta\right)\right)g(t)dt\right] =$$

$$= \sum_{j=1}^{N_s} a_j\left(2\sin(\pi f_c \delta)\right)\int_0^{T_w} \sin\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)g(t)dt +$$

$$+ \sum_{j=1}^{N_s} b_j\left(2\sin(\pi f_c \delta)\right)\int_0^{T_w} \cos\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)g(t)dt$$

Therefore:

$$s_{\text{int}}(t) = \left(2\sin(\pi f_c \delta)\right) \cdot \left[\sum_{j=0}^{N_s-1}\int_0^{T_w}\left[a_j \sin\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)\right]g(t)dt\right] +$$

$$+ \left(2\sin(\pi f_c \delta)\right) \cdot \left[\sum_{j=0}^{N_s-1}\int_0^{T_w}\left[b_j \cos\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)\right]g(t)dt\right]$$

depending upon pulse shape *g(t)*, pulse duration and δ.

In particular, a condition for $s_{\text{int}} = 0$ is:

$\delta \cdot f_c = 2 \cdot k \quad k = 0,1,\ldots$ leading, for parameter δ, to the same condition as before. The other condition for $s_{\text{int}} = 0$ is:

$$\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}\left[a_j \sin\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)\right]g(t)dt\right] +$$

$$+ \left[\sum_{j=0}^{N_s-1}\int_0^{T_w}\left[b_j \cos\left(\pi f_c\left(2t + 2jT_f + 2c_jT_c + \delta\right)\right)\right]g(t)dt\right] = 0$$

depending on other UWB parameters (pulse shape, pulse duration,…).

1.3 Interference from QAM modulated signals to a victim UWB receiver

Following the same procedure in 2.2 and 2.3 the interfering signal at the receiver output can be written as:

$$s_{int}(t)=(2\sin(\pi f_{c1}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[a_{j1}\cdot\sin(\pi f_{c1}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]+$$

$$+(2\sin(\pi f_{c1}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[b_{j1}\cdot\cos(\pi f_{c1}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]+$$

$$+(2\sin(\pi f_{c2}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[a_{j2}\cdot\sin(\pi f_{c2}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]+$$

$$+(2\sin(\pi f_{c2}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[b_{j2}\cdot\cos(\pi f_{c2}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]+$$

$$+\ldots\ldots\ldots\ldots\ldots+$$

$$+(2\sin(\pi f_{cn}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[a_{jn}\cdot\sin(\pi f_{cn}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]+$$

$$+(2\sin(\pi f_{cn}\delta))\cdot\left[\sum_{j=0}^{N_s-1}\int_0^{T_w}[b_{jn}\cdot\cos(\pi f_{cn}(2t+2jT_f+2c_jT_c+\delta))]\cdot g(t)dt\right]$$

and the condition for no interference depending on δ is: $\delta\cdot f_{ci}=2\cdot k \quad k=0,1,\ldots \quad i=1,2,\ldots n$

3. CASE STUDY

In order to understand the role of variables involved and spectra, we present as a case study the results relative to a Gaussian pulse *g(t)*, and a sinusoidal interfering signal.

3.1 Gaussian pulse

The Gaussian pulse we took into consideration has the following expression (in nanoseconds):

$$g(t+0.35)=\left[1-4\pi(t/\tau_m)^2\right]\exp\left[-2\pi(t/\tau_m)^2\right]$$

with τ_m=0.2877.

Figure 1 shows the spectrum of transmitted signal (curve A) with T_w=0.8ns, T_f=100ns; N_h=55; N_s=10; N_c=10, the interfering signal (curve B) with f_c=2GHz, and the integration signal for δ=1ns (curve C1) and δ=2ns (curve C2). In this case the condition of interference annulment is achieved with the parameter δ, and the spectrum of the transmitted signal has not been modified.

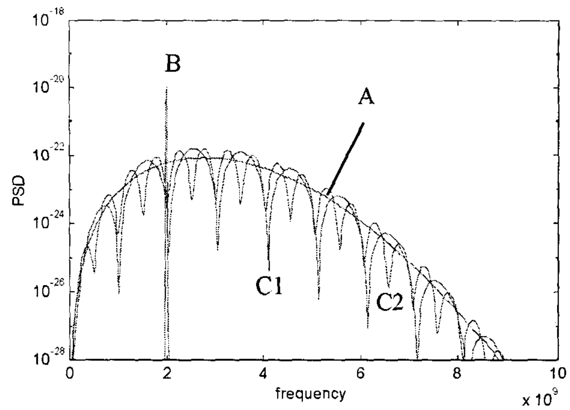

Fig. 1: spectrum of the transmitted signal (curve A) with T_w=0.8ns, T_f=100ns; N_h=55; T_c=1.8ns; N_s=10; N_c=10, the interfering signal (curve B) with f_c=2GHz, and the integration signal for δ=1ns (curve C1) and δ=2ns (curve C2).

4. CONCLUSIONS AND CONSIDERATIONS ON FREQUENCY ESTIMATION

In general (with a small difference for FM modulated signals), we have found that, in order to eliminate the RFI interference from a received UWB signal, the condition that must be satisfied is $\delta\cdot f_c=2\cdot k \quad k=0,1,\ldots,$ while particular conditions can be found for pulse shape and duration.

With the actual technology, typical values of δ are of the order of nanoseconds or fractions of nanoseconds, meaning that the radio frequency interference that can be eliminated is above 2 GHz. However, the above consideration is in complete agreement with [6], in which UWB transmissions are strongly recommended above 3.1 GHz.

In paragraph 1 it is shown that a general condition for interference annulment is:

$\delta\cdot f_c=2\cdot k \quad k=0,1,\ldots$ that corresponds to the condition for which the interfering signal central frequency coincides with a null in the UWB signal spectrum. Because the δ parameter is chosen with the condition: $\delta=\frac{2\cdot k}{f_c}$, an error Δf_c in the frequency estimation brings to a different parameter $\delta=\frac{2\cdot k}{f_c+\Delta f_c}$.

In [3] the Cramer-Rao lower bounds for phase and frequency estimation are derived for QAM signals. Typical values ([3],[4],[5]) of the frequency estimation error, in percentage, goes from 10^{-3} to 10^{-1},depending on the E_b/N_0 at the receiver side and on the goodness of the estimator. For example, for a carrier f_c=1GHz the frequency error Δf_c would range from 1MHz to 100MHz. In this case, the error of the order of magnitude of 1MHz would be negligible in the interference cancellation, while the error of 100 Mhz would bring to a high external interference. Therefore, the frequency estimation is critical and the error must be contained at the lower possible levels.

5. ACKNOWLEDGEMENTS

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