# QUASI COHERENT DETECTION ALGORITHM FOR UWB IMPULSE RADIO

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## I. Introduction

Regulations for Ultra-Wideband (UWB) radio specify only the maximum value of psd and the minimum bandwidth over the assigned UWB frequency band that goes from 3.1 GHz to 10.6 GHz. Neither the type of the carrier nor the modulation technique are defined. The psd of Equivalent Isotropically Radiated Power (EIRP), measured with a resolution of 1 MHz, must be below -41.3 dBm [1]. One-to-one recovery of UWB carriers is not feasible, consequently, a pure coherent UWB receiver cannot be built. On the other hand, noncoherent detectors offer a bad noise performance. As a trade-off, a new near-coherent detector configuration is proposed here where there is no need for an exact recovery of UWB carrier to perform detection.

## II. Modulation schemes used in UWB radio

The waveforms used to carry digital information are ultra wideband signals in UWB radio with 500-MHz minimum bandwidth. Fixed or chaotic carriers can be used to transmit information. The former is a deterministic signal while the latter is a continuously varying wavelet [2]. This paper considers the fixed waveform UWB radio.

### A. *Modulation using fixed waveform*

In the simplest case, one bit information is carried by one fixed UWB wavelet. The structure of this UWB signal is shown in Fig. 1 where $g(t)$ denotes a fixed but arbitrary wavelet, used as carrier, in the pulse bin $T_{bin}$. Pulse bin determines the time elapsed between two consecutive wavelets, i.e. the symbol rate. Its role is to prevent intersymbol interference in a multipath channel. Observation time $T_{obs}$ determines the interval during which the detector observes the received signal. The position $t_{pos}$, the amplitude and the sign of the waveform may be varied in accordance with the digital information to be transmitted but the best noise performance is offered by an antipodal modulation scheme. Therefore, Pulse Polarity Modulation (PPoM) is considered here where the information is mapped into the sign of the radiated deterministic signal.

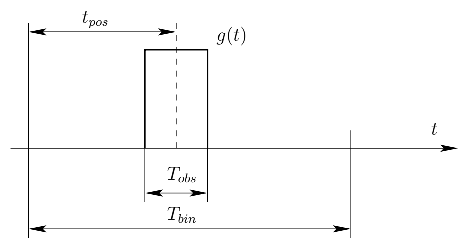


Figure 1: Waveform structure of UWB impulse radio.

### B. *Deterministic wavelets used in UWB impulse radio*

Since regulations specify only the psd mask and minimum bandwidth of UWB wavelet, there is a high degree of freedom in generating UWB waveforms.

In this paper the bell-shaped Gaussian pulse [1] is investigated where the bandwidths are 2 GHz and 500 MHz. The only basis function takes the form

$$g(t) = \sqrt{\frac{2E_b}{\sqrt{\pi}u_b}} \exp\left(-\frac{t^2}{2u_B^2}\right) \cos(\omega_C t) = v(t) \cos(\omega_C t) \tag{1}$$

consequently, the elements of PPoM signal set are $s_{1,2} = \pm g(t)$. The carrier $f_C = \omega_C / 2\pi$ is the UWB center frequency, $E_b$ denotes the energy per bit, and $u_B$ is a constant determined by the 10-dB bandwidth of UWB wavelet [1]. Depending on their bandwidths (i) wideband, 2 GHz and (ii) narrowband, 500 MHz UWB systems are distinguished. The bell-shaped Gaussian wavelets are shown in the time domain for the wide- and narrowband UWB systems in Fig. 2. Although the duration of Gaussian waveforms is infinite the power decreases rapidly as a function of time, consequently, the optimum duration of observation time $T_{obs}$ cannot be determined from the UWB wavelet, it is obtained from the noise performance of the PPoM modulation scheme. By definition, observation time assuring minimum BER is considered as $T_{obs}$.

To implement a near-coherent correlation receiver, a reference signal has to be generated. Because of their spectral shape, the UWB carriers cannot be recovered. Instead, a noise-free reference signal approximating $g(t)$ over $T_{obs}$ as close as possible should be found that may be recovered from the received UWB waveform by implementable circuitry.

As shown in Fig. 2, less than two cycles of carrier are transmitted in wideband UWB radio. The energy of such a signal is concentrated in the main lobe, therefore, the detection may be performed by windowing the received UWB waveform by a square-wave template signal [2]. This technique, referred to as template detection, is used if the energy of UWB signal is spread over a few carrier cycles.

In narrowband UWB radio, the UWB wavelet contains about 10 carrier cycles as shown in Fig. 2 for $f_C = 4$ GHz. In this case a sinusoidal signal recovered by a phase-locked loop (PLL) can be considered as a reference signal. The detection of narrowband UWB signal using a sinusoidal reference is referred to as near-coherent technique.

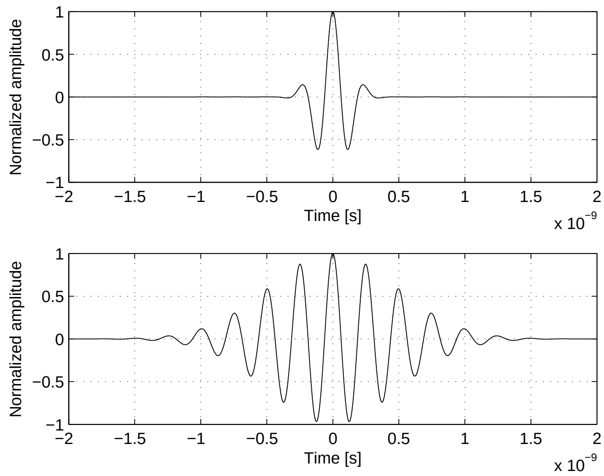


Figure 2: Bell-shaped Gaussian pulses with 2-GHz (upper trace) and 500-MHz (lower trace) bandwidths for $f_C$=4 GHz.

## III. Near-coherent detection technique

In narrowband UWB impulse radio the transmitted signal contains enough cycles of the carrier to be recovered by a PLL, i.e. a sinusoidal reference $c(t)$ is used in the coherent correlation receiver. At the receiver a gated phase-locked loop (G-PLL) structure is used to recover $c(t)$.

The block diagram of near-coherent UWB detector proposed here for the narrowband UWB systems is shown in Fig. 3, where $r_m(t) = s(t) + n(t)$ is the received noisy signal, $c(t)$ denotes the *quasi-recovered* carrier, $z_m$ is the observation variable and $\hat{b}_m$ denotes the recovered digital information. The appellation *quasi-recovered* carrier refers to the main characteristic of near-coherent detection: although both the $r_m(t)$ and $c(t)$ have the same angle, the former has Gaussian envelope while the latter is the output of a G-PLL therefore its envelope is constant. This mismatch in shape results in performance degradation. The information $\hat{b}_m$ can be recovered by correlating $r_m$ with the sinusoidal reference $c(t)$.

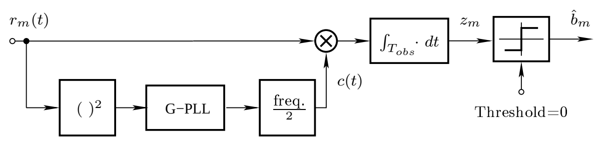


Figure 3: Block diagram of near-coherent UWB detector.

Important advantage of near-coherent detection is that $c(t)$ is a noiseless signal matched to the angle of $r_m(t)$

$$c(t) = \begin{cases} \sqrt{\frac{2}{T_{bin}}} \cos(\omega_C t), & \text{if } |t| < \frac{T_{obs}}{2} \\ 0, & \text{otherwise} \end{cases}$$

The received signal $r_m(t)$ is a modulated waveform. For the recovery of carrier first the modulation has to be eliminated that is performed by squaring the received signal. The spectrum of a UWB signal carrying a random modulation may have no carrier component. However squaring the modulated signal removes the modulation and generates a carrier component at $2f_C$

$$(\pm g(t))^2 = (\pm 1)^2 v^2(t)\cos^2(\omega_C t) = v^2(t)\frac{1+\cos(2\omega_C t)}{2} \tag{2}$$

This $2f_C$ frequency component is selected by a G-PLL and then a frequency divider is used to generate the $f_C$ frequency reference signal.

## IV. Noise performance of near-coherent detection

The model for investigation of the noise effects on the received signal is shown in Fig. 4. Since the transmitted signal is corrupted by white Gaussian noise in an additive manner in the telecommunication channel, the observation signal, a random variable that appears at the output of the correlator can be expressed as

$$z_m = \int_0^{T_{obs}} s_m(t)c(t)\mathrm{dt} + \int_0^{T_{obs}} n(t)c(t)\mathrm{dt} \tag{3}$$

Recall, that $c(t)$ is noiseless, consequently, $n(t)$ in (3) goes under a linear integral transformation. Therefore the distribution of the second term on right hand side remains Gaussian and its expected value is zero [3]. The noise performance is determined from the observation variable. For antipodal modulation scheme using one basis function, the probability of bit error is given in the literature [4]

$$P_e = \frac{1}{2}\mathrm{erfc}\left(\frac{\mu_m}{\sqrt{2\sigma_n^2}}\right) \tag{4}$$

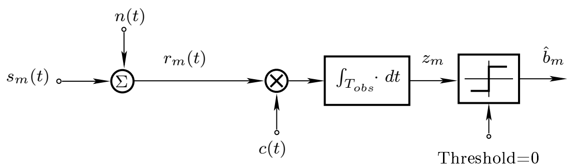


Figure 4: Model for investigation of the noise effects on the received signal.

where $\mu_m$ is the expected value of observation variable and $\sigma_n^2$ is the power of noise, i.e. the variance of $z_m$. To get the BER for near-coherent UWB detection $\mu_m$ and $\sigma_n^2$ have to be found.

Since the second term on the RHS of (3) has zero mean, the mean of $z_m$ is obtained as

$$\mu_m = \mathrm{E}\left[\int_0^{T_{obs}} s_m(t)c(t)\mathrm{dt}\right] = \sqrt{\frac{E_b\sqrt{\pi}u_B}{T_{bin}}}\mathrm{erf}\left(\frac{T_{obs}}{2u_B}\right) \tag{5}$$

where $E[.]$ is the expectation operator.

The channel noise $n(t)$ is modeled by a zero-mean stationary Gaussian process that has a uniform two-sided psd of $N_0/2$. The variance of the observation variable is obtained as [3]

$$\sigma_n^2 = \int_0^{T_{obs}}\int_0^{T_{obs}} R_n(t_1,t_2)c(t_1)c(t_2)dt_1dt_2 \tag{6}$$

where $R_n(t_1,t_2)$ denotes the autocorrelation function of $n(t)$. Since $n(t)$ is stationary and white, its autocorrelation function is

$$R_n(t_1,t_2) = R_n(t_2-t_1) = \frac{N_0}{2}\delta(t_2-t_1) = \frac{N_0}{2}\delta(\tau) \tag{7}$$

Substituting (7) into (6), the variance of $z_m$ is expressed as

$$\sigma_n^2 = \int_0^{T_{obs}}\int_0^{T_{obs}} \frac{N_0}{2}\delta(t-\tau)\frac{2}{T_{bin}}\cos(\omega_C t)\cos(\omega_C\tau)\,dt\,d\tau = \frac{N_0}{2}\frac{2}{T}\int_0^{T_{obs}}\cos^2(\omega_C t)\mathrm{dt} = \frac{N_0}{2}\frac{T_{obs}}{T_{bin}} \tag{8}$$

Substituting (8) and (5) into (4), we get the BER for near-coherent detection

$$BER = \frac{1}{2}\text{erfc}\left(\sqrt{\frac{\sqrt{\pi}u_B\left[\text{erf}\left(\frac{T_{obs}}{2u_B}\right)\right]^2}{T_{obs}}}\sqrt{\frac{E_b}{N_0}}\right) \tag{9}$$

Equations (5) and (8) show that both the mean and variance of observation variable depend on the observation time. Consequently, the BER given by (9) also depends on $T_{obs}$, its value may be minimized by choosing the optimum value of $T_{obs}$. Figure 5 shows the BER as a function of $T_{obs}$. Note, a global minimum exists at $T_{obs} = 1$ ns. This means that (9) can be minimized as a function of $T_{obs}$, its optimum value for our case is at $T_{obs} = 1$ ns.

Note, that any deviation from the optimum value of the observation time, results in a considerable performance degradation. For example, if the observation time is increased from 1 ns to 2 ns then BER also increases, from $10^{-8}$ to $10^{-6}$.

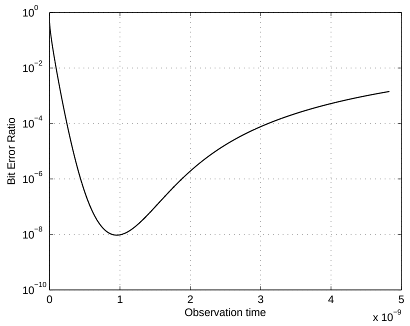


Figure 5: BER as a function of $T_{obs}$ for $E_B/N_0 = 14$ dB.

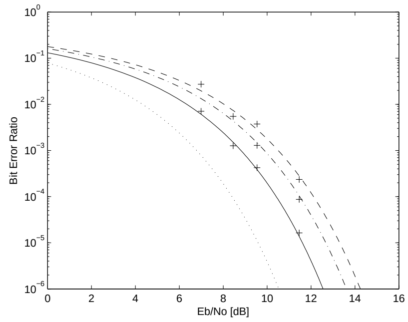


Figure 6: BER of BPSK (dotted), near-coherent detection for optimum $T_{obs}$ (solid), $2T_{obs}$ (dashed) and $0.5T_{obs}$ (dash-dotted).

The theoretical results have been validated by computer simulations. The results of BER simulations are marked by crosses in Fig. 6.

The noise performance of the new near-coherent detector is shown in Fig. 6 for optimum and increased/decreased observation times. The BER of BPSK is also shown for comparison. The transmitted carrier is not perfectly recovered in the proposed approach, instead, the recovered reference signal $c(t)$ is matched only in angle to the transmitted one. This mismatch error reduces the mean of $z_m$, therefore, the noise performance of near-coherent UWB detector always lags behind that of BPSK.

## V. Conclusions

A new near-coherent detection technique has been proposed for narrowband UWB impulse radio. A gated phase locked loop is used for the *quasi-recovery* of the basis function. An optimum $T_{obs}$ has been found that offers the best noise performance. Simulation results validate the closed form expression given for BER.

## References


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