NEW PARAMETERS OF THE ULTRAWIDEBAND SIGNALS AND PROCESSES

Lazorenko O. V.

Kharkiv National University of Radio Electronics, Kharkiv, Ukraine
E-mail: Oleg-Lazorenko@yandex.ru

Abstract

The possibility of distinguishing of the ultrawideband (UWB) and frequency modulated (FM) signals is considered. It is demonstrated that FM signal, being narrowband in each instant of time, with the traditional UWB signal definition usage can be falsely classified as the UWB signal. The dynamic fractional bandwidth conception based on the analysis of the spectral density function of short-time Fourier transform is proposed. The efficiency of the new criterion based on this conception for FM signal analysis is shown.

Keywords: ultrawideband signal, frequency-modulated signal, dynamic fractional bandwidth.

1. INTRODUCTION

Fast development of the UWB technologies creates a new potential for specialists in many branches of science and engineering. The UWB signals have been successfully applied in radar, telecommunication and remote sounding [1-8].

Suddenly, not all definitions in UWB technologies, may be, are quite right now. First, the term 'UWB' is not allowed to be limited only by the applications listed above. Moreover, the UWB signals have not only artificial origin. Many processes in nature having an ultrawide Fourier spectrum can be considered as the ultrawideband ones [9]. Second, there is a problem to distinguish the UWB signals and processes and the signals and processes, for instance, FM-signals, falsely classified by the definition as ultrawideband, but being fundamentally narrowband in each instant of time.

Therefore, the creation of the new parameters for the UWB signal description and the new additional classification criterion based on those parameters is appeared to be advisable and topical.

2. DYNAMIC FRACTIONAL BANDWIDTH CONCEPTION

2.1. UWB SIGNAL DEFINITION

As well known, by the Federal Communications Commission definition [10], given in 2002, UWB signal is the signal having fractional bandwidth μ in bounds $0{,}2 \le \mu < 2$ or having bandwidth Δf greater than 500 MHz. Fractional bandwidth is defined by

$$\mu = 2\,\frac{f_{\max} - f_{\min}}{f_{\max} + f_{\min}}\,, \tag{1}$$

where $f_{\min}$ and $f_{\max}$ are the lowest and the highest frequencies of the one-dimensional Fourier transform (OFT) spectral density function (SDF) of signal, which are defined by the -10dB points from the highest OFT SDF value.

It is significant that the demand to consider as the UWB signals ones having $\Delta f \ge 500\,\text{MHz}$ and $\mu < 0{,}2$, may be, is useful as a practical matter, but is incorrect as physical matter. Fractional bandwidth μ has more significance in physics and, in particular, in non-linear physics and non-linear radio physics [11]. It can be considered as the series expansion parameter. We can surmise that UWB signals and processes conform to the non-linear physics as the narrowband ones correspond to the linear physics.

Other hand, it is more convenient to determine $f_{\min}$ and $f_{\max}$ at the level when OFT SDF decreases in e times relative it's biggest maximum [12]. First, such demand is more valid as physical matter and, second, it satisfies more closely the well known relation

$$\mu \approx 4/N\,, \tag{2}$$

where N is the UWB signal sidelobe quantity [1]. For UWB signals N value is limited by $N \le 20$.

Thus, a signal with $0{,}2 \le \mu < 2$ is the UWB signal, with $0{,}01 < \mu < 0{,}2$ is the wideband signal, with $0 < \mu < 0{,}01$ is the narrowband signal, with $\mu = 0$ is the monochromatic signal and with $\mu = 2$ is the video signal [7].

2.2. FM-SIGNALS AND UWB SIGNALS

Listed above signal classification is quite good for the simple signals, which have signal base $B = \tau_s \Delta f \approx 1$, where τ_s is the signal time duration. Another situation is appeared to be with complex signals having $B \gg 1$. Linear frequency modulated (LFM) signal, given by

$$s_1(t) = A_0 \sin(2\pi f(t) + \varphi_0)\Theta(t), \quad (3)$$

where $\Theta(t) = \eta(t/\tau_s) - \eta(t/\tau_s - 1)$, $\eta(t)$ is Heavyside function, $f(t) = at + f_1$, $a > 0$, φ_0 is the initial phase, $f_1 = f(0)$, can be considered as an example of such complex signal.

For signal (3) it can be simply obtained, that $f_{\min} = f_1$, $f_{\max} = a\tau_s + f_1$ and, therefore, $\Delta f = f_{\max} - f_{\min} = a\tau_s$. Other hand, we can note that

$$\Delta f = B/\tau_s, \quad (4)$$

$$f_0 = (f_{\max} + f_{\min})/2 = f_1 + a\tau_s/2 = = (f_1\tau_s + B/2)/\tau_s. \quad (5)$$

Placing (4) and (5) into (1), we obtain, that $\mu = 2B/(B + 2f_1\tau_s)$. From this it follows that the LFM-signal fractional bandwidth μ with $0 < f_1\tau_s \le 9B/2$ is satisfying the condition of UWB signal definition.

Another way of LFM-signal fractional bandwidth estimation consists in usage of relation (2) simultaneously with the mean signal frequency f_0 Let's denote the frequency bandwidth obtained in this way as μ_0. In such case we can find, that $N \approx 2\tau_s/T_0 = = 2f_0\tau_s = B + 2f_1\tau_s$, where $T_0 = 1/f_0$ and $\mu_0 \approx 4/(B + 2f_1\tau_s)$. Therefore,

$$\mu = B\mu_0/2.$$

Thus, when the condition

$$10 - \frac{B}{2} < f_1\tau_s \le \frac{9B}{2}$$

has been satisfied, the paradoxical situation is observed. Being principally narrowband in each instant of time, the LFM-signal with the traditional UWB signal definition usage can be falsely classified as the UWB signal. Such situation appearance possibility was predicted in [1], but, suddenly, without any answer presence.

2.3. DYNAMIC FRACTIONAL BANDWIDTH

2.3.1. Dynamic Fractional Bandwidth Definition

To improve listed above situation, the new UWB signal parameter, called as the dynamic fractional bandwidth, is proposed to be used for the complex signals. Let's consider the basic idea of the dynamic fractional bandwidth. As well known, the short-time Fourier transform (STFT) of the signal $s(t)$ is defined as

$$\dot{S}(f,\tau) = \int_{-\infty}^{\infty} s(t)w(t-\tau)\exp(-i2\pi ft)dt,$$

where $\dot{S}(f,\tau)$ is the STFT SDF, τ is the variable describing a shift of the finite (or quasi-finite) window function $w(t)$ relatively the signal position in time domain. Using the STFT SDF module $\left|\dot{S}(f,\tau)\right|$, calculated for UWB signal $s(t)$ being finite at $t \in [0, \tau_s]$, and the definition (1), the fractional bandwidth for each constant value of τ at interval $\tau \in [-\tau_s/2, \tau_s/2]$ can be obtained. Therefore, fractional bandwidth comes to be a function of time shift τ an can be called as the dynamic fractional bandwidth $\mu_d(\tau)$. The window function width is proposed to be equal to the signal time duration τ_s.

2.3.2. Dynamic Fractional Bandwidth Peculiarities

Let's consider the dynamic fractional bandwidth peculiarities with analysis of different signal types.

Simple UWB signal model is given by [12]

$$s_2(t) = A_0 \sin\left(2\pi n \frac{t}{\tau_s}\right)\Theta(t), \quad (6)$$

where $N = 2n$, n is natural number. For this UWB signal it is obtained, that $\mu_d(\tau) \to 2$ for $n = 1$ and

$$\mu_d(\tau) \approx \begin{cases} \dfrac{\mu}{\dfrac{\tau}{\tau_s} + 1}, & \tau \in \left[-\dfrac{\tau_s}{2}, 0\right]; \\ \dfrac{\mu}{1 - \dfrac{\tau}{\tau_s}}, & \tau \in \left(0, \dfrac{\tau_s}{2}\right]; \end{cases}$$

for $n \ge 2$, where μ is the signal fractional bandwidth calculated with OFT SDF usage.

The analysis of the UWB signal model (6) with $N = 4$ ($\mu = 1$) is given at fig. 1. By the dashed line

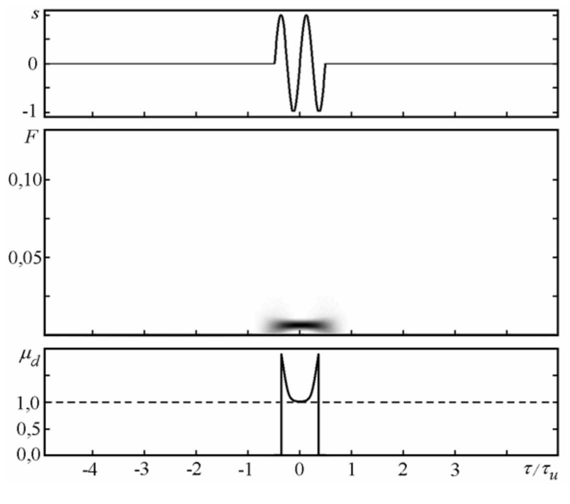

Fig. 1. Analysis of the UWB signal model (6) with $N = 4$ ($\mu = 1$): a – the signal in time domain, b – the STFT SDF module, c – the dynamic fractional bandwidth.

here and later the value of μ is denoted. No wonder that $\mu_d(0) = \mu$ (fig. 1, c). In this case all signal $s(t)$ is placed in window $w(t)$. But the larger the $|\tau|$ value is, the smaller the signal sidelobe number in window is placed and, therefore, the larger the $\mu_d(\tau)$ value appears.

At fig. 2 the analysis of signal model (6) with $N = 20$ ($\mu = 0{,}2$) is shown. The most significant interest is attracted by the LFM-signal analysis results shown at the fig. 3. As would be expected, despite the fact that $\mu \approx 1{,}7$, the value of $\mu_d(\tau)$ is visibly less than μ for any τ.

Founding on the conducted investigations, the new criterion based on the dynamic fractional bandwidth concept and allowing to distinguish the UWB and narrowband FM-signals is proposed. Thus, if for given signal or process the condition $\mu_{d\max} \geq \mu$ was satisfied, then the signal or process can be called as the UWB one and, accordingly, can't in opposite case.

CONCLUSIONS

- It is demonstrated that FM signal, being narrowband in each instant of time, with the traditional UWB signal definition usage can be falsely classified as the UWB signal.
- The dynamic fractional bandwidth as the new parameter for the UWB signal description is introduced.
- The new criterion based on the dynamic fractional bandwidth concept for the distinguishing of the UWB and FM signals is proposed.

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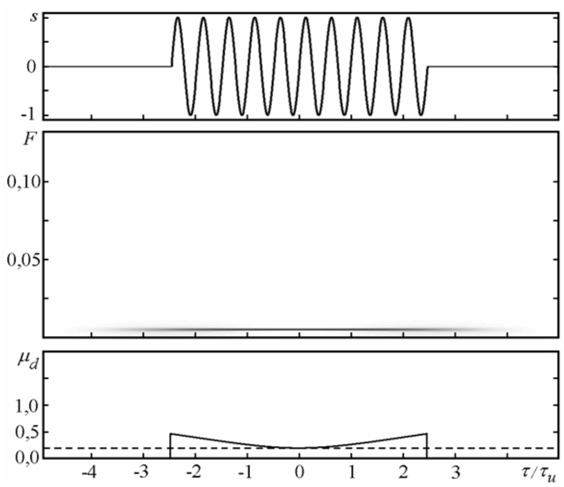

Fig. 2. Analysis of the signal model (6) with $N = 20$ ($\mu = 0{,}2$): a – the signal in time domain, b – the STFT SDF module, c – the dynamic fractional bandwidth.

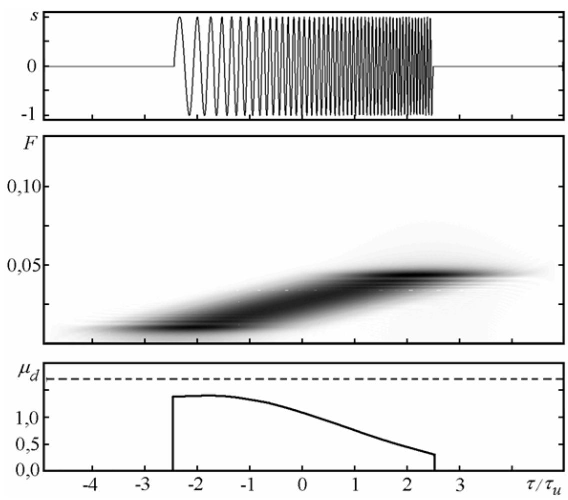

Fig. 3. LFM-signal model (3) analysis ($\mu = 1{,}7$): a – the signal in time domain, b – the STFT SDF module, c – the dynamic fractional bandwidth ($\mu_{d\max} \approx 1{,}4$).