A Possibility for UWB Spectrum Shaping

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Abstract – **Below is reviewed an opportunity for UWB spectrum shaping though pulse synthesis in discrete time. Assessment of the obtained increase of the UWB systems performance was carried out.**

I. Introducion

Recently the interest in the ultra-wideband (UWB) technology, especially in the so-called impulse radio (IR) has increased. IR is a promising candidate for application in precise positioning systems, radar applications, as well as in short range communications, because it allows achieving of high data rates (hundreds of MBPS), while at the same time it permits reusing of the spectrum, occupied by the already existing users. IR conveys information through train of extremely short baseband pulses (pulse-width in the order of tenth of nanosecond) [1,2].

Below is a very simplified mathematical description of the used IR signal:

$$s(t) = \sum_{k=0}^{\infty} A_k g_t(t - kt_f - t_k), \tag{1}$$

where the frame duration t_f determines the mean pulse repetition frequency, and $g_t(t)$ is the basic transmitted pulse. The time shift t_k determines the position of the k-th pulse in the k-th frame and depends both on the data modulation, and on a pseudo random time-hopping sequence. The amplitude A_k of the k-pulse is determined by the data modulation.

II. Purpose of the Article

An opportunity for UWB spectrum shaping will be studied. Its practical feasibility will be considered and some possible implementations will be suggested. The improvement of the performance of the UWB communication systems will be assessed.

III. UWB Spectrum

The UWB signal may be presented as follows:

$$s(t) = g_t(t) \otimes M(t), \tag{2}$$

where $M(t)$ is a pulse excitation process, which includes both the time hopping and the data modulation. The power spectral density (PSD) of the UWB signal is then given by

$$S_{UWB}(f) = |G_t(f)|^2 . S_M(f), \tag{3}$$

where $G_t(f)$=*[$g_t(t)$] and S_M is the PSD of $M(t)$. If there is an appropriate signal design $S_M(f)$ is generally flat. Consequently the spectrum shape of the UWB signal is determined by $G_t(f)$ [3,4].

For now pulse generation is mainly implemented through impulse excitation of the transmitting antenna, where there are not great opportunities for effective pulse spectrum control.

Precise spectrum control, however, is highly desirable. Firstly, It would provide the opportunity for PSD shaping, maximally corresponding to the emission masks, imposed by the regulatory authorities. Consequently, there would appear an opportunity to increase the transmitted power. It should be noted that it would be possible, through appropriate pulse spectrum shaping, to compensate the frequency dependence of the antenna gain.

Furthermore, an opportunity to adapt the UWB systems to the changing interference scenarios would be created. In the UWB correlation receivers the generation of template waveforms with a precisely controlled spectrum, would facilitate optimal filtering in the conditions of non-white noise and interference.

IV. Essence of the Proposed Approach

This article proposes pulse generation in discrete time. According to the desired spectrum, the required pulse form can be found through inverse Fourier transform. Then it may be approximated through its discrete samples. In the definition of the desired spectrum shape, the frequency dependence of the antenna gain, and the fact that non-ideal pulses would represent the samples could be taken into account. The generation of the samples may be performed in various ways depending on the technology state and the requirements to spectrum shaping precision. The most radical approach is digital as much as possible. A sample implementation, similar to that of the frequency synthesizers, employing direct digital synthesis, is displayed at Fig. 1a. If it is necessary to achieve higher frequencies, which at the moment cannot be achieved by the DDS technology and in case of a simpler pulse shape, the approach displayed by Fig. 1b may be applied. In this case however, flexibility is much lower.

It should be noted that once being calculated the values of the samples remain unchanged until changes in the interference scenario. If the UWB device does not provide for adaptation to the changing interface scenarios, these values may be hardware preset.

Suppose that the desired spectrum of the transmitted pulse is $G_t(\omega)$, and the transfer function of the transmitting antenna plus the additional filter (if any) is $H_A(\omega)$. Further-

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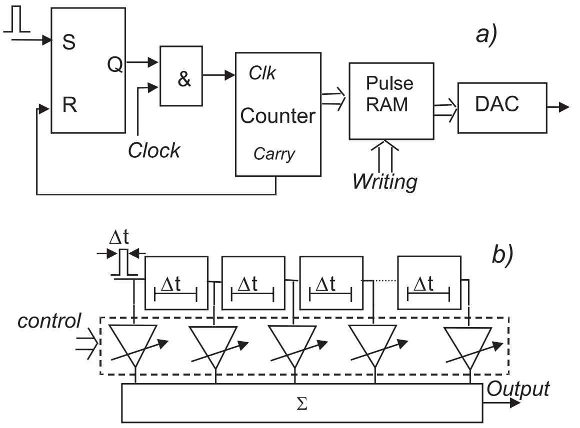

Fig. 1.

more, $G_S(\omega)$ is the spectrum of the elementary pulse, representing the samples of the transmitted pulse. Then, the pulse to be generated may be described as:

$$\begin{aligned} g(t) &= \Phi^{-1}\Big[\frac{G_t(\omega)}{H_A(\omega).G_S(\omega)}\Big] \\ &= \Phi^{-1}\Big[\frac{|G_t(\omega)|}{|H_A(\omega)|.|G_S(\omega)|}e^{j[\varphi_t(\omega)-\varphi_A(\omega)-\varphi_S(\omega)]}\Big] \\ &= \Phi^{-1}[|G(\omega)|e^{\varphi(\omega)}], \qquad (4) \end{aligned}$$

where $\varphi_A(\omega)$ and $\varphi_S(\omega)$ are known and $\varphi_t(\omega)$ may be arbitrary. Consequently, there is an opportunity to select $\varphi(\omega)$ where it is possible to optimize the transmitted pulse.

V. Feasibility

Obviously the proposed approach would complicate and make more expensive the UWB devices. Currently permits FCC operation of UWB devices in the frequency ranges 0...0.9 GHz and 3.1...10.6 GHz. Therefore the minimal sample rates are 1.8 GSPS and 21.2 GSPS respectively. The implementation shown in Fig. 1a for devices operating below 0.9 GHz is completely possible with respect to the current state of technology.

It should be noted that the pulse formation requires, as may be seen below, several dozens of samples, so the necessary memory is incomparably smaller than the memory employed in a DDS frequency synthesizer. The needed clock frequency instability is in the order of several percent, which also simplifies the implementation. The high cost is a problem, however it is expected to go down. With respect to the devices operating in the range 3.1 and 10.6 GHz, initially, the approach displayed at Fig. 1b seems more realistic.

In the last several years, the semiconductor technology has progressed rapidly and the achievable clock frequencies have increased dramatically [5]. It has been reported that SiGe bipolar transistors with $f_t = 350$ GHz and a 4.7 ps gate delay had been achieved [6,7].

A method for ultra-fast, highly reproducible signal synthesis and sampling, based on the so-called “Libove Gate architecture”, is presented in [8]. Thus bandwidth up to 20 GHz (40 GS/second) is achievable using a slightly complicated scheme.

Therefore the completely digital pulse synthesis will be widely accessible very soon, and its price will considerably go down.

VI. Results

Computations have been made showing a possible increase of UWB device performance, using the above approach. Pulses with a various number of samples N were generated, in compliance with FCC spectral masks for indoor and handheld UWB devices operating in 3.1...10.6 GHz range (Fig. 2). Fig. 3 shows PSD of the generated pulse for one of the cases ($N = 64$). A comparatively small number of samples are enough to achieve a sufficiently good adjustment of pulse PSD to the emission mask.

In the pulse generation it is admitted that $H_A(\omega)$ is the same like the one used in the generation of second derivative of the gaussian pulse following the classical approach. Sampling frequency $f_s = 25$ GHz was selected so as to make possible a good suppression of the aliases. The sam-

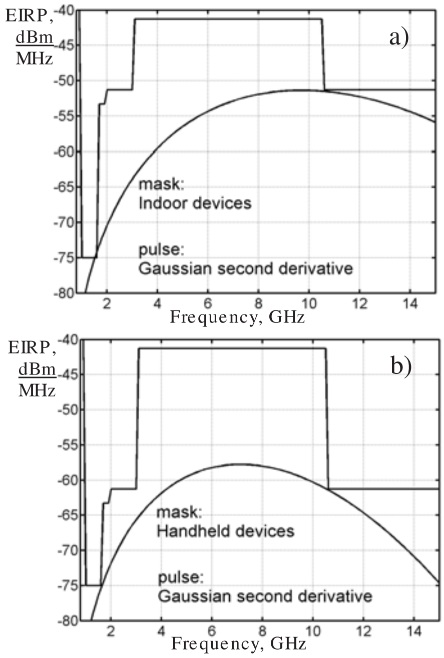

Fig. 2. UWB spectral masks

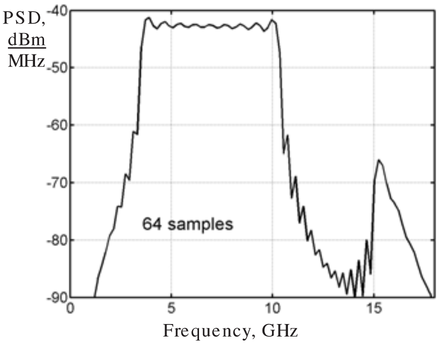

Fig. 3.

ples are presented by idealized rectangular pulses with duration $\Delta t = 1/f_s$.

Assuming that $S_M(f) = \text{const}$, the maximal possible transmitted power is calculated. The latter is compared to those, which is achievable with the use of the most frequently proposed second derivative of the gaussian pulse, suitable for generation, following the traditional approach. The results are provided in Table 1.

Table 1.

Pulse	Feasible power, dBm		Improvement, dB	
	indoor	handheld	Indoor	Hand-held
Gaussian 2-nd derivative	-14.6 (-7.5)*	-20 (-17.6)*		
Synthesized, N=32	-5.1	-5.1	9.5 (2.4)	14.9 (12.5)
Synthesized, N=48	-4.53	-4.53	10.07 (2.97)	15.47 (13.7)
Synthesized, N=64	-4.27	-4.27	10.33 (3.23)	15.73 (13.3)
Synthesized, N=128	-3.95	-3.95	10.65 (3.55)	16.05 (13.7)

Ideal case: -2.55 dBm in 3.1–10.6 GHz

* Assuming an additional rejection in the GPS band is implemented

The calculation of the power, emitted in the employed frequency range, is made through numerical integration, according to:

$$P_t = \int_{f_B}^{f_H} S_{UWB}(f)df, \qquad (5)$$

where f_H and f_B are the boundaries of the frequency range, object of our interest.

The results show that through the reviewed method there is a considerable increase of the transmitted power as compared to the case when the most frequently proposed second derivative of the gaussian pulse is used.

In order to obtain a desired bit error rate (BER), it is necessary to provide a certain value of the signal to noise ratio per bit in the receiver.

$$q_0 = E_b/N_0 = P_rT_b/N_0 = P_r/(R_bN_0) = P_t/(R_b.N_0.PL),$$

where P_r is the received power and PL is path loss. Then $R_b = P_t/(PL.q_0.N_0)$.

Consequently by obtaining an increase of the transmitted power by approximately 10 dB for indoor devices and 15 dB for handheld devices (Table 1), the increase of the achievable bit rate would be 10 and 32 times, respectively. In case of a fixed bit rate it is possible to increase the value of PL, and as a result the UWB system range in line of sight conditions will widen 3.2 and 5.6 times, respectively.

Some recent publications propose the use of higher derivatives of the Gaussian pulse. For example PSDs of the fourth and seventh derivatives fit best to the masks for indoor and handheld devices, respectively (Fig. 4). They rely on the traditional method for pulse generation.

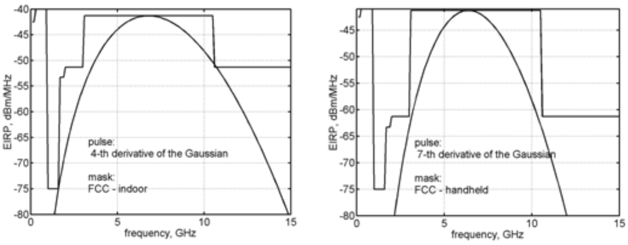

Fig. 4. PSD of the 4-th and 7-th derivative of the Gaussian pulse

The achievable transmitted power is -5.1 for indoor and -6.5 dBm for handheld devices, which is quite close to the possibility of the approach proposed in this article. The latter, however, as mentioned before, provides some additional advantages.

VII. Conclusions

An approach for UWB spectrum shaping was reviewed and some possible implementations were suggested. The performance improvement of the UWB communication systems, obtained through this approach, was assessed. The improvements are considerable, and the technical implementation is completely feasible, although at a higher price. The latter, however, will go down in near future. Further research will focus on the sensitivity of the obtained PSD to the inaccuracies of the technical implementation and on optimization of the generated pulses.

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