An Advanced Technique for Generating Pulses for Indoor UWB Systems

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***Abstract* — In this paper a mixer based method of generating Ultra Wideband (UWB) pulses is described. By mixing two sinusoidal signals which are derived from multiplying circuits connected to the same rf-generator an adequate output signal is achieved, which simply has to pass through a gating circuit in order to be used as a UWB pulse that is compliant to the demands of the Federal Communications Commission (FCC) for indoor UWB systems.**

***Index Terms* — Analog circuits, data communication, digital radio, harmonic distortion, mixers, pulse generation.**

I. INTRODUCTION

Since the FCC has regulated the emission limits of UWB-radiation in February 2002 [1], the focus on developing circuits for generating UWB-pulses is to meet that specific spectral mask, which limits the bandwidth of the frequency spectrum of UWB-radiation.

This means that for indoor UWB systems the Equivalent Isotropic Radiated Power (EIRP) is limited to – 41.3 dBm in the frequency range from 3.1 GHz up to 10.6 GHz. For higher frequencies above 10.6 GHz the EIRP is limited to – 51.3 dBm. For lower frequencies below 3.1 GHz the EIRP caused by indoor UWB systems is limited to – 51.3 dBm in the frequency range from 1.99 GHz to 3.1 GHz, to – 53.3 dBm in the frequency range from 1.61 GHz to 1.99 GHz and to – 75.3 dBm in the frequency range from 0.96 GHz to 1.61 GHz. For other UWB systems the limits are similar or even more restrictive.

Former research of UWB has been done by using Gaussian pulses. This is due to the best time-bandwidth-product provided by that signal form. The disadvantage of Gaussian pulses is the infinite time extension.

In order to reduce the technical effort to form Gaussian pulses, a number of circuits producing similar pulse shapes are investigated. Circuits using Step Recovery Diodes (SDR) in order to form adequate pulses [2], [3] consumes to much power. Therefore the efficiency of this method is quite poor.

Other pulse shapes have been published focusing on the orthogonal characteristic of the used functions [4]. But infinite time response of the modified Hermite polynomials is also the major drawback [5].

Unfortunately, a Gaussian pulse does not meet the demands of the FCC for indoor UWB systems very well, whereas the 4th derivative of such a pulse is well suited to fulfil the requirements, if the pulse duration, that is the time which encloses 95 % of the pulse energy, is about 0.5 ns.

Therefore, similar signals with band pass characteristics complying with the FCC mask seem to be more reasonable. Such a signal should be time limited and should ideally consist of sinusoidal wavelets.

In [6], a novel pulse waveform is proposed referred to as the carrier interferometry (CI) pulse waveform for use in UWB systems. The CI pulse waveform corresponds to the super positioning of N orthogonal sub carriers. Simulation results over indoor channels confirm that the novel CI-UWB system is capable of significantly exceeding current UWB systems: the proposed system can provide up to 64 times the data rate of current time domain UWB systems.

However, superposing of N independent sine waves requires N oscillator circuits. All of them have to be phase and amplitude controlled.

A significantly less complex method of generating suitable UWB pulses that meet the demands of the FCC for indoor UWB systems and can be optimised to transmit as much energy as possible within the pulse is presented in this paper.

II. MIXER BASED METHOD

A mixer based method is used to generate pulses for indoor UWB systems. In order to minimize the number of needed components, the occurring frequencies are spectrally related. Especially, only one single oscillator is needed to provide the signal with a fundamental frequency from which all other needed signals are produced by means of frequency multipliers. The block diagram of the required circuit is pictured in Fig. 1.

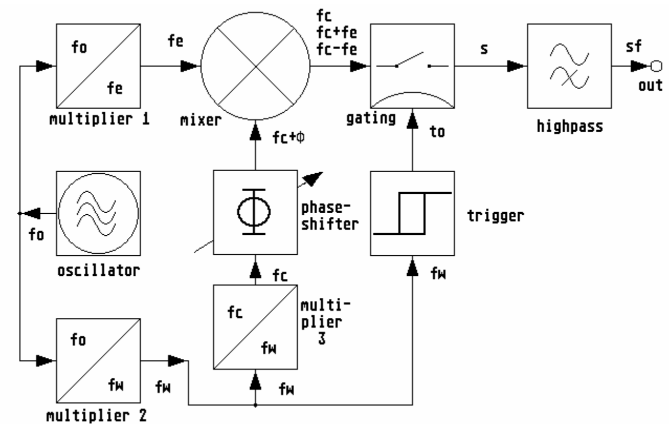

Fig. 1. Block diagram of the mixer based UWB pulse generator.

The sinusoidal signal of an rf-generator (oscillator) with the frequency (fo) is subdivided into two paths. Both paths are connected with frequency multipliers, respectively. One frequency multiplier (multiplier 1) produces a sinusoidal signal with the envelope frequency (fe). The other frequency multiplier (multiplier 2) produces a sinusoidal signal with the window frequency (fw). The sinusoidal signal with the window frequency (fw) is subdivided into two further paths. One path is connected to a third frequency multiplier (multiplier 3) producing a sinusoidal signal with the carrier frequency (fc). The other path is connected to a trigger circuit (trigger) which produces a gating time (to) which is strongly correlated to the window frequency (fw). By shifting the trigger level you can tune the phase shift of the signal to be gated. By tuning the hysteresis you can adjust the duration of the gating time (to).

The sinusoidal signal with the carrier frequency (fc) enters a variable phase-shifter (phase-shifter), so you can tune the phase shift of the signal to be mixed. Especially, it is possible to decide whether a sine ($\Phi = 0$) or a cosine ($\Phi = 90°$) signal is to be mixed.

The two sinusoidal signals with the envelope frequency (fe) and with the probably phase-shifted (+Φ) carrier frequency (fc) enter the mixer.

The mixer is of no balanced type, this means that at the output terminal of the mixer are released the lower sideband frequency signal (fg – fe), the upper sideband frequency signal (fc + fe) and the signal with the carrier frequency (fc). Approximatively, the carrier signal (fc) comprises 50 % of the total mixer output signsl energy, whereas each of the sideband signals (fc – fe and fc + fe) comprise 25 % of it, respectively.

Now, this synthesised signal is applied to a gating circuit (gating) which is controlled by the gating time (to). At the output of the gating circuit (gating) the UWB pulse (s) appears. It has to pass through a high-pass filter (high pass) for completing the forming of the shape in order to meet the demands of the FCC for indoor UWB systems. The ready for use filtered UWB pulse (sf) can be gathered from the output terminal (out) of the high-pass filter (high pass).

III. OPTIMIZED DESIGN EXAMPLE

The presented method allows a number of combinations of the used signal frequencies, phasing of the involved signals and gating time duration. Hence this method is more flexible and allows a better pulse shape optimisation than the approach without mixer reported in [7]. An design example presented here is optimised to transmit as much energy as possible within the pulse without violating the demands of the FCC for indoor UWB systems. Therefore, we aimed at a preferably flat approximation of the FCC spectral mask in order to achieve the maximum of pulse energy within the band from 3.1 GHz to 10.6 GHz.

The rf-generator (oscillator) is adjusted to the fundamental frequency (fo) = 0.48 GHz.

The frequency multiplier ratio of the first frequency multiplier (multiplier 1) is selected to be 5, this stands for the envelope frequency (fe) = 2.40 GHz.

The frequency multiplier ratio of the second frequency multiplier (multiplier 2) is selected to be 2, this stands for the window frequency (fw) = 0.96 GHz.

The frequency multiplier ratio of the third frequency multiplier (multiplier 3) is selected to be 7, this stands for the carrier frequency (fc) = 6.72 GHz.

The trigger circuit (trigger) is set to detect the zero crossings of the window frequency signal. Therefore, the gating time is (to) = 0.52 ns.

The variable phase-shifter (phase-shifter) is tuned to a phase shift of ($\Phi = 90°$). Therefore, the signal with the carrier frequency (fc) is a cosine signal when entering the mixer.

At the output port of the mixer we have a lower sideband frequency signal with (fg – fe) = 4.32 GHz, an upper sideband frequency signal with (fc + fe) = 9.12 GHz and a cosine based signal with the carrier frequency (fc) = 6.72 GHz.

The combination of these three signals are gated with the gating time (to) = 0.52 ns.

At the output of the gating circuit (gating) the UWB pulse (s) appears. Fig. 2 shows the course of the normalized amplitude of the UWB pulse over a symmetric time axis.

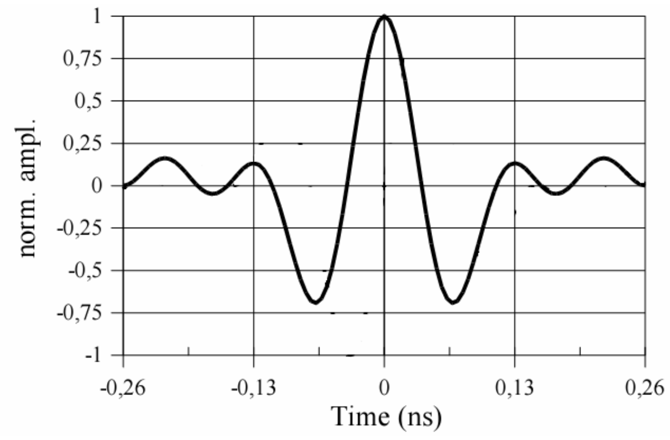

Fig. 2. The course of the normalized amplitude of the UWB pulse over a symmetric time axis.

The high-pass filter (high pass) is chosen to have a cut-off frequency of 2.0 GHz, in order to filter the lower frequency parts of the pulse spectrum.

Fig. 3 shows in a half logarithmic scale the power spectral density (PSD) of the filtered UWB pulse (sf) at the output terminal (out) of the mixer based UWB pulse generator over the maximum power spectral density (PSD0) of – 41 dBm at a frequency range from 1 GHz to 14 GHz. The FCC spectral mask for indoor UWB systems is given as a dashed curve in the same figure.

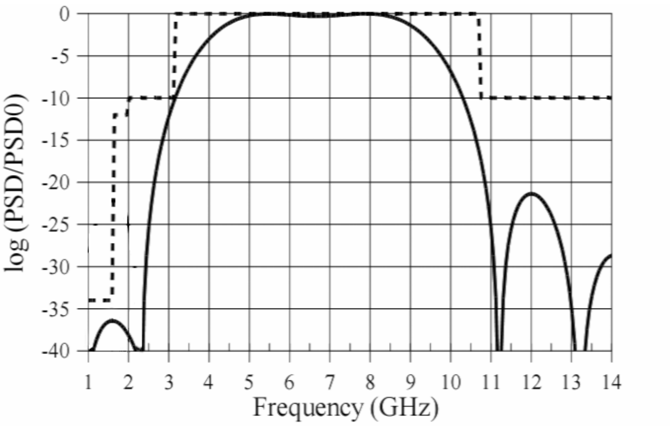

Fig. 3. Spectrum of the of the filtered UWB pulse (solid) and the FCC spectral mask for indoor UWB systems.

IV. THEORY

From signal theory we know that the time function

$$f_r(t) = \mathrm{rect}\left(\frac{t}{T}\right), \qquad (1)$$

corresponds to the spectral density

$$F_r(\omega) = T\,\mathrm{si}\left(\omega\frac{T}{2}\right), \qquad (2)$$

in which

$$\omega_0 = \frac{2\pi}{T}. \qquad (3)$$

is the first zero crossing of the spectral density. If we superpose two or more rectangular pulses, described by the rect-function, nearly any spectral density shape can be approximated.

If we consider ω_0 the bandwidth of an equivalent low-pass signal and join two frequency shifted si-functions symmetrically around a third non-shifted si-function the spectral density can be written as

$$X(\omega) = t_0\,k\,\mathrm{si}\left(\omega\frac{t_0}{2}\right) + t_0\left(\mathrm{si}\left(\omega\frac{t_0}{2} + \varphi\right) + \mathrm{si}\left(\omega\frac{t_0}{2} - \varphi\right)\right) \qquad (4)$$

The first zero crossing in the right half-plane of (4) can be derived by

$$x_0 = \omega_0\frac{t_0}{2}. \qquad (5)$$

From (5) follows directly

$$t_0 = \frac{2x_0}{\omega_0}. \qquad (6)$$

A flat approximation of the FCC spectral mask for indoor UWB systems can be found by some empirical iteration. A very good shape (Fig. 3) results for

$$k = \sqrt{2} \qquad (7)$$

and

$$\varphi = \frac{5}{4}\pi. \qquad (8)$$

The equivalent low-pass time domain signal x(t) is a gated cosine waveform with a certain offset. It modulates a carrier signal frequency (fc) to approximate the FCC spectral mask for indoor UWB systems.

The complete mathematical description of the time domain signal u(t) is

$$u(t) = \hat{u}\cos(2\pi f_c t)\,\mathrm{rect}\left(\frac{t}{t_0}\right)\left(k + 2\cos\left(\frac{2\varphi}{t_0}t\right)\right), \qquad (9)$$

We define an envelope frequency (fe) and a window frequency (fw), with a window frequency (fw) associated with the gating time (t_0), i.e. the time between the zero crossings, respectively:

$$f_w = \frac{1}{2t_0} . \tag{10}$$

In the equation for the fundamental frequency

$$f_0 = \frac{\omega_0}{2\pi} \tag{11}$$

we insert (6), which is solved for the bandwidth ω_0 and (10), which is solved for the gating time (t_0) and get the relations

$$f_0 = \frac{2 f_w x_0}{\pi} \tag{12}$$

and

$$f_0 = \frac{x_0}{\pi t_0} . \tag{13}$$

For the envelope frequency (fe) we chose

$$f_e = \frac{\varphi f_0}{x_0} \tag{14}$$

or

$$f_e = \frac{\varphi}{\pi t_0} . \tag{15}$$

Spectral relation means that there is a relatively prime fractional q:

$$q = \frac{f_c}{f_w} \tag{16}$$

in which

$$q = \frac{n}{d} , \quad \text{with} \quad d, n \in \square \tag{17}$$

From that fractional q we find a fundamental frequency (fe) whose multiple is the necessary carrier frequency (fc) to shift the signal

$$f_c = m \frac{f_e}{n} , \quad \text{with} \quad m \in \square \tag{18}$$

The multiple m calculates from

$$m = \left\lfloor n \frac{6.85\,\mathrm{GHz}}{f_e} \right\rfloor \tag{19}$$

or

$$m = \left\lfloor n \frac{6.85\,\mathrm{GHz}}{f_e} \right\rfloor + 1 \tag{20}$$

The floor brackets denote the next smaller integer of its argument. The evaluation of the spectral locus determines the value to be choosen.

VII. Conclusion

A simple mixer based method which allows a number of combinations of the used signal frequencies, phasing of the involved signals and gating time duration has been presented. This method is very flexible and allows an easy pulse shape optimisation to transmit as much energy as possible within the pulse without violating the demands of the FCC for indoor UWB systems. A flat approximation of the FCC spectral mask is attained in order to apply the maximum of pulse energy within the band from 3.1 GHz to 10.6 GHz.

REFERENCES

[1] "UWB Emission Limits", FCC 02-48, Washington, D.C., 14.02.2002

[2] T. Buchegger, G. Oßberger, C. Diskus, A. Springer, A. Stelzer, "A novel low-cost ultra wideband microstrip pulse forming network for Gaussian monocycle generation", Proceedings of the International Workshop on Ultra Wideband Systems (IWUWBS '03), June, 2003, Oulu, Finland.

[3] J. S. Lee, C. Nguyen, "Novel low-cost ultra-wideband ultra-short-pulse transmitter with MESFET impulse-shaping circuitry for reduced distortion and improved pulse repetition rate", IEEE Microwave and Wireless Components Letters, Vol. 11, No. 5, pp. 208 – 210, May, 2001.

[4] M. Ghavami, L. B. Michael, S. Haruyama, R. Kohno, "A novel UWB pulse shape modulation system", Wireless Personal Communications, Volume 23, Number 1, pp. 105 – 120, October, 2002.

[5] M. Ghavami, L. B. Michael, R. Kohno, "Hermite function based orthogonal pulses for ultra wideband communications", Wireless Personal Multimedia Communications, 2001, Denmark.

[6] Z. Wu, F. Zhu, C. R. Nassar, "High performance ultra-wide bandwidth systems via novel pulse shaping and frequency domain processing", IEEE Conference on Ultra Wideband Systems and Technologies, pp. 53 – 58, May, 2002.

[7] R. Zimmer, P. Waldow, A.Beyer, "An improved method of generating UWB pulses for high datarate communication", IEEE Radio and Wireless Symposium, pp. 143 – 145, January, 2006.