A Mixer Based Method of Generating Pulses for Indoor UWB Systems

by

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Overview

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- **The Mixer Based Method**
- **Theoretical Background**
- **An Optimized Design Example**
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Introduction

Since the Federal Communication Commission (FCC) regulated the emission limits of UWB-radiation in February 2002 in his document entitled:

“UWB Emission Limits”, FCC 02-48, Washington, D.C., 14.02.2002,

the focus on developing circuits for generating UWB-pulses has to meet that specific spectral mask, which limits the bandwidth of the frequency spectrum of UWB-radiation.

Introduction

Hence, it follows that for indoor UWB systems the Equivalent Isotropic Radiated Power (EIRP) is limited. The appropriate values are given by the table shown below:

Frequency Range in GHz	EIRP / dBm
0.96 – 1.61	- 75.3
1.61 – 1.99	- 53.3
1.99 -3.1	- 51.3
3.1 – 10.6	- 41.3
Above 10.6	- 51.3

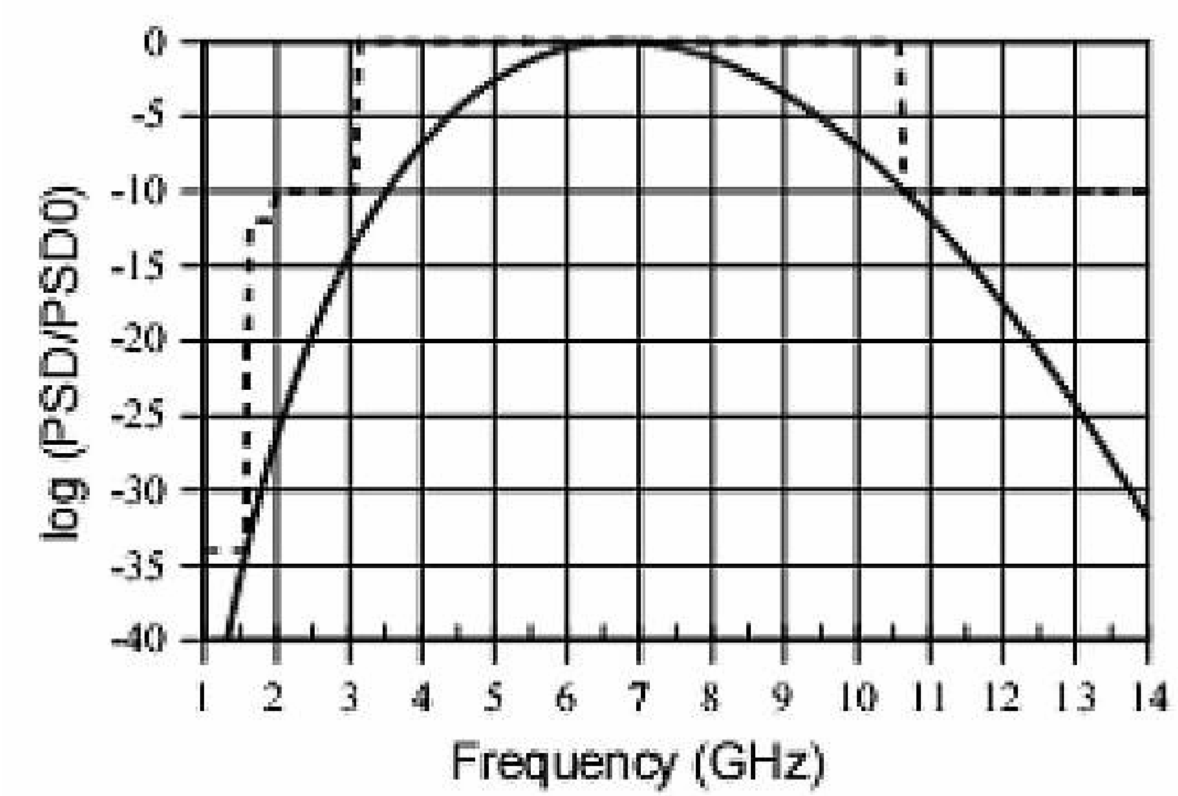
Introduction

Most research on UWB is done by using Gaussian pulses. This is due to the best time-bandwidth-product provided by that signal form. The mathematical description of the signal in time-domain and in frequency-domain is similar:

$$\boxed{In\ time\ domain: e^{-at^2},\ In\ \ frequency\ domain: \sqrt{\frac{\pi}{a}}e^{-\frac{\omega^2}{4a}}}$$

The simulation of UWB circuitry can be done in time domain as well as in frequency domain without great expense. The disadvantage of Gaussian pulses is the infinite time extension.

Introduction



Spectrum of the 4th derivative of a Gaussian pulse (solid) and the FCC (Federal Communication Commission) indoor mask (dashed).

- PSD power spectral density of the spectral component
- PSD0 maximum power spectral density of -41dBm/MHz

Introduction

In a paper entitled

"High performance ultra-wide bandwidth systems via novel pulse shaping and frequency domain processing",

presented by Z. Wu, F. Zhu and C. R. Nassar, a novel pulse waveform is proposed referred to as the carrier interferometry (CI) pulse waveform for use in UWB systems.

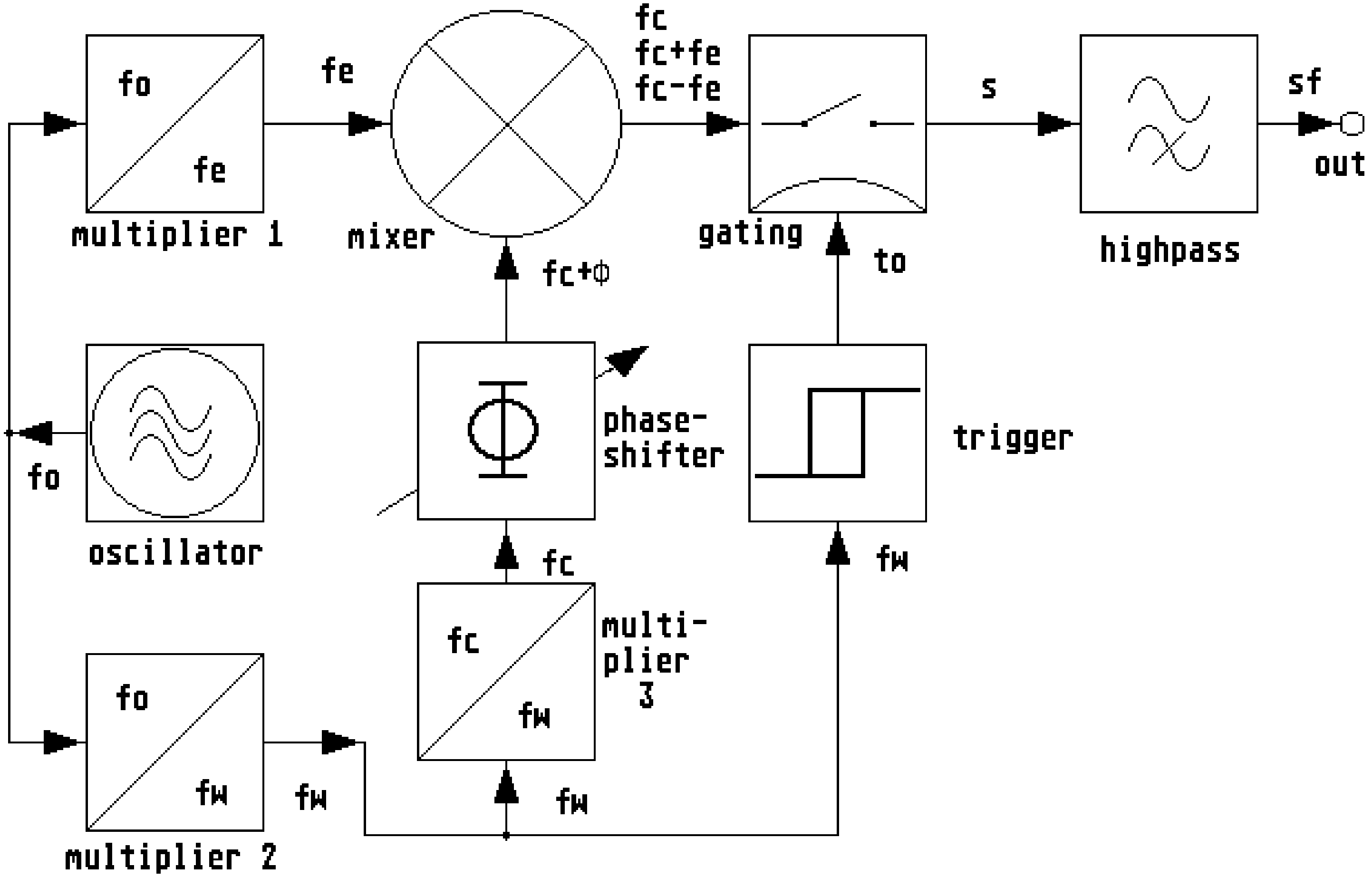
The CI pulse waveform corresponds to the superimposing of N orthogonal sub carriers. Simulation results over indoor channels confirm that the novel CI-UWB system is capable of significantly exceeding current UWB systems: the proposed system can provide up to 64 times the data rate of current time domain UWB systems.

Introduction

However, superimposing 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 Federal Communication Commission (FCC) for indoor UWB systems and can be optimized to transmit as much energy as possible within the pulse is introduced in this presentation.

The Mixer Based Method



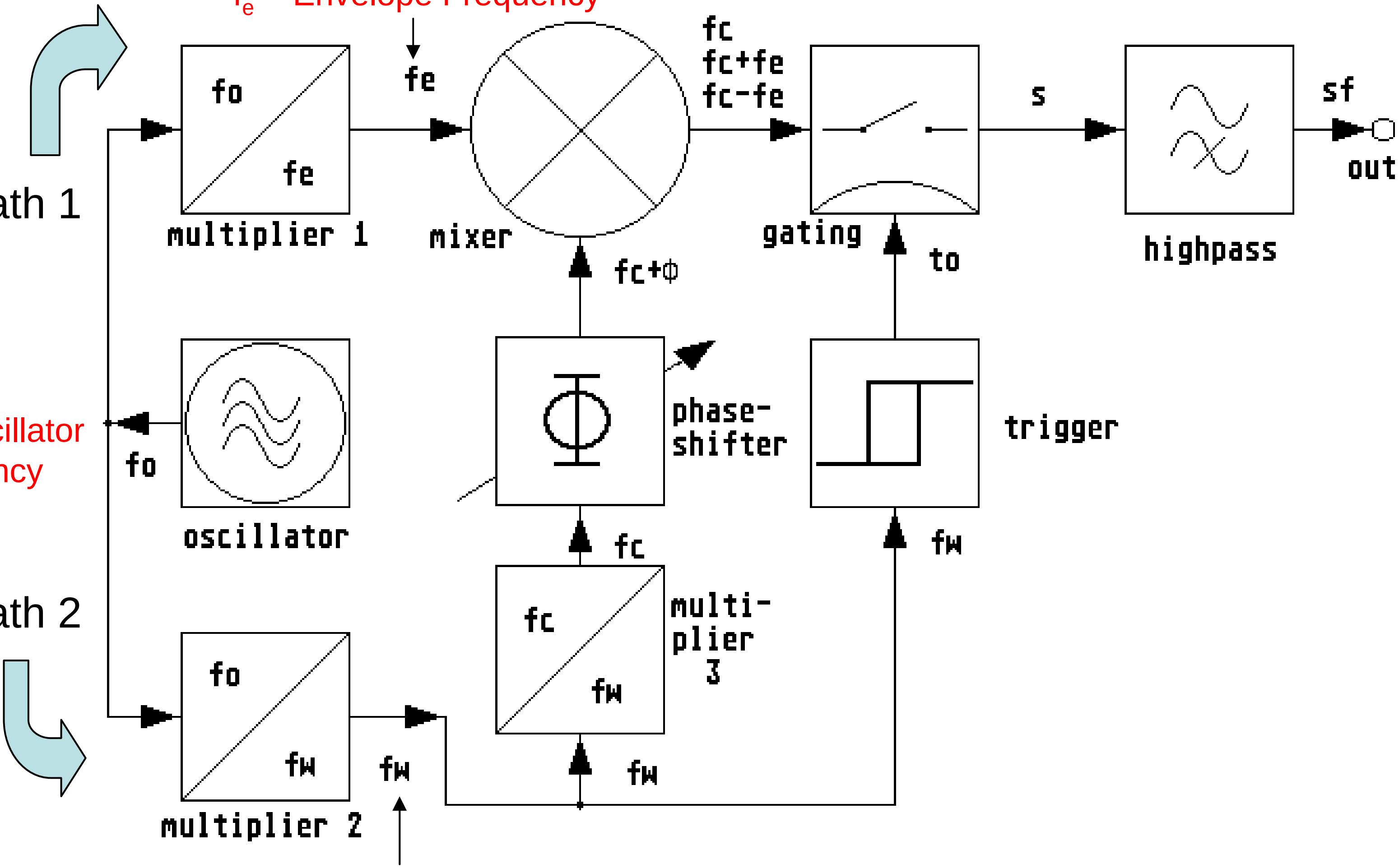
The Mixer Based Method

f_e = Envelope Frequency

Path 1

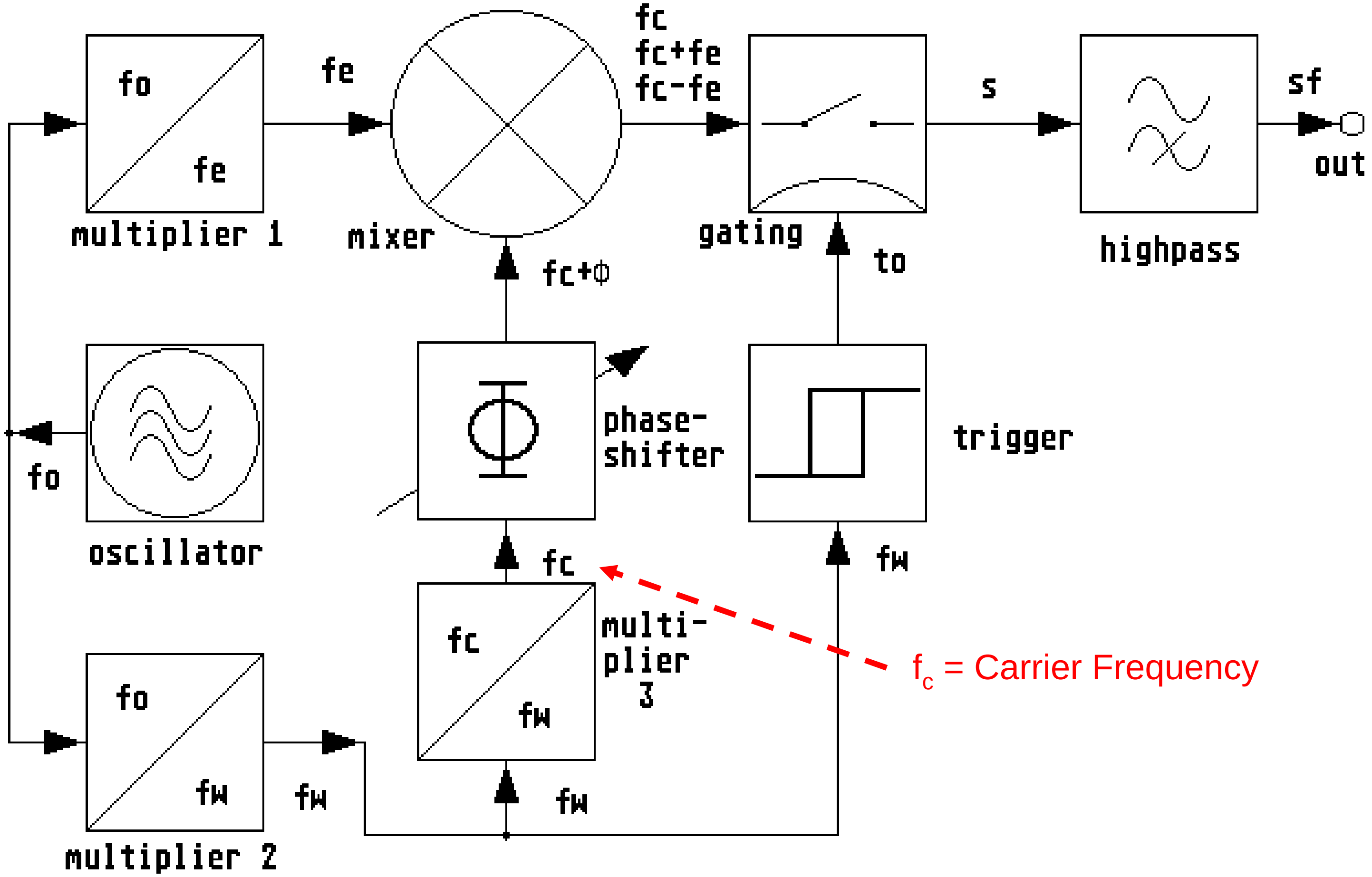
f_o = Oscillator Frequency

Path 2



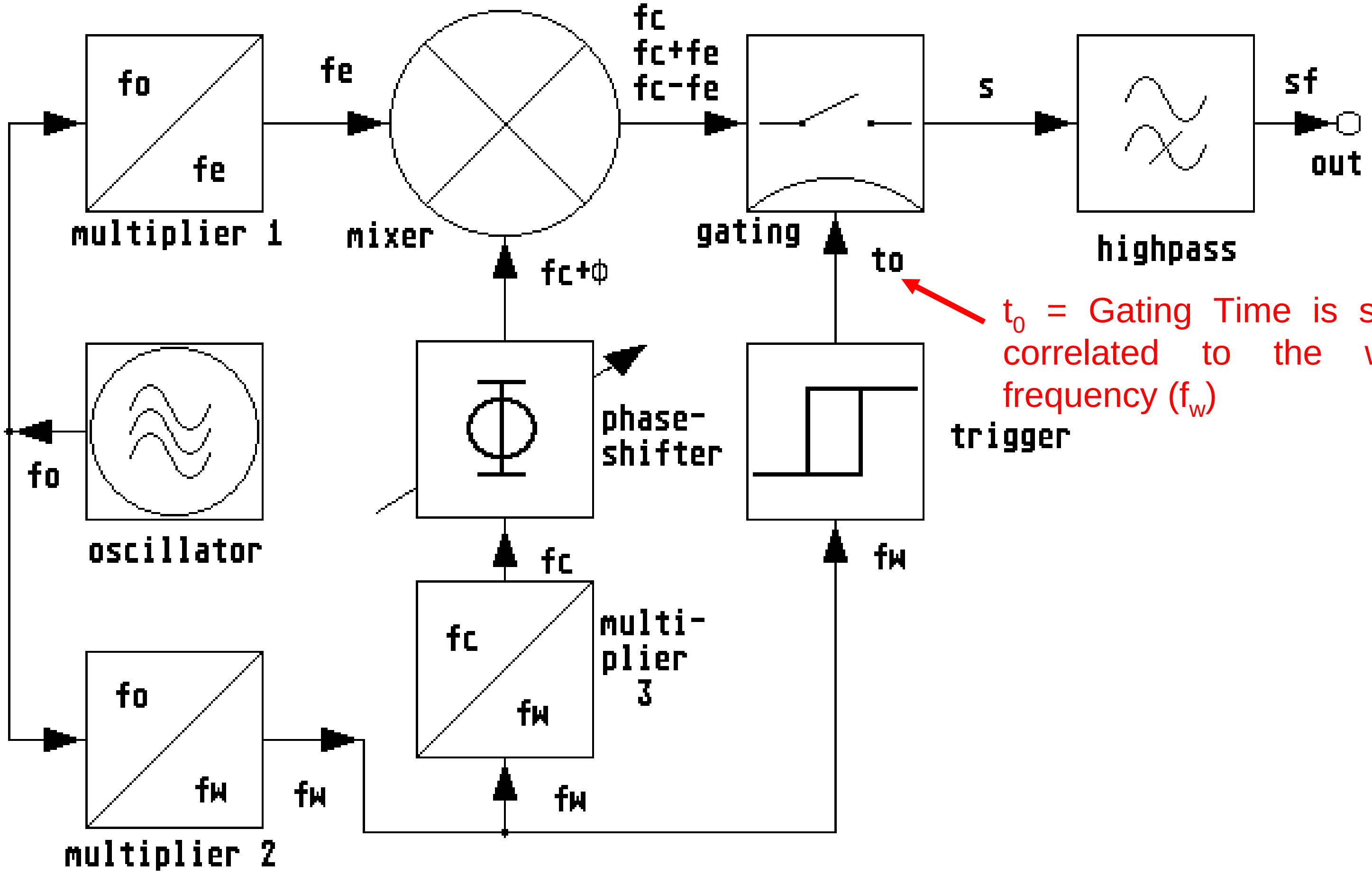
f_w = Window Frequency

The Mixer Based Method



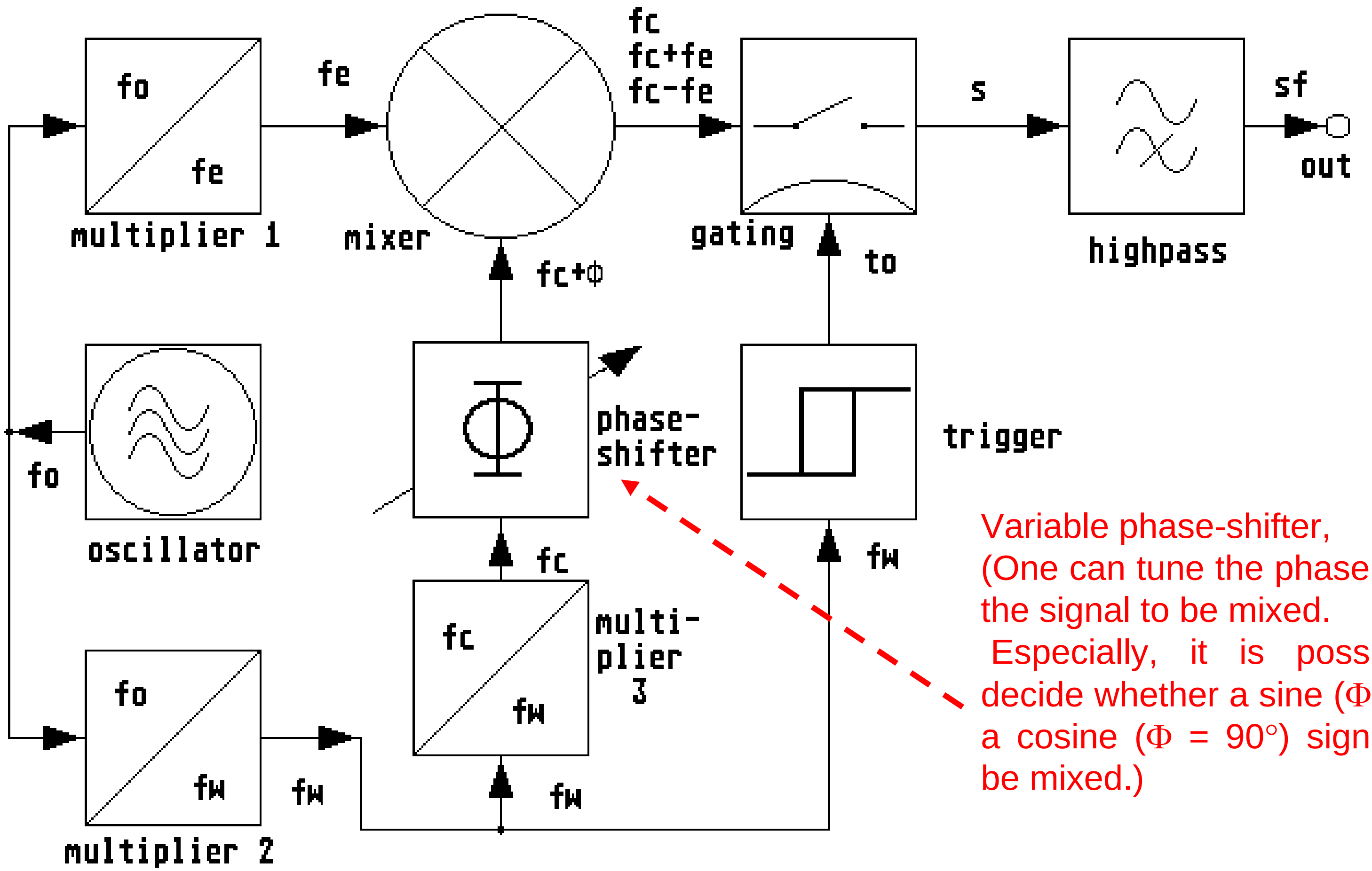
f_c = Carrier Frequency

The Mixer Based Method



t_0 = Gating Time is strongly correlated to the window frequency (f_w)

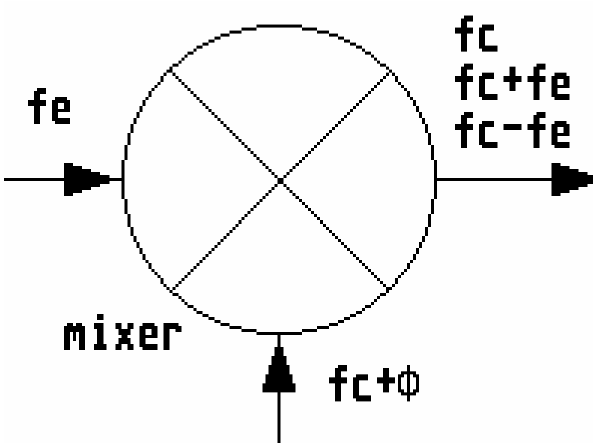
The Mixer Based Method



Variable phase-shifter,
(One can tune the phase shift of the signal to be mixed.
Especially, it is possible to decide whether a sine (Φ = 0) or a cosine (Φ = 90°) signal is to be mixed.)

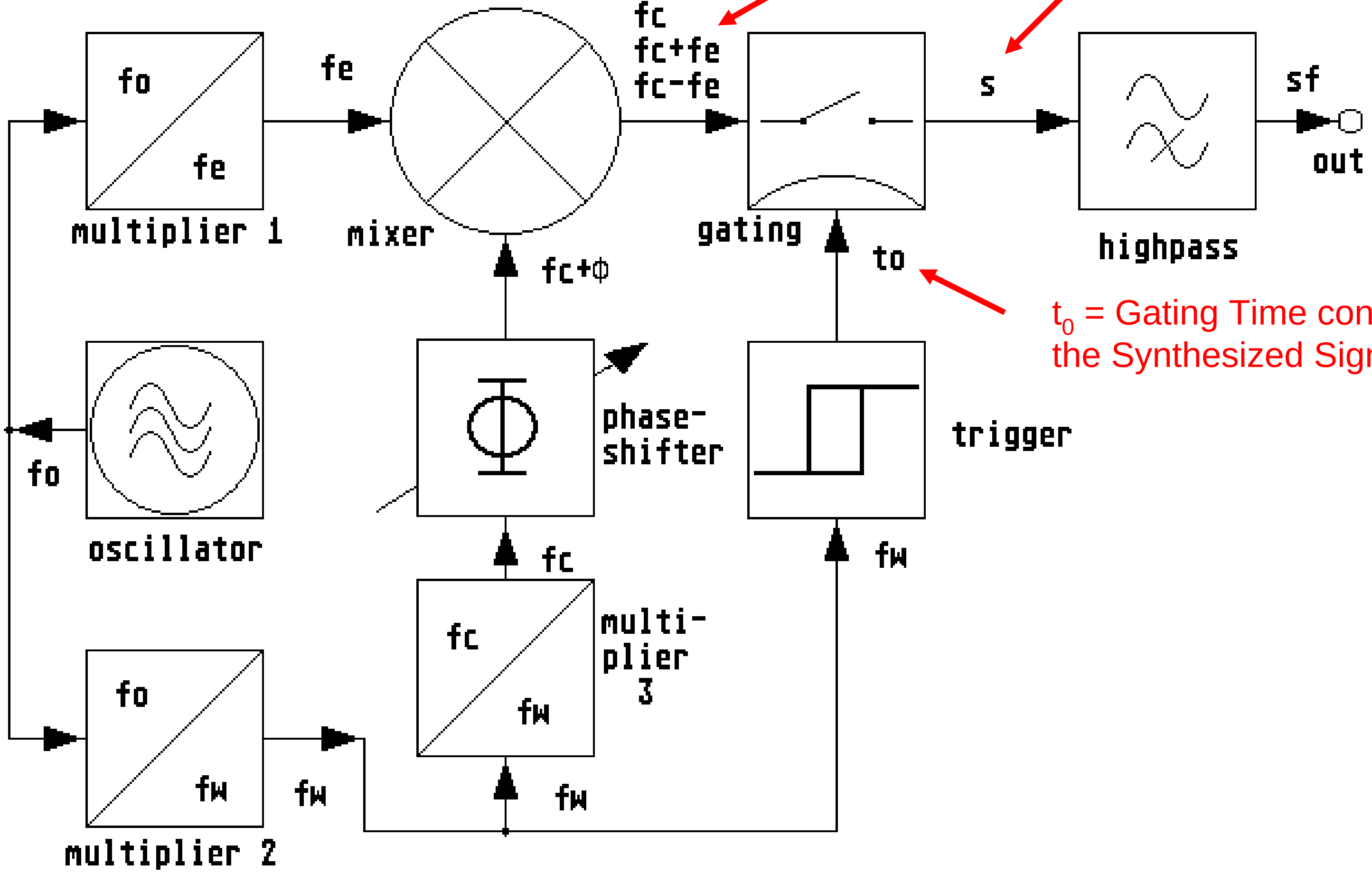
The Mixer Based Method

The mixer is of no balanced type:
the output terminal of the mixer are released the lower sideband frequency signal ($f_g – f_e$), the upper sideband frequency signal ($f_c + f_e$) and the signal with the carrier frequency (f_c).



The carrier signal (f_c) comprises 50 % of the total mixer output signal energy, whereas each of the sideband signals ($f_c – f_e$) and ($f_c + f_e$) comprise 25 % of it, respectively.

The Mixer Based Method



Synthesized Signal

s = UWB pulse

sf = filtered UWB pulse

t_0 = Gating Time controls the Synthesized Signal

Theoretical Background

It is well known that the time function

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

corresponds to the spectral density

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

with

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

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

Theoretical Background

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, thus the spectral density can be written as

$$X(\omega) = t_0 k \operatorname{si}(\omega \frac{t_0}{2}) + t_0 (\operatorname{si}(\omega \frac{t_0}{2} + \varphi) + \operatorname{si}(\omega \frac{t_0}{2} - \varphi)) \tag{4}$$

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

$$x_0 = \omega_0 \frac{t_0}{2} \tag{5}$$

and from here, it yields

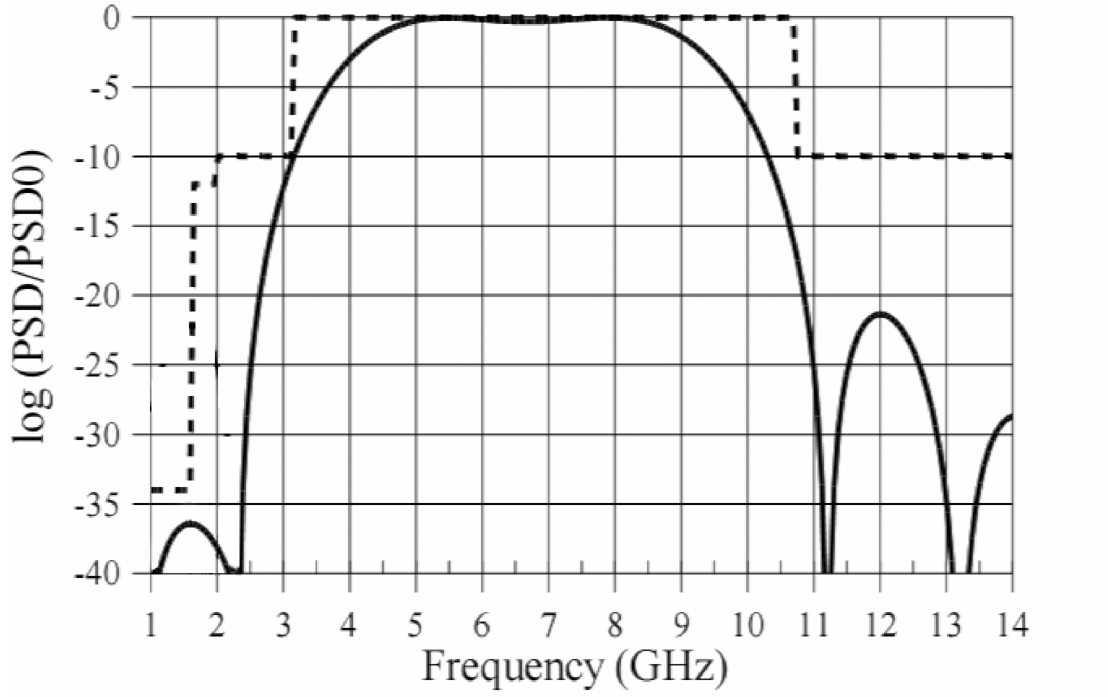
$$t_0 = \frac{2 x_0}{\omega_0} \tag{6}$$

Theoretical Background

A flat approximation of the FCC spectral mask for indoor UWB systems can be found by some empirical iteration.

$$k = \sqrt{2} \qquad (7) \qquad\qquad \varphi = \frac{5}{4}\pi \qquad (8)$$

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



Theoretical Background

The complete 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 (f_e) and a window frequency (f_w), with a window frequency (f_w) associated with the gating time (t_0), i.e. the time between the zero crossings, respectively:

$$f_w = \frac{1}{2t_0} \qquad (10)$$

For the fundamental frequency is valid

$$f_0 = \frac{\omega_0}{2\pi} \qquad (11)$$

Theoretical Background

Using Eqs. (6) and (10), we get the relations

$$f_0 = \frac{2 f_w x_0}{\pi} \qquad (12) \qquad \text{and} \qquad f_0 = \frac{x_0}{\pi t_0} \qquad (13)$$

For the envelope frequency (f_e) we chose

$$f_e = \frac{\varphi f_0}{x_0} \qquad (14) \qquad \text{or} \qquad f_e = \frac{\varphi}{\pi t_0} \qquad (15)$$

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

$$q = \frac{f_c}{f_w} \qquad (16) \quad \text{in which} \quad q = \frac{n}{d}, \ \text{with } d, n \in N \qquad (17)$$

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

Theoretical Background

$$f_c = m \frac{f_e}{n}, \text{ with } m \in \mathbb{N} \qquad (18)$$

The multiple m calculates from

$$m = \left\lfloor n \frac{6.85\text{GHz}}{f_e} \right\rfloor \qquad (19)$$

or

$$m = \left\lfloor n \frac{6.85\text{GHz}}{f_e} \right\rfloor + 1 \qquad (20)$$

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

An Optimized Design Example

The method presented here is more flexible and renders possible a better pulse shape optimisation than the approach without mixer reported in earlier paper. The method allows a number of combinations

- of the used signal frequencies,
- phasing of the involved signals and
- gating time duration.

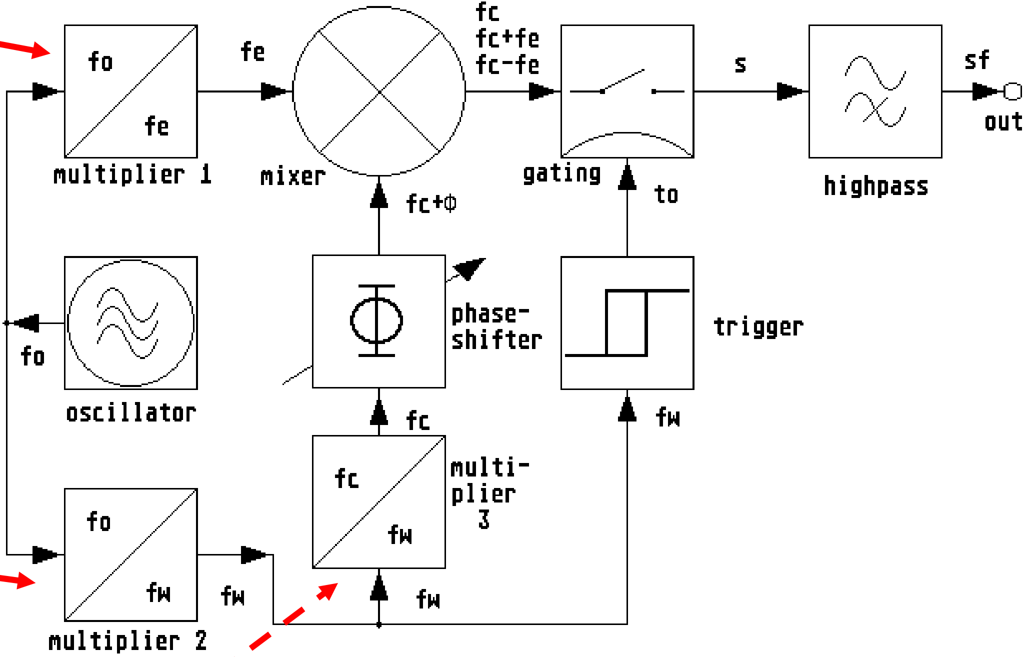
In the following design example a system is optimised to transmit as much energy as possible within the pulse without violating the demands of the Federal Communication Commission (FCC) for indoor UWB systems. Therefore, in order to achieve the maximum of pulse energy within the band from 3.1 GHz to 10.6 GHz, a preferably flat approximation of the FCC spectral mask is applied.

An Optimized Design Example

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

The frequency multiplier ratio of the first frequency multiplier (multiplier No. 1) is selected to be 5, this stands for the envelope frequency (f_e) = 2.40 GHz.

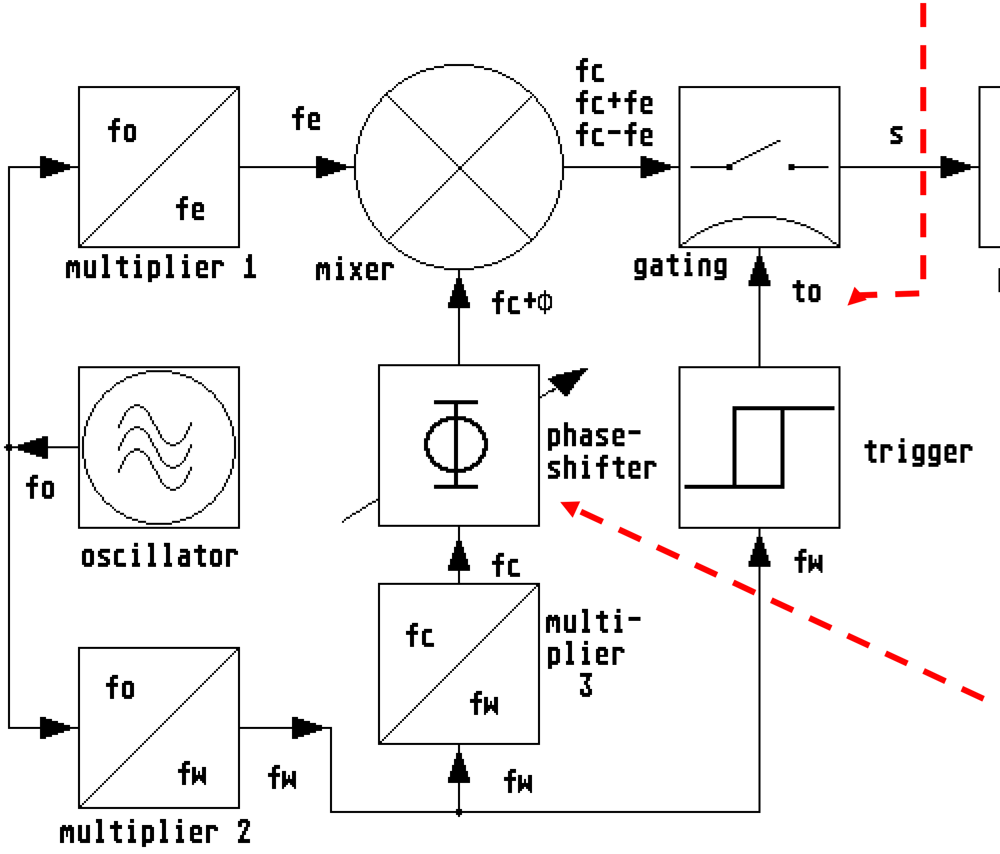
The frequency multiplier ratio of the second frequency multiplier (multiplier No. 22) is selected to be 2, this stands for the window frequency (f_w) = 0.96 GHz.



The frequency multiplier ratio of the third frequency multiplier (multiplier No. 3) is selected to be 7, this stands for the carrier frequency (f_c) = 6.72 GHz.

An Optimized Design Example

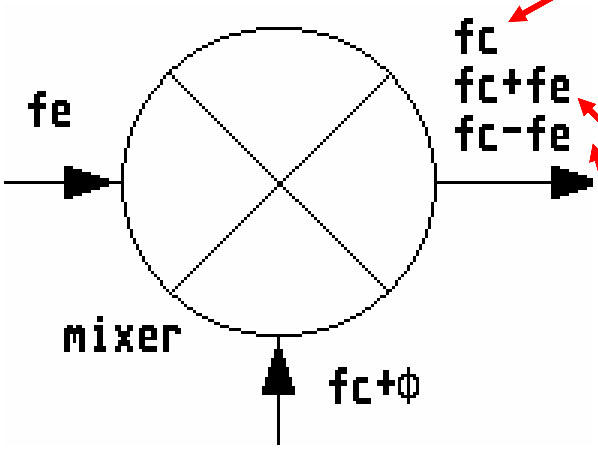
The trigger circuit (trigger) is set to detect the zero crossings of the window frequency signal f_w. Therefore, the gating time is t_o = 0.52 ns.



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

An Optimized Design Example

At the output port of the mixer the following signals will appear:



a cosine based signal with the carrier frequency $(f_c) = 6.72$ GHz.

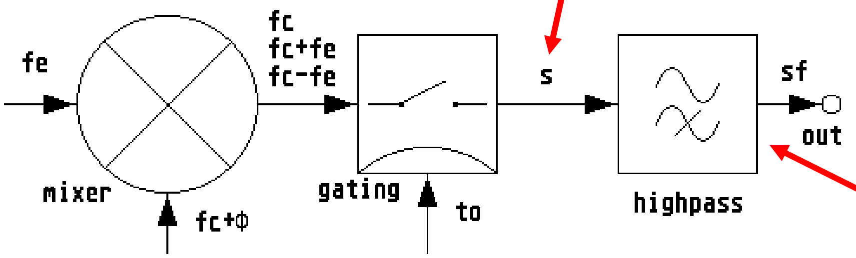
an upper sideband frequency signal with $(f_c + f_e) = 9.12$ GHz and

a lower sideband frequency signal with $(f_g – f_e) = 4.32$ GHz,

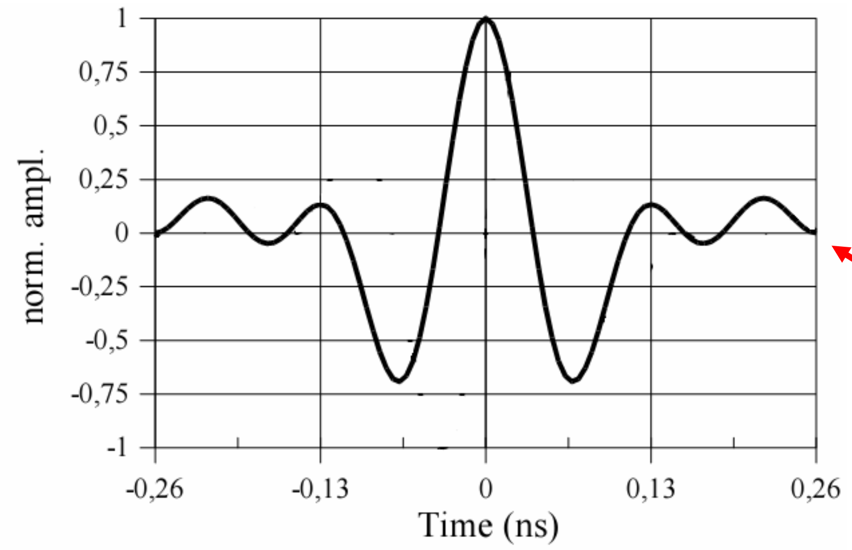
The combination of these three signals are gated with the gating time $(t_o) = 0.52$ ns.

An Optimized Design Example

At the output of the gating circuit (gating) the UWB pulse (s) appears.



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.

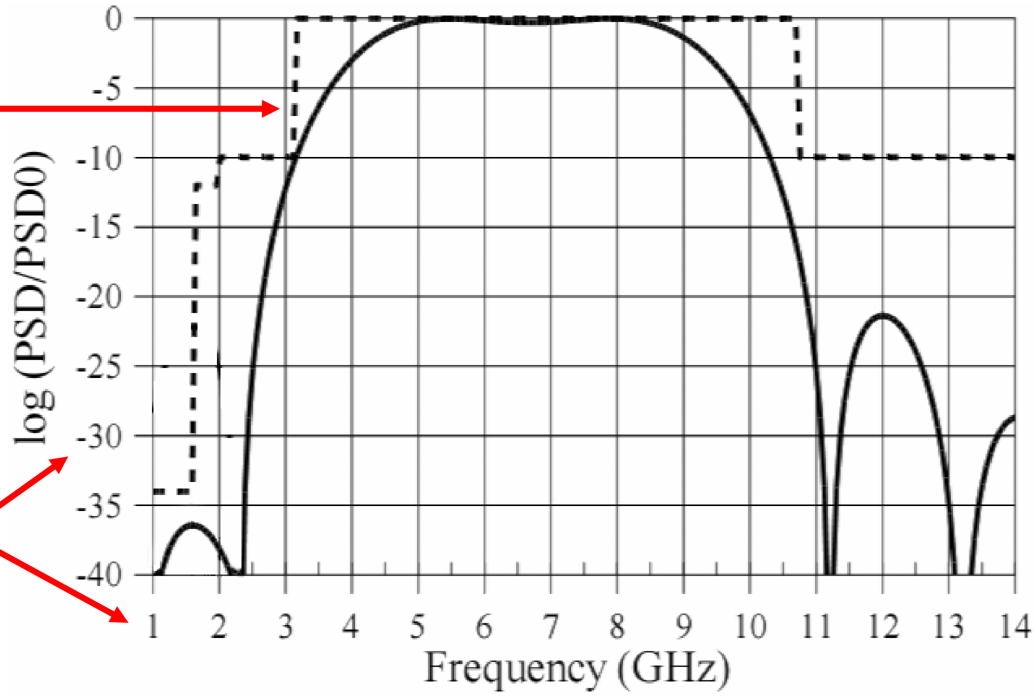


This Figure shows the course of the normalized amplitude of the UWB pulse (s) over a symmetric time axis.

An Optimized Design Example

FCC spectral mask for indoor UWB

a half logarithmic scale



This Figure shows the power spectral density (PSD) of the filtered UWB pulse (s_f) 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.

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 Federal Communication Commission (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.