Design of Narrow Pulse Generator for UWB Short Range Time Domain Radars

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***Abstract*—Short range ultra-wideband (UWB) radars like through wall Imaging radars (TWIR) and Ground penetrating radars (GPR) needs to have good range resolution and better barrier penetration capabilities. This requirement calls for large instantaneous bandwidth towards low center frequency. These radar systems conveniently achieve the bandwidth requirement using time domain technique with a narrow pulse generator. The key subsystem for these radars is design of the UWB pulse sources with sub nanosecond pulse width and very low ringing. Various ultra-wideband waveform shapes have been analyzed and a SRD based low ringing Gaussian UWB pulse generator circuit is designed and developed for stated applications.**

***Index Terms*—SRD, Gaussian, monocycle, ringing, ultra-wideband,**

I. INTRODUCTION

Federal Communications Commission's (FCC's) reform [1] on ultra-wideband (UWB) regulation in 2002 made the use of UWB license-free. It enticed researchers and concerned industries across the globe to use it in any and every way for academic, business and research purpose. Hard limits were imposed on power-spectrum of UWB pulse shapes as a measure to avoid any disturbance to the licensed-spectrum users. These limits and the choice of signal shapes are analyzed in Section II which is undoubtedly important for efficient use of resources towards a UWB application.

The signals falling under the UWB classification are of very short duration and can be termed as Impulses. Many impulse radars have been designed to detect, identify and characterize hidden objects and also the ones beneath the ground by transmitting and analyzing the received signal. These radars have also been used for buried mine detection [2], pavement damage detection [3], asset geo-location [4], rescue operations [5], breast cancer detection [6] and see-through-wall (STW) imaging [7, 8]. The typical block diagram of the time domain radar is shown in Figure1.

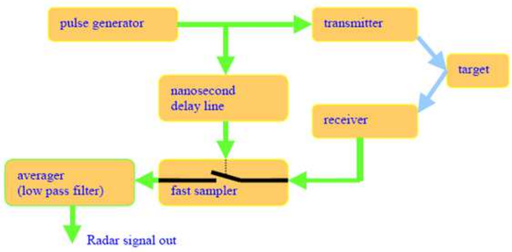

Figure 1 Simplified Block diagram of UWB Radar

The key subsystem of these systems is the pulse generator and the most common method for pulse generation has been by using step recovery diodes (SRD) [8-10]. Section II of the paper presents various possible UWB waveforms. The design, analysis and measurement of SRD based Gaussian pulse generator is discussed in Section III. Conclusion is presented in Section IV.

II. DIFFERENT UWB WAVEFORMS

The FCC adopted changes in UWB regulation on February 14, 2002 as First Report and Order; ET Docket 98-153 and released it on April 22, 2002. It made the use of UWB license-free which enticed researchers and concerned industries across the globe to use it in any and every way for academic, business and research purpose.

The FCC also imposed a set of rules on spectral masks for maximum allowable transmission power for UWB applications. These spectral limitations (in order to avoid its potential interferences with existing communication systems) created challenges in signal generation and transmission of UWB system.

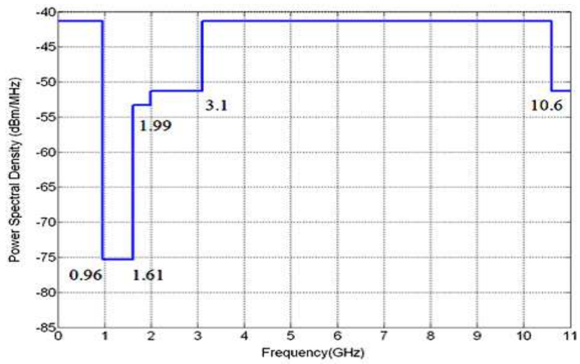

Figure 2 FCC's UWB mask for permissible signal characteristics

The power spectral density of the signal had to be less than -41.3 dBm/MHz. Global positioning system(GPS) band being used for many critical operations for public safety, navigational purposes and spotting emergency locations had to be free of any interference. GPR devices were allowed to operate in any part of the spectrum, provided the signal was shot vertically to the ground and the device had a turn-off switch with an operator. The UWB spectrum usage limits are shown in Figure 1. It gives an idea about the shape of spectrum which the signals should be having for being used in the license free UWB band.

A. Classification of UWB Pulses and their properties

The term pulse has been rigorously used to emphasize the time-limitedness of the signal. The existing UWB pulses have been categorized as Orthogonal Gaussian Pulse (OGP), Orthogonal Modified Hermite Pulse (OMHP) and Prolate Spheroidal Pulse (PSP). An introduction to the families of UWB pulses has been given with special emphasis on Gaussian pulse's family.

It represents a class of pulses that resemble the famous Gaussian function with σ and μ as parameters and is mathematically represented as

$$g(t) = \frac{1}{\sigma\sqrt{2\pi}} e^{\{ -\frac{1}{2}(\frac{t-\mu}{\sigma})^2 \}} \quad (1)$$

This family of pulses comprises of the basic Gaussian pulse and its derivatives. The basic Gaussian pulse is defined for a pulse-duration τ and normalized amplitude. Assuming,

$$\mu = \frac{\tau}{2} \; ; \; \sigma = \frac{\tau}{7} \quad (2)$$

The basic Gaussian pulse can be represented as

$$g(t) = e^{\{ -\frac{1}{2}(\frac{t-\frac{\tau}{2}}{\frac{\tau}{7}})^2 \}} \quad (3)$$

The factor is as a result of orthogonalization [13] of the Gaussian pulse. Derivatives of g(t) or the filtered forms of g(t) have higher center frequency and lower bandwidth. The first derivative is a monocycle (m(t)) and is represented by

$$m(t) = -\frac{49}{\tau^2} \cdot \left(t - \frac{\tau}{2}\right) \cdot e^{\{ -\frac{1}{2}(\frac{t-\frac{\tau}{2}}{\frac{\tau}{7}})^2 \}} \quad (4)$$

The second derivative of g(t) is a Mexican Hat pulse ($m_h(t)$) and is represented by

$$m_h(t) = \left[\left(\frac{49}{\tau^2}\right).\left\{-1 + \left(\frac{49}{\tau^2}\right) \cdot \left(t - \frac{\tau}{2}\right)^2\right\}\right] \cdot e^{\{ -\frac{1}{2}(\frac{t-\frac{\tau}{2}}{\frac{\tau}{7}})^2 \}} \quad (5)$$

B. Orthogonal Modified Hermite pulses (OMHP)

The class of polynomials represented by (6) is called Hermite polynomials ($h_p(t)$) [14].

$$\mathrm{h_p}(t) = (-\tau)^n . e^{t^2/2\tau^2} \frac{d^n}{dt^n}\left(e^{-t^2/2\tau^2}\right) \quad (6)$$

These polynomials are orthogonalized and are represented as Orthogonal Modified Hermite polynomials ($h_n(t)$)

$$h_n(t) = (-\tau)^n . e^{t^2/4\tau^2} \frac{d^n}{dt^n}\left(e^{-t^2/2\tau^2}\right) \quad (7)$$

The mathematical representation of UWB pulses belonging to this family can be obtained for different values of n.

C. Prolate Spheroidal pulses (PSP)

The mathematical representation of pulses in this family is obtained as solutions of a second order differential equation

$$\frac{d}{dt}\left\{(1 - t^2)\frac{d\psi(t)}{dt}\right\} + (\lambda - c^2t^2)\psi(t) = 0 \quad (8)$$

For different values of λ which represents the energy concentration of the pulse, different expressions for ψ(t) are obtained.

$$\lambda = \frac{\int_{-T/2}^{T/2} |\psi(t)|^2 dt}{\int_{-\infty}^{\infty} |\psi(t)|^2 dt} \quad (9)$$

In [13] an approximate solution was found and was represented as in (9) with T as its duration and c as the speed of an electromagnetic wave in vacuum.

D. ORTHOGONALITY OF UWB PULSES

The UWB pulses are bound to have a wide bandwidth and as a result they will interfere with signals in other licensed communication channels like GPS. To prevent interference of UWB signal with those in licensed bands, the condition of Orthogonality of functions expressed in (10) is imposed on pulse shapes.

$$\int_{-\infty}^{\infty} f_n(t) f_m(t) dt = 0 \; ; \qquad for\; n \neq m \quad (10)$$

The condition above is satisfied only by orthogonal functions. For non-orthogonal functions, a weight function $w(t)$ is used to make it orthogonal.

$$\int_{-\infty}^{\infty} f_n(t) f_m(t) w(t) dt = 0 \; ; \qquad for\; n \neq m \quad (11)$$

E. INTER-CLASS CORRELATION

The pulses belonging to the class of OGP are same as the OMHP except for an amplitude-scaling factor and a time-scaling factor. The PSPs are orthogonal in nature and hence their weight function is 1.

All these classes belong to solutions of the famous second-order differential equations representing different Sturm-Liouville boundary value problems. So, they cannot be time-limited theoretically, but the PSPs are considered within the time limit and due to this time-limitedness the pulses belonging to PSP class are relatively more immune to jitter.

The other way of enforcing time-limitedness is to use fast decaying pulses. This can be achieved by differentiating the basic pulse and using the higher order derivatives. Both the OGP and OMHP class use derivatives to change the shape and increase spectral efficiency whereas the PSP uses variation of energy concentration in the pulses.

It has been shown [15] in literature that the odd-order derivatives of the basic Gaussian pulse are having a better spectral efficiency compared to the even-order derivatives.

A comparison [16] based on auto-correlation function of UWB pulses was reported which stated that monocycle pulse is best among the possible pulses with respect to spectrum shape, precision for radar applications and realization complexity.

III. DESIGN OF GAUSSIAN PULSE GENERATOR

As per the discussion in the previous section, the most efficient shape of a UWB waveform belongs to the Gaussian pulse family. Now, a good Gaussian pulse shape is one with good symmetry and this property should be retained as the derivatives are being shaped up. There are a number of parameters that govern the shape of a waveform, hence it can be conceptualized as a problem of multivariate multi-objective optimization. An optimal waveform shape has not been established yet for applications like STW imaging and it is still a subject of further studies. The most commonly used waveforms are Gaussian pulse, monocycle and other odd derivatives.

The designed Gaussian pulse generator circuit has been explained here by parting it into three sections viz. step generator, 3dB attenuator and pulse shaper. A schematic representation of the Gaussian pulse generator circuit is shown in Figure 3.

The Step-generator section consists of an input-matching network to reduce distortions and an SRD in series mode to produce step signals with low rise time. The input matching network employed is an RC low-pass filter to allow only the trigger signal pass through to SRD. The 3dB balanced resistive attenuator is a symmetrical π-network with resistive lumped elements for UWB performance. It is employed to reduce the impedance mismatch and reduce the distortions by attenuating the fast leakage step while returning from stub and again when it is reflected from the source. So, the step generated by SRD (the wanted one) is attenuated once but the unwanted fast leakage step is attenuated twice. The pulse shaper section consists of a shorted stub in shunt configuration and a Schottky diode (SD) in series.

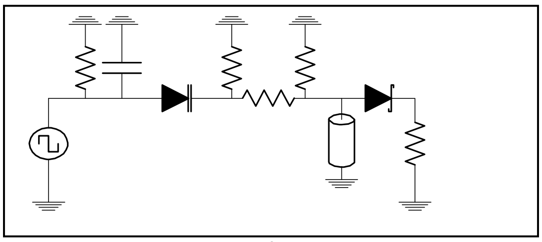

Figure 3 Schematic of Gaussian Pulse generator

The design optimization and simulation was done using ADS2009 software. The Gaussian waveform obtained using simulation is shown in Figure 4.The salient attributes of the waveform is given in table 1.1.

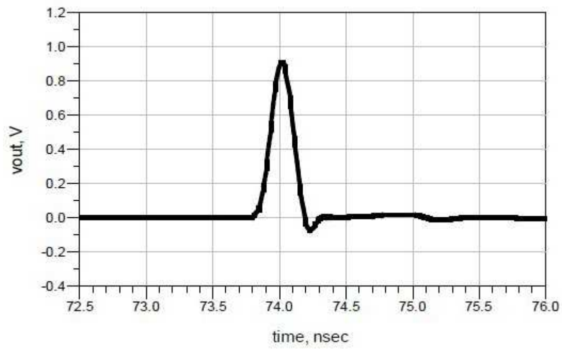

Figure 4 Simulation Result of Gaussian Pulse generator

Table 1.1

Characteristic Property	Value
Peak Value	0.91V
Rise-time (10% − 90%)	119ps
Fall-time (90% − 10%)	116ps
FWHM (50% − 50%)	190ps
Ringing	-22dB

The microstrip layout of the designed pulse generator was drawn in the same platform (ADS2009). The layout for the same is shown in Figure 5.

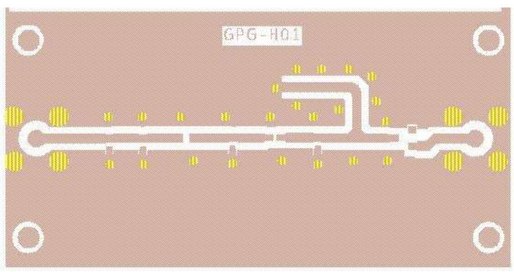

Figure 5 Layout of the circuit

The photograph of the fabricated Gaussian pulse generator is shown in Figure.6.

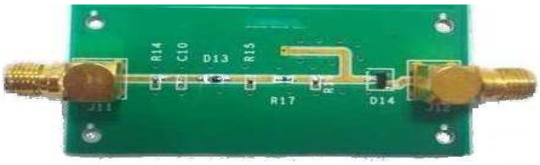

Figure 6 Photograph of Gaussian Pulse Generator Board

The generator circuits were tested using Agilent's 33220A waveform generator as a seed source. The source signal is shown in Figure 7. The signal is a bipolar square wave of 10MHz and with voltage levels at 2V and -2V. The rise time and fall time were set to 3ns but the observed risetime of the input was found to be 3.44ns and the falltime was 3.3ns.

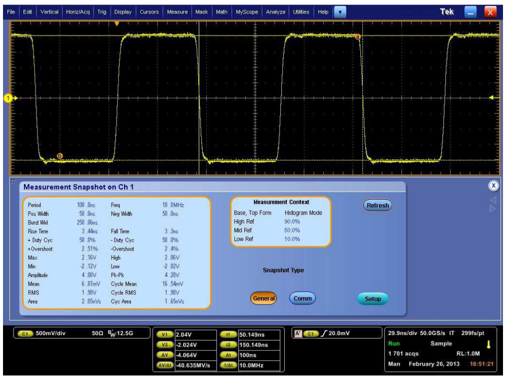

Figure 7 The 10MHz source signal

The waveform parameters were measured using Tektronix TDS6124C Oscilloscope. The snapshoot of the output waveform is shown in Figure 8.The important parameters of the waveform obtained from simulation and measurement is compared in Table 1.2.

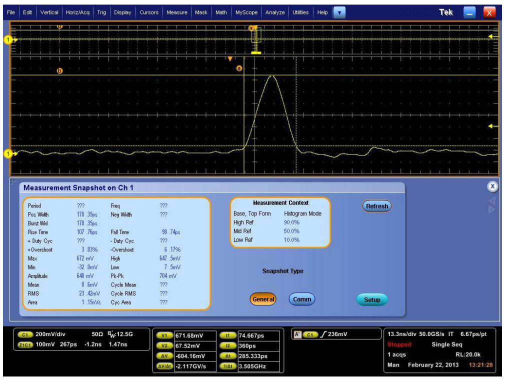

Figure 8 Measured Output Waveform

Table 1.2

Parameters	Simulation	Measurement
Voltage (V)	0.91	0.87
Risetime (ps)	119	119
Falltime (ps)	116	109
FWHM (ps)	190	170
Ringing in dB	-22	-22

IV. CONCLUSION

The SRD based Gaussian pulse generator designed and developed shows sharp rise and fall time, narrow pulse width and low ringing. These features makes it promising source for baseband time domain short range radar applications.

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