TUNABLE SUB-NANOSECOND ULTRA WIDEBAND NARROW PULSE GENERATOR FOR MICROWAVE IMAGING

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TUNABLE SUB-NANOSECOND ULTRA WIDEBAND NARROW PULSE GENERATOR FOR MICROWAVE IMAGING

by

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LIST OF ABBREVIATIONS

AC	Alternating Current
ADC	Analog-to-Digital Converter
AGC	Automatic Gain Control
AHC	Advanced High-speed CMOS Technology
BW	Bandwidth
CML	Current Mode Logic
CMOS	Complementary Metal-Oxide-Semiconductor
DAC	Digital-to-Analog Converter
DC	Direct Current
DEMUX	Demultiplexer
DS-CDMA	Direct Sequence Code-Division Multiple Access
DSO	Digital Storage Oscilloscope
DSP	Digital Signal Processing
ECL	Emitter-Coupled Logic
ETSI	European Telecommunications Standards Institute
FFT	Fast Fourier Transform
FWHM	Full Width of Half-Maximum

GPIB	General Purpose Interface Bus
HWHM	Half Width Half Maximum
IR	Impulse Radio
LDO	Low Dropout
LNA	Low Noise Amplifier
LO	Local Oscillator
LPF	Low-Pass Filter
LVPECL	Low Voltage Positive Emitter-Coupled Logic
LVTTL	Low Voltage Transistor-Transistor Logic
MB-OFDM	Multi-band Orthogonal Frequency-Division Multiplexing
MESFET	Metal –Semiconductor Field Effect Transistor
MOSFET	Metal-Oxide Semiconductor Field Effect Transistor
ms	Milli Second
MHz	Mega Hertz
MUX	Multiplexer
NLTL	Non-Linear Transmission Line
NPG	Narrow Pulse Generator
PA	Power Amplifier
PAPR	Peak-to-Average Power Ratio

PCB	Printed Circuit Board
PECL	Positive Emitter-Coupled Logic
PPG	Pulse/ Pattern Generator
PRF	Pulse Repetition Frequency
ps	Pico Second
PSD	Power Spectral Density
RF	Radio Frequency
SMA	Sub Miniature Version A Connector
SMD	Surface Mount Device
SNR	Signal to Noise Ratio
SRD	Step-Recovery Diode
TL	Transmission Line
TTL	Transistor-Transistor Logic
UWB	Ultra Wideband
VGA	Variable-Gain Amplifier
VNA	Vector Network Analyzer
VSWR	Voltage Standing Wave Ratio
WBA	Wideband Amplifier
WLAN	Wireless Local Area Network

LIST OF SYMBOLS

V_{IH}	Input HIGH Voltage
V_{IL}	Input LOW Voltage
V_{pp}	Peak-Peak voltage
V_{th}	Threshold reference voltage
Z_0	Characteristic impedance
t_f	Fall Time
t_r	Rise Time
$\varepsilon_{r,eff}$	Effective relative permittivity
ε_r	Relative permittivity of substrate material
η_0	Wave impedance of free space
h	Separation between signal line and reference plane
t	Thickness of signal line
W	Width of signal line
Δ	Centroid position difference
σ	Pulse shape factor (Gaussian)
τ	Pulse Duration
H	Image Entropy

PENJANA DENYUT SEMPIT SUB NANO SAAT JALUR LEBAR ULTRA BOLEH TALA UNTUK PENGIMEJAN GELOMBANG MIKRO

ABSTRAK

Sejak akhir-akhir ini, sistem berasaskan Jalur Lebar Ultra (UWB) mempamerkan prestasi metrik yang lebih tinggi berbanding sistem komunikasi jalur sempit. Pengimejan gelombang mikro UWB adalah sebuah aplikasi baru dalam bidang bioperubatan, pengesanan objek dan beberapa bidang lain. Penjana Denyut Sempit (NPG) adalah salah satu elemen penting bagi sistem pengimejan UWB dan ciri-ciri sebahagiannya menentukan prestasi keseluruhan sistem. Pelbagai reka bentuk NPG telah dibangunkan untuk aplikasi tertentu dan kebanyakannya direka untuk integrasi teknologi CMOS. Tambahannya, reka bentuk ini kurang fleksibel untuk penalaan lebar denyut pengguna. Dalam kajian ini, sumbangan utama adalah reka bentuk sub nano saat NPG berkos rendah dengan pelbagai ciri seperti penalaan tempoh denyutan dan untuk menjana bentuk denyut dengan masa menaik dan menurun ultra-cepat yang mampu mempertingkatkan kualiti pengimejan gelombang mikto UWB. Reka bentuk ini bertujuan untuk mengurangkan kos NPG dengan penggunaan komponen yang tersedia. Masa peralihan yang sangat rendah membawa kepada julat BW yang lebih tinggi dalam spektrum frekuensi dan akan memberi tanda untuk meningkatkan kualiti imej telah dibina daripada radar sistem pengimejan UWB. Denyut yang paling singkat yang dihasilkan oleh NPG yang dicadangkan itu adalah kira-kira 820 ps dengan masa menurun kira-kira 64 ps dan tahap denyut 200 mV (pengakhiran tunggal). Data denyut yang dinyatakan di atas telah disimulasikan dalam algoritma pembinaan semula imej (EDAS) untuk mengesan objek hipotetikal dan imej-imej

yang dihasilkan menunjukkan peningkatan kualiti yang ketara berbanding dengan denyut Gaussian (atau derivatif) dalam tempoh yang sama. Nilai entropi imej telah dikurangkan daripada 248 ke 51. Simulasi ini mengesahkan kesan konsep trapezoid denyut (atau derivatif) ke atas resolusi imej. Untuk pengesahan lanjut, eksperimen sistem pengimejan UWB telah dijalankan dengan tatasusunan lingkaran antena untuk mengesan dan mencari sasaran yang berbeza yang diperbuat daripada bahan-bahan yang dipilih. Denyutan NPG yang dicadangkan digunakan, selepas dikuatkan, kepada sistem ini. Imej yang dibina semula dibandingkan dengan apa yang diperolehi dari sumber denyut lain seperti VNA dan PPG. Imej-imej yang dihasilkan daripada NPG yang dicadangkan menunjukkan kualiti yang lebih baik dalam kebanyakan kes. Berbanding dengan imej VNA, entropi imej berkurangan daripada 63.66 ke 43.23 untuk rod tanah liat dan daripada 143.77 ke 46.5 untuk rod aluminium. Keputusan memberangsangkan NPG yang dicadangkan diharap boleh digunakan sebagai sesuatu yang berguna untuk mendapatkan imej resolusi yang lebih tinggi dan pengesanan ketepatan sasaran yang lebih baik dalam pelbagai aplikasi industry

TUNABLE SUB-NANOSECOND ULTRA WIDEBAND NARROW PULSE GENERATOR FOR MICROWAVE IMAGING

ABSTRACT

In recent years, the Ultra Wideband (UWB) technology-based systems exhibited higher performance metrics over narrow band communication systems. The UWB microwave imaging is an emerging application in the biomedical, object detection, and ranging fields. The Narrowband Pulse Generator (NPG) is an essential element of any UWB imaging system and its characteristics partially determine the overall performance of the system. Numerous NPG designs have been developed for specific types of applications and most of them designed for CMOS technology integration. Additionally, they lack the flexibility of user pulse width tuning. In this research, the main contribution is the design of a low-cost sub-nanosecond NPG with many features like tunable pulse duration and to generate a pulse shape with ultra-fast rise and fall times that could enhance the quality of UWB microwave images. The design aims to reduce the NPG cost with the use of off-the-shelf components. The very low pulse transition times led to higher BW values in the frequency spectrum and would presage to enhance the quality of images been reconstructed from UWB radar imaging systems. The shortest pulse provided by the proposed NPG is about 820 ps with a fall time of about 64 ps and a pulse level of 200 mV (single-ended). The aforementioned pulse data has been simulated in a locally developed image reconstruction algorithm (EDAS) to detect hypothetical objects and the resultant images show significant quality enhancement in comparison to a Gaussian pulse (or its derivative) with an equivalent duration. Image entropy values have been reduced from 248 to 51. This simulation validated the concept of

trapezoidal pulse (or its derivative) influence on image resolution. For a further validation, an experimental UWB imaging system has been configured with a circular array of antennas to detect and locate different targets made of selected materials. The proposed NPG pulses have been applied, after amplification, to the above system. The reconstructed images compared to those obtained from other pulse sources like the VNA and PPG. The images generated from the proposed NPG show better quality in most cases. Compared to VNA images, image entropy values dropped from 63.66 to 43.23 for clay rod, and from 143.77 to 46.50 for an Aluminum rod. The promising results of the proposed NPG can hopefully be applied as a useful tool to obtain higher resolution images and better target detection accuracy in many industrial applications.

CHAPTER ONE

INTRODUCTION

1.1 Introduction

The UWB systems were born at the end of the nineteenth century and started with spark gap transmissions (Nikookar and Prasad, 2008). The first appearance for a practical UWB technology was a military radar system as it can detect targets through the trees and underneath the ground surface (Ghavami et al., 2004). However, nowadays the UWB technology extended to participate in many industrial, medical, and consumer applications. UWB systems have advantages over narrow band systems like low emitted power, low equipment cost, high data rates, reduced multipath fading, higher accuracy in positioning systems, and extremely low interference effect with other communication systems.

Unlike conventional narrow band communication systems, UWB systems have their spectrum spread along a very wide range of frequencies as depicted in Figure 1.1.

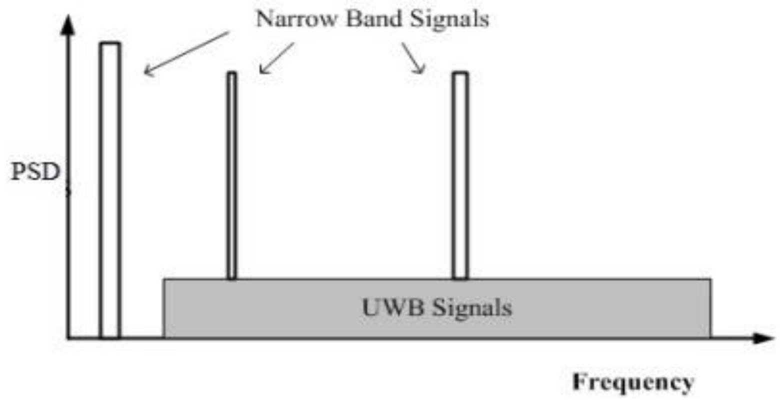

Figure 1.1: Power Spectral Density for Communication Systems

The extremely wideband spectrum allows UWB systems for underlay usage of unlicensed spectrum and this will increase spectrum efficiency and open gates for more wireless communication applications (Arslan et al., 2006). One of the vital elements of any UWB system is the Narrow Pulse Generator (NPG). The characteristics of the generated pulses determine the frequency contents of the signal spectrum and their PSD levels. Many researchers proposed and developed a variety of NPGs, based on different techniques and topologies (Bourdel et al., 2010). Some techniques, like pulse generation by transposition and combination, are most suitable for CMOS integration technology, while other techniques, like fast logic gates and fast switching devices, can easily be built for laboratory experimental use as they are based on low-cost components from the electronics market. Researchers are still developing new NPGs to obtain efficient PSD envelopes and enhanced tuning features in order to adapt for recent applications.

UWB radar microwave imaging is one of the first applications of the UWB technology. Through-wall radar imaging, object detection, and biomedical radar imaging are merely some categories of this emerging field. In the through-wall imaging, target movement detection and object location can be detected from a few meter ranges (Amin, 2011). Object detection with radar imaging exploits the very short pulses to obtain a location accuracy of a centimeter range, or even less (Elkhouly et al., 2011). UWB radar medical areas of application are extending. This technology can be applied to hospitals, Intensive Care Units, and operation theaters with low cost and low maintenance efforts. The UWB radar can be used for remote monitoring of patient body and his organs. Furthermore, high-resolution images could be reconstructed from processing the reflected pulses from the body tissues (Nikookar and Prasad, 2008). In fact, the UWB radar medical imaging functionally acts like the ultrasound but with more advantages like the non-contact feature and the higher resolution imaging. Breast cancer early detection is of great interest to researchers, and the UWB imaging offered an effective and safe tool in this application (Lim et al., 2008, Yuce, 2013).

A UWB radar imaging system requires special antennas to operate the required BW and with good impulse response to reduce the dispersion and output ringing. For time-domain UWB imaging, the antennas should have constant gain and a linear phase along the operating BW. Many UWB antenna designs have been proposed for UWB radar imaging but each design has some drawback features like the size, weight, and cost (Amin, 2011). There is a need for innovative designs to compromise among BW, compactness, and cost challenges.

In order to obtain a high resolution or super-resolution images, an efficient image reconstruction algorithm is essential. During the last two decades, many algorithms have been proposed, and the confocal microwave imaging technique was the familiar one (Lim et al., 2008). The development of a fast and efficient algorithm is a challenge for researchers.

1.2 Problem Statement

The UWB technology has been applied to the radar microwave imaging applications for more than twenty years, and those applications include biomedical, movement detection, object detection, ranging, and positioning. The conventional way in those applications is to transmit very short duration UWB pulses and process the reflected (received) pulses from one or more antennas, with special algorithms to reconstruct an image, detect and/or track an object, or find the location of a target precisely, depending on the nature of the specific application. The main problems associated with the UWB radar microwave imaging systems are:

1. Narrow Pulse Generator (NPG) design

   The NPG is a vital element in any UWB imaging system. Different techniques are available nowadays to build UWB NPGs. The critical decision is the right selection of the NPG for a specific category of applications. The cost, complexity of design, easiness of use and interface to other RF equipment, and the NPG topology: integrated or hybrid, are important factors that determine the category of the selected NPG.

2. NPG output waveform characterization

   The output narrow pulses of the NPG determine the envelope of the frequency spectrum and the PSD of the UWB imaging system. For a reconstructed image, low-frequency components are necessary to maintain image features, while the high-frequency contents entail image details. The shape of the narrow pulse, pulse duration time, rise and fall times, pulse BW, and pulse amplitude are still questionable, as no optimal or general solution has been developed yet.

3. Radar imaging

   In the biomedical and object detection UWB applications, the main challenge for researchers is to obtain a high or super-resolution images. In the ranging and positioning applications, the accuracy of measurements is the main challenge. The advancement in UWB technology is growing fast and thus more opportunities for better achievements are available.