DEVELOPMENT OF A FREQUENCY MODULATED CONTINUOUS WAVE RADAR FOR SLOW MOVING TARGET DETECTION

BY

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A thesis submitted in fulfilment of the requirement for the degree of Master of Science (Communication Engineering)

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ABSTRACT

Frequency Modulated Continuous Wave (FMCW) radar system is frequently used for remote sensing applications which require high sensitivity and continuous monitoring. There are many factors that affected the radar's performance; they are including applied techniques, characteristic of detecting a target and experimental environment. Those factors also provide the impact on the expenses of the radar fabrication. This research aims to develop an inexpensive S-band FMCW radar with radar sensitivity improvement for slow moving target applications. The pre-design phase of the radar is simulated in Advanced Design System (ADS) 2014 software to find the radar's breakthrough. The proposed radar operates at 2.4GHz carrier frequency with 10.41dBm transmit power. It established a 2.8m range resolution from 53.2MHz bandwidth. A computer-based system is used for Data Acquisition (DAQ) system and digitalized signal process. Chirp period-bandwidth product of Frequency Modulated (FM) waveform and deramping process with maximum range of 200meters and Radar Cross Section (RCS), σ of $1m^2$ improve the radars' Signal to Noise Ratio (SNR) by 42dB. Next, the radar is tested in several experiments to evaluate the capability of the radar to determine range and velocity of the slow moving target. The experiments are conducted in a Microwave Laboratory of International Islamic University Malaysia. Fast Fourier Transform (FFT) method is used for analog to digital conversion. Additionally, Moving Target Indicator (MTI) - chirp cancellor technique is implemented on ranging measurement for clutter rejection. Based on the conducted experiments, the radar proves that it is able to detect the target that moves at very slow speed. It provides accurate measurement for a target which moves more than 1m/s speed with a 6.73% percentage error. It also achieves an accurate and precise range measurement for slow moving target detection with 0.18% percentage error. Hence, the proposed FMCW radar design is capable to provide high sensitivity performances despite its low-cost fabrication.

خلاصة البحث

كثيراً ما يستخدم نظام الرادار الموجي المتواصل التردد (FMCW) لتطبيقات الإستشعار عن بعد التي تتطلب حساسية عالية ورصد مستمر. هناك العديد من العوامل التي تؤثر على أداء الرادار. فهي تشمل التقنيات التطبيقية، وميزة الكشف عن الهدف والبيئة التجريبية. تؤثر هذه العوامل أيضا على نفقات تصنيع الرادار. يهدف هذا البحث إلى تطوير غير مكلف للمدى الترددي S لنظام (FMCW) رادار مع تحسين حساسية الرادار لتطبيقات الهدف بطيئ الحركة. يتم محاكاة مرحلة ما قبل التصميم للرادار في نظام برمجيات التصميم المتقدم (ADS)2014 للعثور على إختراق الرادار. الرادار المقترح يعمل على ناقل بتردد 2.4 GHZ وبقوه إرسال تساوي 10.41dBm. تم تثبيت دقه الرادار عند نطاق 2.8 متر من عرض النطاق ترددي 53.2 ميجا هرتز. تم استخدام نظام حاسوبي (DAQ) لأقتناء البيانات ومعالجه الإشارة رقمياً. عرض النطاق الترددي اChirp period من التضمين الترددي الموجي (FM) وعملية معالجه التخميد مع أقصى مدى من 200 متر عند مساحه سطح الرادار (RCS), σ of $1m^2$ يحسن نسبه الإشاره الى الضجيج للرادار (SNR) بنسبة 42 .dB بعد ذلك، يتم إختبار الرادار في عدة تجارب لتقييم قدرة الرادار على تحديد مدى وسرعة الهدف بطيئ الحركة. تم إجراء التجارب في مختبر الميكروويف في كليه الهندسه في الجامعة الإسلامية العالمية ماليزيا. يتم استخدام طريقة تحويل فورريير السريع (FFT) لتحويل الإشارات التماثليه إلى إشارات رقمية. بالإضافة إلى ذلك، تقنيه تحرك مؤشر الهدف (MTI) - chirp cancellor نُفِذت على قياس التراوح لرفض الجلبة. استناداً إلى التجارب التي أجريت، اثبت الرادار أنه قادر على الكشف عن الهدف الذي يتحرك بسرعة بطيئة جداً. كما اثبت الرادار أنه يوفر قياس دقيق للهدف الذي يتحرك بسرعه أكثر من 1 m/s مع نسبة الخطأ 6.73٪. كما أنه يحقق دقة لقياس المدى المحدد للكشف عن الهدف بطيئ الحركة مع نسبة مئوية للخطأ 0.18٪. وبالتالي، فإن تصميم رادار FMCW المقترح قادر على توفير أداء حساسية عالية على الرغم من تصنيعه منخفض التكلفة

APPROVAL PAGE

I certify that I have supervised and read this study and that in my opinion, it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a thesis for the degree of Master of Science (Communication Engineering).

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DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

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LIST OF ABBREVIATIONS

2D	2-dimensional
3D	3-dimentional
ADS	Advanced Design System
ADC	Analog to Digital Converter
CW	Continuous Wave
DAQ	Data Acquisition
DDS	Data Display
DDS	Direct Digital Synthesis
EDA	Electronic Design Automation
FFT	Fast Fourier Transform
FM	Frequency Modulated
FMCW	Frequency Modulated Continuous Wave
FSK	Frequency Shift Keying
GB- SAR	Ground Based Synthetic Aperture Radar
HPBW	Half Power Beam Width
IDFT	Inverse Discrete Fast Fourier Transform
IEEE	Institute of Electrical and Electronics Engineers
ITU	International Telecommunication Union
LFM	Linear Frequency Modulated
LOS	Line-of-Sight
LNA	Low Noise Amplifier
MCMC	Malaysian Communications and Multimedia Commission
MDS	Minimum Detectable Signal
MTI	Moving Target Indication
MIMO	Multiple Input Multiple Output
NF	Noise Figure
PCB	Printed Circuit Board
RADAR	Radio Detection and Ranging
RCS	Radar Cross Section
RF	Radio Frequency
SAW	Surface Acoustic Wave
SISO	Single Input Single Output
SNR	Signal to Noise Ratio
UHF	Ultra High Frequency
VCO	Voltage Control Oscillator
WAV	Waveform Audio

LIST OF SYMBOLS

P_t	Peak transmit power
G	Antenna gain
λ	Operating signal wavelength
σ	Radar cross section
S_{min}	Minimum detectable signal
τ	Pulse width
C_0	Constant speed of light
Δr	Range resolution
σ^0	Backscatter coefficient
∂A	Area of interception
A_e	Effective aperture
ρ_a	Antenna aperture efficiency
A	Antenna physical area
θ	Beam width
D	Antenna diameter
f_0	Centre frequency
V_r	Radial velocity
f_d	Doppler frequency
a_t	Instantaneous transmitter signal
α	Transmit signal chirp rate
b_0	Amplitude receive signal
S_{IF}	Beat signal
R	Target range
B	Bandwidth
f^+	Up chirp
f^-	Down chirp
K	Boltzmann constant
T_0	Room temperature 290K
B_n	Noise receiver
F_n	Receiver noise factor
Δt	Time difference between transmit and receive signal
N	Number of samples per pulse
X(k)	Receive signal in digital domain
k	Stability factor
Δ	Delta
ν_q	ADC noise floor
V_{p-p}	Peak to peak voltage
Pr_{min}	Minimum receive power
S21	Forward gain
S22	Reverse reflection coefficient
S11	Forward transmission coefficient
S12	Reverse gain

CHAPTER ONE

INTRODUCTION

1.1 OVERVIEW

Remote sensing is an approach of accomplishing information of a target or phenomenon using assembled electronic devices from distance or wirelessly. Remote sensor technology has an enormously huge area of applicability such as in military, geology, medical, agronomy and forestry. It is best implemented for any situation in which direct measurements are not possible and long range applications, for instance; satellite communication, natural disaster monitoring and airplane traffic controlling. The technology is categorized into two types; passive and active remote sensing system.

Passive remote sensor measures energy which is available naturally, sunlight is a regular source of radiation measured by the sensor. Examples of the sensors are including film photography, infrared, charge-couple devices and radiometers ("Remote Sensing," n.d.). On the other hand, an active remote sensor generates and emits its own source of energy towards a target and measures backscattered energy from the target. Hence, information of the required target is obtained by measuring and analyzing the backscattered energy. In other words, the active remote sensor is a two-way operation while the passive remote sensor is a one-way operation. One main advantage of the active remote sensors is that the emitted radiation can be preconditioned by the user to highlight the target object in a certain way.

Radio Detection and Ranging (RADAR) is a well-known example of active remote sensor applications which is mostly used by researchers and engineers these days. Basically, radar technology transmits microwave signal into space until hits target and some portion of return radiation from a reflected target is collected by using receiver antenna. A signal processing technique is implemented to measure and analyze the collected raw data of the return signal to be able to earn information of required object. Over the past century, conventional radar is only used for detecting and allocating a target. However, thanks to an evolution and development of the radar technology, modern radars are produced as well as extending the capability of the radars, such as accurate targeting, target identification and classification, navigation, guidance, imaging and etc. (Kassatokis, 2014).

The radar system is generally operating at microwave frequency range of 300MHz until 300GHz. Since it generates and emits a short wavelength of electromagnetic signals, its operation is unaffected by all types of weather and light conditions such as darkness, rain, snow, fog, smoke and dust during transmitting signal into space. In addition, radar is best used for long range applications as the radiation travels with the speed of light in space. Hence, it is an efficient tool for scientific measurement.

Frequency Modulated Continuous Wave (FMCW) radar is widely used for safety applications since decades ago. They are including hazards; snow avalanche monitoring(M Ash, Brennan, Vriend, Mcelwaine, & Keylock, 2011) and landslide monitoring (Luo et al., 2014), road safety; pedestrian detection (Ariel Etinger et al., 2014) and vehicle collision mitigation (Roggero, Zhao, & Zucchelli, 2015). Nowadays, users or authorities are eager for sophisticated radars which can provide good sensitivity for the particular applications. A radar device is classified as possessing good sensitivity when it is able to detect and measure a target in worst conditions. For example, a small target which moves at very low speed with a lot of interferences' existence.

The target in such condition produces weak backscattered signal in which normally neglected by conventional radar due to high sensitivity requirement of the hardware which consequently increased the incur development cost. However, the neglected signal could cause a massive effect such as loss of lives due to road crashes. According to (A Etinger et al., 2014), more than 3000 people around the world lose their lives every day due to the particular reason where half of the victims are pedestrians who are exposed road users. Hence, a radar remote sensor that is sensitive enough to detect the aforementioned slow moving target is needed to reduce the severity of damages.

Meanwhile, the selection of equipment and techniques are among the crucial factors that affect the capability of the detector as well as its cost of fabrication. For that reason, many researchers and industries have contributed ideas, innovations and improvements for its betterment. Numerous great radar projects were done for the slow moving target studies. However, they provide good sensitive radar remote sensors by implementing sophisticated approaches such as advanced electronic tools and techniques due to big budget possessing and many technical experts were involved.

Therefore, this research has explored processing technique of Doppler principle in an inexpensive FMCW radar system design for detection of weak backscattered signal while providing comparable sensitivity as the previous work. At the Microwave Laboratory of International Islamic University Malaysia, various experiments were conducted to investigate its reliability to detect slow moving target as well as to accurately measure the range and velocity of the slow moving target. It is expected that the outcome of this research can be implemented into vehicle safety applications for moving pedestrian detection and monitoring. It is also hoped that the implementation of the output of this research project can assist Malaysian authorities such as Malaysian Automotive Association to take appropriate actions in order to reduce the losses and damages.

1.2 STATEMENT OF THE PROBLEM

Previous work had been conducted in London whereby FMCW radar system with phase array technique were implemented for slow moving target applications. (M Ash et al., 2011). It claimed that the target minimum speed that can be determined accurately by the radar system was 5.7m/s. One of the main factors effected the minimum speed determination is the radar sensitivity. Since the radar has complicated circuitry design at the receiver system, it provides a lot of noise and subsequently reduce the radar sensitivity performance.

According to (A Etinger et al., 2014), pedestrian movement can be very slow, approximately speed of 0.5m/s. Radar system with higher sensitivity should be suggested. Therefore, this research develops a low cost FMCW radar system with deramping process to improve the previous radar's sensitivity so that it capable to detect and determine the speed and range of the slow moving target.

1.3 RESEARCH OBJECTIVES

The objectives of this research are as the followings:

i. To develop a low cost S-band FMCW radar system with radar's sensitivity improvement for slow moving target applications (i.e: pedestrian detection)
ii. To determine the speed and range of the pedestrian using Doppler principle.
iii. To investigate the performance of the FMCW radar with different type of speeds, ranges and targets.

1.4 RESEARCH METHODOLOGY

The methodology of this research consists of the following activities:

i. Preliminary investigation

This research starts with understandings of some basic principle of the conventional radar system and how it is working. Reflectivity of a target and receive signal detection level are also reviewed. In addition, FMCW radar basic block diagram will be introduced along with its superior advantages for moving target applications. Numerous studies on previous related works will be outlined while identifying their implemented parameters and methods for the radar system.

ii. Approaches and parameters analysis

The relevant approaches of radar's design determine its performance outputs. There are several main approaches that will be taken close attention during the design process. They are including operating frequency, waveform modulation, antenna, target, Data Acquisition (DAQ) system and simulation computational software. These approaches will be selected based on their cost-effectiveness, sensitivity and reliability to detect slow moving target.

iii. Simulation analysis

Preliminary design of FMCW radar system is tested using Agilent Advanced Design System (ADS) version 2014. It is compatible for RF and microwave applications. Several simulators are provided by the software such as Envelope, Harmonic Balance, Scattering Parameters and also Budget analysis. By utilizing the software, any flaws and radar’s breakthrough is detected, hence finalized radar system with optimized performance is successfully designed.

iv. Design decision analysis

The proposed FMCW radar system consists of four main parts. They are including transmitter, receiver, antenna, and DAQ system. Each part contains several assembled electronic components.

v. Purchase and assemble electronic components

The proposed components are purchased from multiple manufacturers according to their availability in stock. RF components such as Voltage Controlled Oscillator (VCO), amplifier, mixer and splitter are bought from Mini-Circuits while other components are from Farnell14 element and eBay. After that, they are assembled and fabricated an FMCW radar hardware.

vi. Experimental test analysis

Various experiments are carried out to investigate the capability of the radar to detect and measure the range and velocity of a slow moving target. Different types of targets, distances and speeds are applied during the analysis. The activities are held in a Microwave Laboratory. The collected raw data is analysed in MATLAB 2013a with Moving Target Indication (MTI) algorithm for range measurement while Doppler principle for speed measurement. Based on the conducted experiments, the performance evaluations of the radar for the particular goals are achieved and subsequently concluded with percentage error.

Flow chart of the research methodology is summarized as in Figure 1.1:

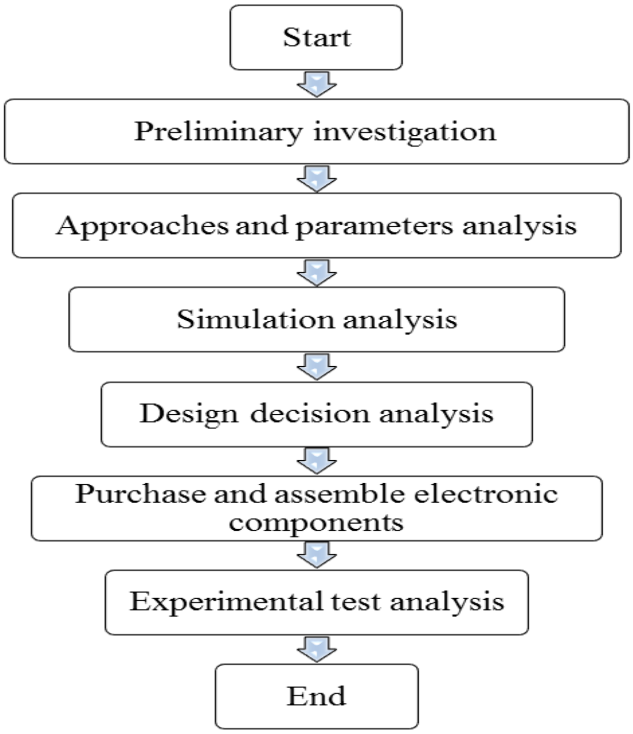

Figure 1.1: Research methodology flow chart

1.5 RESEARCH SCOPE

Radar system for detection and measurement is an extensive topic. There are various radar system that can be used for the specific purpose such as pulse radar, Continuous Wave (CW) radar and Frequency Modulated Continuous Wave (FMCW) radar. However, this thesis covers FMCW radar only. Besides, this project focused on the elements which effected the radar sensitivity performance. In addition, this research dedicates specific digital signal processing technique for clutter rejection, Moving Target Indication. Other common digital signal processors such as range processing, azimuth processing, array and location calibrations are not covered in this thesis. The analyses are validated by conducting real time experimental activities in indoor area, outdoor experiments are out of scope. The radar system examined human movement in which its Radar Cross Section is estimated to 1 (Skolnik, 2001). However, micro Doppler effect due to human moving of hands or legs is not covered in this thesis.

1.6 THESIS ORGANIZATION

This thesis is arranged into six parts. Chapter 1 outlines overview about radar system background and its general principle. It also includes research problem statements and its significant, research objectives, research scope, research methodology, and research layout.

Second chapter describes background theory in this research field which consists of basic radar theory and FMCW radar principle together with its advantages and disadvantages. Another focus of this Chapter 2 is the Doppler principle along with signal processing for slow moving target detection. Literature surveys of previous related works are also included.

Third chapter comprises detail explanations on step by step procedures to accomplish the radar system design. Among them, radar considerations and selected methods are included. Furthermore, FMCW radar hardware is fabricated and its bill of materials is listed.

Fourth chapter presents the simulation analyses of radar system by using Agilent Advanced Design System (ADS) version 2014. Oscillation, scattering parameters and link budget analysis are provided. This chapter also provides the performance analyses of designed radar system to detect moving target by using Doppler principle.