IMPROVEMENT OF RANGE RESOLUTION IN PASSIVE BISTATIC RADAR USING FM SIGNALS

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IMPROVEMENT OF RANGE RESOLUTION IN PASSIVE BISTATIC RADAR USING FM SIGNALS

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Submitted by **Mohammed Alsudani**

Approval of the Graduate School of Natural and Applied Sciences, Çankaya University.

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, by way of thesis for the degree of Master of Science.

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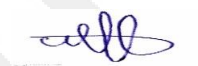
Signature : 

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ABSTRACT

IMPROVEMENT OF RANGE RESOLUTION IN PASSIVE BISTATIC RADAR USING FM SIGNALS

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In this thesis, it is tried to explain the principles of processing in two-way passive radar systems in a simple and conceptual way. Subsequently, the problem is detected in passive radar systems based on FM radio signals in the presence of interfering signals, including system noise, clutter (multi-path recurrent echoes), direct path signal, and received echo received from the target. In this thesis, the amplitude resolution for near-field targets is increased by the use of FM signals. A diagnostic algorithm that calculates the distance between two targets is proposed. The ultimate goal is to improve the resolution of the domain for near-term purposes. The amplitude resolution is inversely proportional to the signal bandwidth. Thus, with increasing bandwidth, amplitude resolution and targets closer are correctly detected. To ensure the correct operation of this algorithm, one, three, and seven FM channels are used to broadcast the signal to detect nearby targets.

Keywords: Range Resolution, Passive Bistatic Radars, FM Signals

ÖZET

FM SİNYALLERİNİ KULLANARAK PASİF BİSTATİK RADARLARDA ARALIK ÇÖZÜNÜRLÜĞÜNÜN İYİLEŞTİRİLMESİ

Mohammed ALSUDANI

Yüksek Lisans, Elektronik ve Haberleşme Mühendisliği

Danışman:Asistan.Prof.Dr.Özgür ERGÜL

Ocak 2020, 64 Sayfa

Bu tezde iki yönlü pasif radar sistemlerinde işlem prensiplerini basit ve kavramsal bir şekilde açıklamaya çalışılmıştır. Ardından, sistem gürültüsü, dağınıklık (çok yollu yinelenen yankılar), doğrudan yol sinyali ve hedeften alınan yankı dahil olmak üzere karışan sinyallerin varlığında FM radyo sinyallerine dayanan pasif radar sistemlerinde sorun tespit edilir. Bu tezde, yakın alan hedefleri için genlik çözünürlüğü FM sinyalleri kullanılarak arttırılmıştır. İki hedef arasındaki mesafeyi hesaplayan bir tanı algoritması önerilmiştir. Nihai amaç, alanın yakın vadeli amaçlar için çözümünü iyileştirmektir. Genlik çözünürlüğü, sinyal bant genişliği ile ters orantılıdır. Böylece, artan bant genişliği ile, genlik çözünürlüğü ve yakın hedefler doğru bir şekilde tespit edilir. Bu algoritmanın doğru çalışmasını sağlamak için yakındaki hedefleri tespit etmek amacıyla sinyali yayınlamak için bir, üç ve yedi FM kanalı kullanılır.

Anahtar kelimeler: Menzil Çözünürlüğü, Pasif Bistatik Radarlar, FM Sinyalleri.

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LIST OF ABBREVIATIONS

PBR	passive bistatic radar
LFM	Linear Frequency Modulation
FM	Frequency Modulation
PM	Phase Modulation
DVB	digital video broadcast
DAB	digital audio broadcast
PCR	passive covert radar
PCL	passive coherent location
BBC	British Broadcasting Corporation
Rx	Receiver
Tx	Transmitter
VHF	Very High Frequency
UHF	Ultra-High Frequency
CW	Continuous Wave
DEW	Distant Early Warning
GSM	Global System for Mobile Communications
GPS	Global Positioning System
OFDM	Orthogonal frequency-division multiplexing
DSP	Digital signal process

CHAPTER 1

INTRODUCTION

1.1.Passive Radar Overview

The term “passive radar” means a certain radar technique, which makes use of already existing signals including communication, radio navigation or transmissions waves as its transmission source; therefore, it is contrary to the conventional monostatic radars because they only use their transmitters and an antenna in order to transmit or receive the signal while the optimized pulse-like signal performs the function of the radar. Despite the wide use of the concept of passive radar, some other techniques gained substantial significance. Military users use some techniques such as passive covert radar (PCR) and passive coherent location (PCL). Moreover, another popular and effective bistatic technique is passive bistatic radar (PBR), which physically separates the receiver and the transmitter, and practically exhibits various properties of this radar type. In addition, the “hitchhiking” technique applies if some monostatic radar is a transmission source.

Some other passive radars include non-cooperative radars, transmission radars, symbiotic radios and parasitic radars [1, 2]. Both PCL and PCR radar systems use non-cooperative or "opportunity" illuminators as objective illumination sources. Instead of optimally transmitting waveforms using a dedicated/specific transmitter (like conventional radar systems), passive radars use those telecommunication signals, which are already transmitted and they exist in the air, such as analog TV signals, FM radio signals, satellite communication signals, GSM mobile network signals, or digital video broadcast (DVB) signals.

A major advantage of using non-cooperative illuminator is almost impossible-to-reveal signal because it doesn't use its own transmitter, its maintenance and usage are easy because it works with the already established transmitter network, and besides, it has no essential frequency assignment needs. The greatest flipside of this system is its uncontrollable power and waveform; therefore, this system uses certain signals, which may be inappropriate to achieve the objectives of radar usage. It also means that it requires high computation power [3, 4].

Earlier, passive bistatic radars (PBRs) gained popularity as it had lower costs because of its digital receiver technology and lower computing power requirement. In the mid-1980s, researchers tested another Passive Bistatic Radar because of increasing broadcast digitalization, and even now, they are subjected to continuous investigation. They were specifically used for FM and TV signals. Certain other commercial broadcasts including DAB and DVB have been under investigation for usage as a part of PBR systems, which gained substantial popularity among academic researchers and military radar users [5].

The Schema for radars and Passive Bistatic Radar (PBR) system is shown in figure 1.

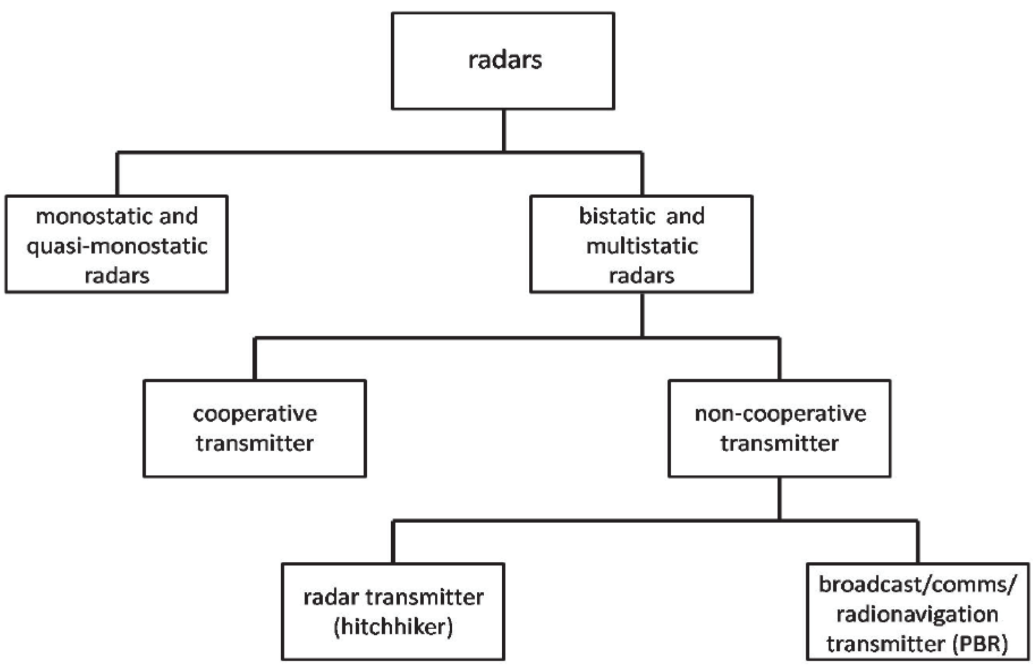


Figure 1. Block diagram of radars and Passive Bistatic Radar (PBR) system [1].

The bistatic radars either use their transmitters, which facilitate bistatic operation or opportunity transmitters, which are designed for broadcasting or other purposes. In the presence of a monostatic radar, a bistatic radar performs as a hitchhiker, as shown in **Figure 1** [6].

In case of non-radar transmissions including communication signals, broadcasting, and radio navigation signals, a bistatic radar is termed as a “passive” radar [6, 7].

For several military uses, transmitters of opportunity can be either cooperative or non-cooperative. The aforementioned transmitters are generally friendlier transmitters while the later ones are normally hostile transmitters used in common broadcasting processes. Generally, a majority of the PBR systems use the non-cooperative type of transmitters [8].
In PBR radars, the receiver (Rx) and the transmitter (Tx) are located at different sites; however, in monostatic radars both transmitters and receivers are located at the same site. In PBR systems, transmission and receiving antennas are located at different places.

Certainly, these radars do not illuminate the object but utilize illuminations of the transmitters of opportunity for commercial broadcasts [9-11].

Figure 2: illustrates the differences between the bistatic and monostatic radars:

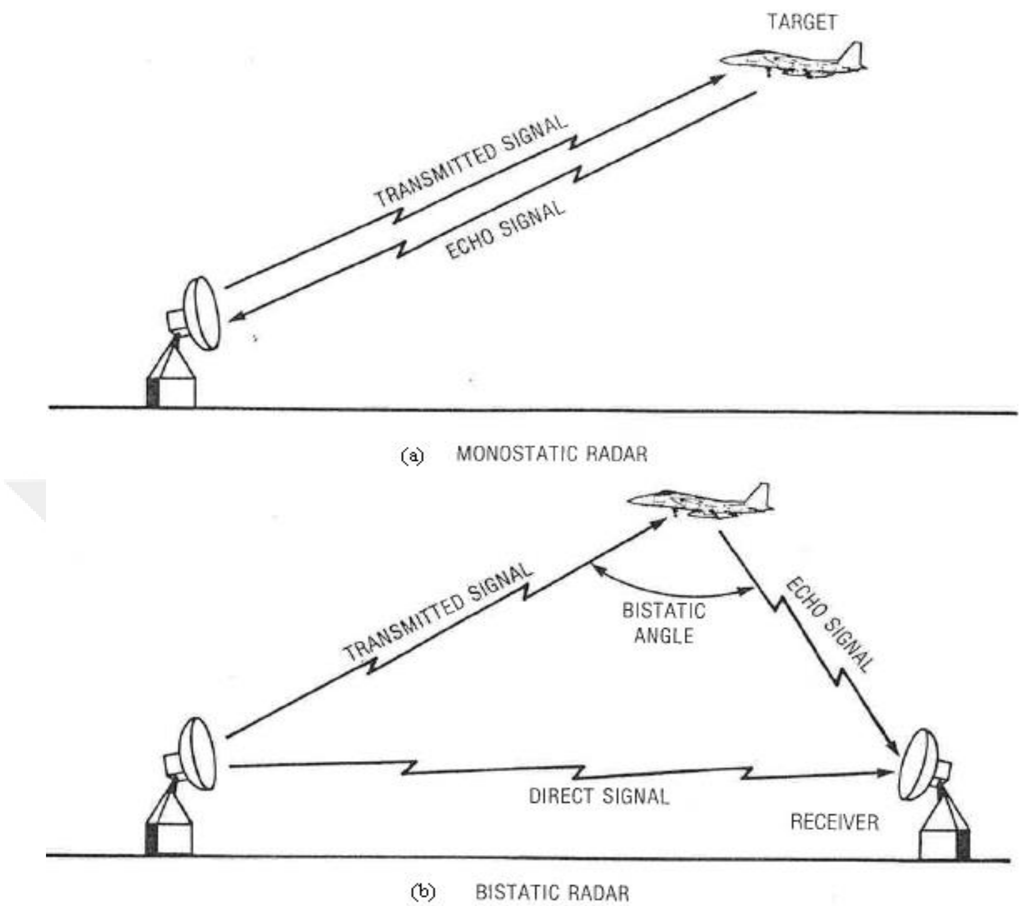


Figure 2: (a) Monostatic radars use a single transmitting and receiving antenna (b) Bistatic radars use separate receiving and transmitting antennas located at long distances from each other

1.2.Benefits and Issues of PBR systems

1.2.1. Benefits

1. Both communication and broadcasting transmitters are installed at high altitudes, which results in broader coverage.
2. This system uses some already existing transmitters, so passive radars have substantially lower operational costs as compared to the conventional radars.
3. This kind of radars doesn't have licensing problems.
4. It is possible to use VHF and UHF frequency bands with this kind of radars, which are generally unavailable for other radar systems. The mentioned frequencies can help detecting even stealthy targets because in this case, the wavelength matches

the target’s physical dimensions while the forward scatter provides relatively broad-angle scatter.

5. Their receivers do not emit any signal; so, in case of using inconspicuous receiving antenna, a passive radar receiver remains covert and undetectable.
6. Deploying countermeasures is difficult-to-implement against passive radars. Efforts to jam this kind of radar systems may be futile because in order to jam their functioning, the waves will need to be spread over a wide area in multiple directions.
7. Passive radars need no additional spectrum, because of which, they are sometimes called “green radars."
8. They can be used for enormous transmission ranges. Practically, passive radars can make use of almost every emission [12].

1.2.2. Issues

1. The transmissions of passive radars have waveforms, which are not optimized for the purpose of radar applications; therefore, selecting the correct waveform is critical for optimally using them.
2. In case of analog signals, instantaneous modulation controls the ambiguity function (Doppler-range resolution). Some modulation types perform better but digital modulation does not have such problems; therefore, it is preferred.
3. Their waveform is generally continuous (with 100% duty cycle); therefore, the multipath and the direct signal are suppressed through substantial processing for detecting weak target echoes.
4. Almost all the bistatic radars have poor range and Doppler resolution for certain targets, which are closer to the baseline between the receiver and the transmitter [13].

1.3 History of Passive Radar Systems (PRS):

In 1935, Robert Watson-Watt tested the passive radars for the first time in Daventry (United Kingdom), which detected a Heyford bomber within almost 8-mile range with the help of the British Broadcasting Corporation (BBC) shortwave broadcast at a distance of six miles [14].

In early 1930s, no technology was available that could allow an antenna to switch between the transmission and receiving modes. Consequently, all the early radars were bistatic. It is important to note that many countries inducted the mentioned bistatic systems in their air defense during that era, for example, Japan developed bistatic CW radar (Type A), United Kingdom inducted the Chain Home System, France employed bistatic Continuous Wave (CW) radar in a barrier/fence system, Germany developed a passive bistatic system called as the Kleine Heidelberg device, and Russia inducted a bistatic CW system for detecting aircrafts. This type of systems was installed in the UK at seven sites in the form of bistatic receivers while the British Chain Home radars were used as non-cooperative illuminators.

The synchronizers were developed in 1936, after which, the monostatic systems' popularity substantially increased mainly because the monostatic systems were now without major geometric complications as now, they had separate sites for the transmitter and the receiver that made the usage of monostatic systems straightforward and easier-than-before.

After that, the Bistatic systems were ignored until early 1950s when scientists discovered stimulating possessions of the scattered radar energy, after which, the United States started developing a new bistatic system in 1955, which is called as AN/FPS-23 flutter radar in order to protect the North American Distant Early Warning (DEW) Line. The CW fixed-beam bistatic fence radar had the ability to detect even the low-flying bombers, which crossed the DEW line. It had the ability to cover low-altitude gaps, which SENTINEL monostatic radars were unable to cover. After that, Fluttar radars remained deployed to protect the DEW line for almost five years.

Some amateurs showed interest in passive radars back in 1960s; however, this technology remained neglected until Deventry experiments 50 years later. Passive radars again received attention in 1980s when low-cost computing technologies and powerful digital signal receiving technologies were available. This time, experts and designers used a wide range of broadcast signals with the help of digital signal processing technologies. Moreover, they used cross-correlation techniques for substantial signal processing gains to detect the target, and estimate the target's Doppler shift and bistatic range.

Later, during early 1990s, passive radars received even more attention because at that time, low-cost analogue-to-digital converters were available. They allowed dynamic range for analyzing the Doppler-shifted sound echoes and analogue TV signals' vision carriers [9].

So far, many countries have initiated passive radar development programs. Lockheed-Martin Mission Systems announced to develop the first commercial system in 1998 called as "the Silent Sentry System," which uses Frequency Modulation (FM) radio signals as well as analog television transmission systems. At that time, several commercial organizations announced to develop passive radar systems including the BAE Systems' CELLDAR. It used different technologies including the FM radio-based Homeland Alerter developed by Thales Air Systems and GSM base stations [15].

During 2000s, radar developers developed many passive radar systems and supporting hardware including dynamic-range receivers and high-speed processors, and all this happened when the defense and research budgets were shrinking despite growing surveillance needs [9].

Since the passive radar systems are low-cost, it encouraged several tight-budget industries and several university laboratories to develop and improve them. In addition to the low-cost features, passive radars need more computation power and sophisticated algorithm but less hardware.

Now, there is global rise in interest in research and development of passive radars, including major US research hubs (University of Washington, Air Force Research

Labs, Georgia Technical Research Institute, Raytheon, and the Illinois University), NATO C3 Agency, which is located in the Netherlands, British research facilities (Roke Manor Research, University of Birmingham, QinetiQ, BAE Systems, and University College London), ONERA labs, which are located in France, FGAN-FHR in Germany, and Warsaw University of Technology in Poland.

Many government and academic research centers are engaged in active research processes in some other countries such as Russia, Iran, China, and South Africa, which resulted in significant developments in passive radars [16-19].

After observing such a massive trend for developing newer and improved PBR systems, it can be predicted that the PBR system research, development and use are likely to continue because of some significant reasons:

The first reason is increasing population and the likelihood that the military operations may be conducted near the populated areas. The existence of communication and broadcast signals is another advantage at these population centers. Moreover, UHF and VHF signal frequencies emerging from high-power TV and FM radio stations are suitable for installation and functioning of the PBRs. In addition, new technologies have resolved the synchronization and timing challenges specifically after the development of the GPS satellite navigation system.

Other reasons behind the popularity of the PBR systems include their simplicity and low cost. Along with advancements in the signal processing and digitalization, the PBR radar research has greatly benefitted. If this trend is analyzed based on Moore's law, advancements in the PBR technologies are likely to increase in the coming times [20].

CHAPTER 2
LITERATURE REVIEW

2.1. Bistatic Radar Theory

Passive Bistatic Radar (PBR) systems are dual radars that are low cost and undetectable due to lack of dedicated transmitter. In fact, these radar systems use in-environment signals such as Analog Television (TV) signals, Frequency Modulation (FM) radio, Digital Video Broadcasting-Terrestrial (DVB-T), GSM, and satellite. Generally, the choice of a suitable signal depends on parameters such as the transmitter coverage area, power, frequency band, signal bandwidth and ambiguity function form. As such, the bandwidth is determined by the signal bandwidth, and the power of target detection depends on the ambiguity function of those signals. Although most digital signals have a better ambiguity function than analog signals, the transmitter's lower power makes only short-range transmitters accessible. In this regard, the commercial FM radio signal is one of the appropriate signals that, in addition to achieving good performance in them, its manufacturing costs are reasonable [14].

Passive radar systems are known accordingly under various names, including PBR and Passive Coherent Location (PCL).

Nowadays, these systems are being re-considered due to the significant advancements in digital processors and analogue to digital converters [14, 21, 22]. Despite the benefits of PBR systems based on commercial FM radio signals, these radars also have disadvantages that neglecting them can severely affect the performance of these radars [21]. Among the significant disadvantages of these radars can be noted that in some cases it is necessary to add complexity to the system in order to achieve the proper performance:

1) In PBR systems transmitter position, waveform and transmitting power, Not under the radar designer's control. Therefore, unlike conventional single-radar radios, the transmitted signal is not predetermined and even its characteristics are time-varying. This means that for processing in PBR systems, in addition to the monitoring channel, a dedicated channel called the reference channel is required to have a copy of the transmitted signal.

2) In the care channel ideally, we expect to receive only the signal of the targets being sought.

In practice, however, in addition to receiving the target signal, clutter or multipath signals and direct path signals are also received which are far more powerful than the recursive signals of the targets and can detect the target itself. Therefore, the detection problem in these radars, which face strong interference signals, is of particular importance.

In this study we have tried to address the issue of detection in passive systems based on FM radio signals in the presence of interfering signals including system noise, clutter; (directional echoes due to multi-path phenomenon). And the received echoes of interference objectives. In this regard, two categories of processing algorithms have been studied in passive radars. In the first category, the two engineering detector structures presented in References [21, 23] are discussed. In Adesktah, they have the advantage of being one of the most sophisticated and highly optimized precision detectors in Nazarlaris.

The work presented in References [21, 24] based on the criteria of detection probability and false alert probability does not investigate the performance of the detectors presented in the study . In this study, we will try to compare the two above-mentioned detection structures with respect to the above two criteria, so that PBR system designers can choose between the two above-mentioned structures.

2.2. Modeling the received signal in the reference and care channels:

In a simple structure, one PBR system can be comprised of two antennas - one for providing the reference signal in the reference channel, and the other for receiving the target signals in the area of care as shown in **Figure 3**. Usually the reference channel antenna is a narrow-pattern antenna that is directed towards the transmitter. But the care channel antenna has a relatively wide pattern that is designed with respect to the radar care area. In practice, a linear or circular array antenna is commonly used for both surveillance and reference channels, but the radiation is generated by each channel separately and individually [25, 26]. An overview of a PBR system from the point of view of received signals in the reference and care channels is illustrated in **figure 3.**

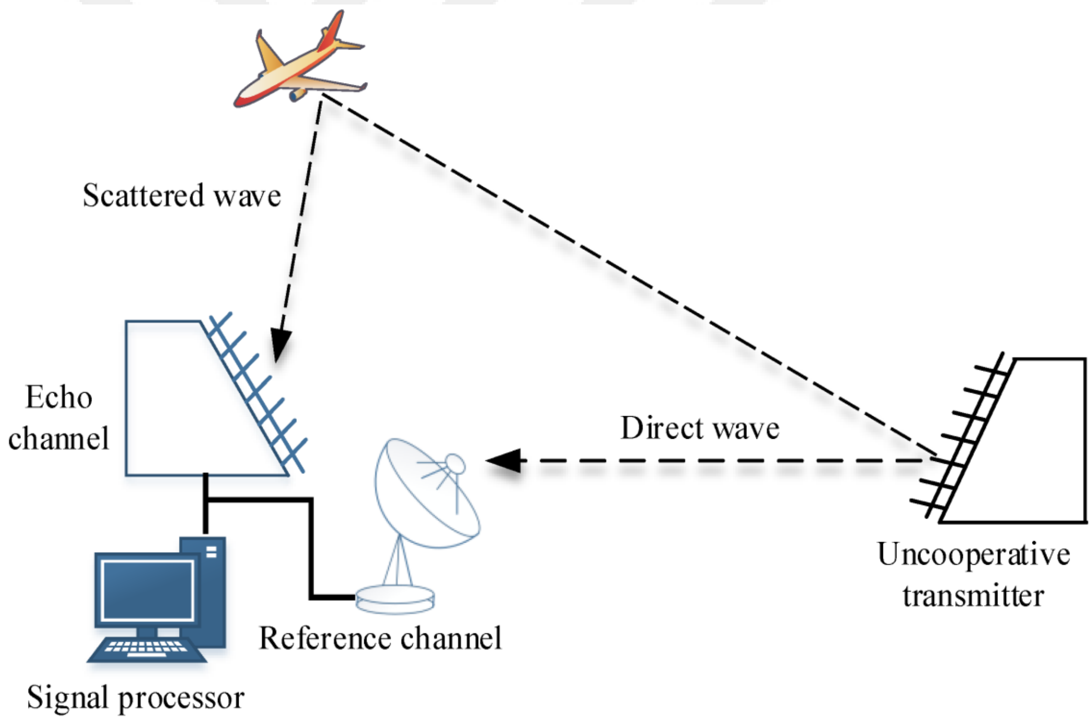


Figure 3: An overview of a PBR system from the point of view of received signals in the reference and care channels [26].

In the general case, the sample of nth signal equivalent to the baseband equivalent in the channel of care during T integration time can be considered as (2.1), [24, 27]:

$$X_s[n] = \beta_0 \, s[n] + \sum_{i=1}^{N_c} \beta_i \; [n] s\left[n - n_i^{(c_0)}\right] + \sum_{m=0}^{k-1} a_m \, s\left[n - n_m^{(t)}\right] e^{jn\Omega_m^{(t)}} + n_s[n] \quad (2.1)$$

The Generic passive radar signal processing scheme is shown in **figure 4.**

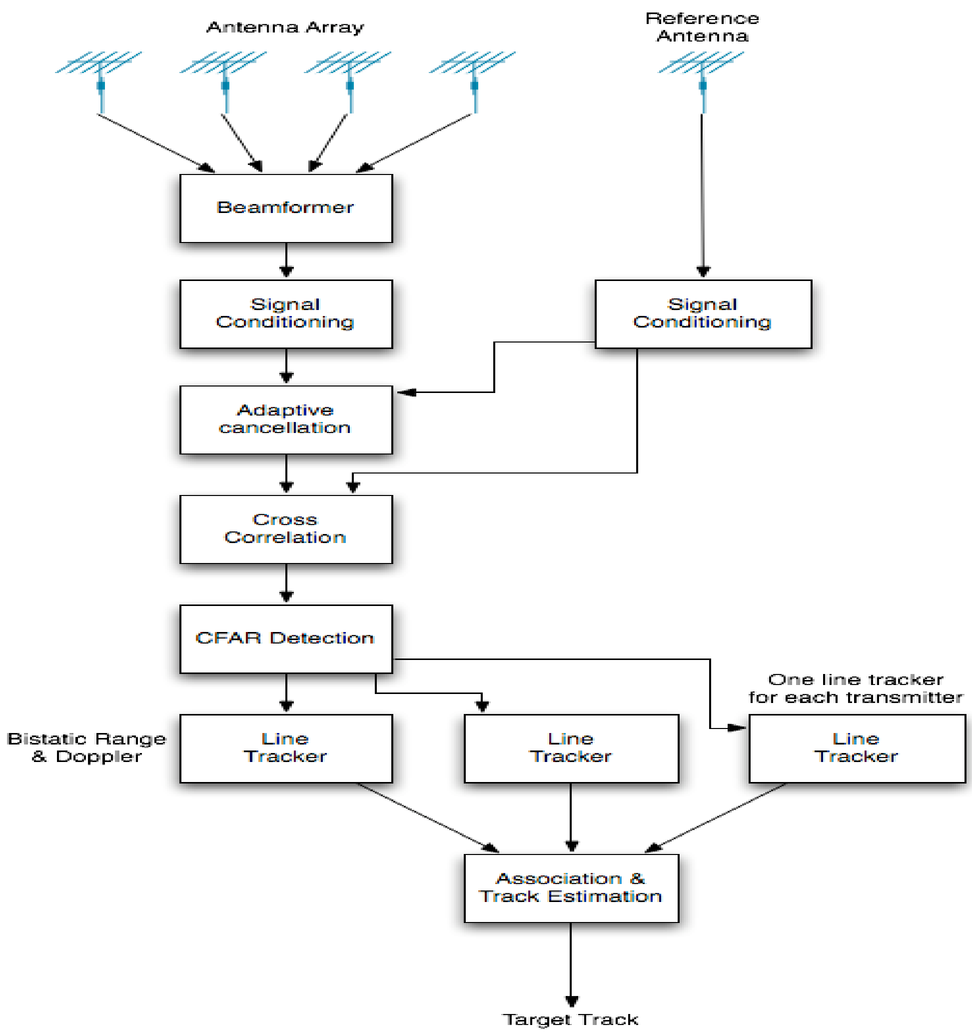


Figure 4: Generic passive radar signal processing scheme [28]

This section introduces conceptual, theoretical and mathematical definitions of PBR performance. Understanding these issues will allow the literature search to thoroughly examine relevant topics without further explanation, and provide a basis for further development of these ideas and equations in the dissertation. This study focuses on a special passive radar program in which the target and the receiver are mobile and the transmitter is not stationary and cooperative. In this section, the detailed theory required for this research is described. See [6] for a broader overview of Bistatic Radar.

2.3. Passive Radar Signals:

Public relations systems use opportunity lawyers. These lights are mostly FM Radio, Digital Audio (DAB), Digital Video Broadcast (DVB), GSM Phone and Wireless Signal. Naturally, different types of broadcasting have different radar functions and commercial advantages.

2.3.1. FM Radio Broadcast:

The invention of FM radio is a very high frequency (VHF) invention of the 1930s to provide high quality sound to listeners. In most European countries, DAB systems are beginning to replace FM broadcasts, but are still used in developing countries and will be used in the near future. The FM broadcast band is between 87.5 and 108 MHz, with each adjacent channel separated by 200 kHz and a frequency deviation of -75 kHz, resulting in a maximum bandwidth of 150 kHz for the FM channel [21].

The total bandwidth of the FM channel largely depends on the transmitted message signal, meaning a silent speech results in less total bandwidth than rock music. This large change changes the overall resolution of the FM-based PR system from 1.5 km to 15 km [14, 16, 17, 22].

2.3.2. Digital Audio and Video Broadcast:

The Digital Audio Broadcasting System (DAB) was introduced in 1995 by the Norwegian Broadcasting Organization. DAB, Digital Video Broadcasting (DVB) and many other digital modulation-based systems use the Frequency Vertical Division

(OFDM) to transmit digital data. DAB offers more radio channels due to lower sound speed, better sound quality and more fade and multi-sound resistance. In DAB standards, DAB bandwidth signal bandwidth is fitted to 1.536 MHz DAB-based PR systems, due to the pulse-shaped output in the filter in accordance with high bandwidth and noise-like spectra, the product the lateral OFDM design provides better resolution. However, compared to FM radio, the total DAB signal output power is substantially low to 1 to 10 kW, thus making it less recognizable in comparison to FM-based PR systems [22].

2.3.3. GSM Telephone Signals:

GSM base stations offer the lowest total detection rate compared to FM, DAB and DVB radio. The main reason for this is the low transmission power. However, GSM base stations are located in a tight network, so it may be useful to monitor several base stations efficiently when passing through the coverage area.

For this reason, GSM-based PR systems can be useful for monitoring vehicle traffic. However, GSM signals are not useful in the aircraft detection scenario [17].

2.4. Performance Summary:

Table 1 summarizes the performance of DVB, GSM, FM radio and DAB telephone signals. The FM radio has the highest transmit power and it is reported that FM radio is able on detecting the targets at 300 km bistatic range.

Table 1: Performance of main opportunity illuminators [20]

Transmission	Frequency	Modulation, bandwidth	Pt Gt	Power density
HF broadcast	10–30 MHz	DSB AM, 9 kHz	50 MW	-67 to-53 dBW m^{-2} at r1 = 1000 km
VHF FM (analogue)	~100MHz	FM, 50 kHz	250 kW	-57 dBW m^{-2} at r1 = 100 km
UHF TV (analogue)	~550MHz	vestigial-sideband AM (vision); FM (sound), 5.5 MHz	1 MW	-51 dBW m^{-2} at r1 = 1000 km
Digital audio broadcast	~220MHz	digital, OFDM 220 kHz	10 kW	-71 dBW m^{-2} at r1 = 100 km
Digital TV	~750MHz	digital, 6 MHz	8kW	-72 dBW m^{-2} at r1 = 100 km
Cellphone base station (GSM)	900MHz, 1.8 GHz	GMSK, FDM/TDMA/FDD 200 kHz	100 kW	-81 dBW m^{-2} at r1 = 10 km
Cellphone base station (3G)	2 GHz	CDMA 5 MHz	100W	-81 dBW m^{-2} at r1 = 10 km

Since DVB and DAB enjoy by the same transmit power, they have similar detection range. Nevertheless, DVB offers higher bandwidth and this issue is useful in the range resolution sense. DAB transmitter is more popular than DVB where DAB reduces the entire freedom and coverage of the system. GSM telephone signals enjoys by the best urban coverage but with lowest transmit power. The use of many GSM base stations allows the capability of tracking a target through many base stations. Nevertheless, the efficiency of GSM base stations of air traffic detection is limited by very low detection range [20]. High transmit power is considered one of the main advantages of FM radio. Although transmitters of DVB, DAB and FM consist similar omnidirectional, antennas and install on high masts, comparatively if we compare the transmit power of FM radio with digital systems, we can see that the power of FM radio is better selection in long range detection. Low range resolution of FM based PR system is considered one of its main shortcomings because of the low baseband signal bandwidth. In our study, broadcasts of FM radio are considered as a chance illuminator because of the low range resolution and longer detection range.

2.5. Illuminators of Opportunity:

Broadcast signals including Digital Audio Broadcast (DAB), FM radio and analogue television enjoy by excellent coverage and high transmitter powers. Since these characteristics, they are considered nice opportunity illuminators of PCL applications [29]. At first sight, transmitters of analogue television look to a clear selection due to their large bandwidth and very high equivalent radiated powers. However, the 64 microliter line spin time produces high lateral lobes in the uncertainty function, which results in a range uncertainty of 19.2 km [16]. Using only a very small amount of analogue TV spectrum is very useful, as 15 kHz separation of line return is not useful because any line return power is low compared to all power. Howland showed that Doppler and ball bearing information could be removed from the analogue video-signal carrier to track the aircraft up to 150 kilometers from the transmitter and 260 kilometers from the receiver [21]. Howland received the received bandwidth in a few kHz, just a few of the analogue 5.5 MHz television spectrum.

Thus, this method is called as narrow band processing. Since Doppler measurement include low content of information, the system should detect the target's Doppler history for extended period for locating the target entirely. Moreover, the location relies on the preliminary location evaluate of the target [30]. The suitability of GSM communication signals for passive radar applications has been investigated. Through a conducted system, it is discovered that GSM based PLC can efficiently perceive and track the ground-moving targets including humans and vehicles.

Nevertheless, signals of GSM are not suitable on detecting the air-borne targets because of the low radiated power [31]. In addition, digital broadcast signals including Digital Audio Broadcast (DAB), Digital Video Broadcast (DVB) and Digital Television (DTV) are foundations in no cooperative illumination. The amount of coverage in DAB is about 9 kilometer (where the SNR drops to 15dB) [17]. Poullin mentioned that the range of accomplished resolution in DAB is 200 m [22].

Cherniakov and Saini clarify that the elements of determination in the DTV-T transmission present many unwanted peaks in the function of ambiguity which they try to accomplish with many algorithms [32]. Saini and Cherniakov concluded that DTV-T is considered a good candidate in applications of passive radar. The Global Navigation Satellite System (GNSS) is utilized as the no cooperative illuminator [33]. The receiver of radar in the positioned stationary on the ground and plane are the two basic configuration that must be taken into consideration.

The system attempts to discover the objects on the ground. Another research on PLC has been conducted by the use of no cooperative satellite such as Global star or GPS as illuminator is that emphases on the 2-D resolving aptitude inside the ground plane[34].

Unlike narrow band processing, bandwidth processing uses almost the entire spectrum of the waveform of abuse in the receiver. The FM broadcast waveform is separate from a distinct station with a bandwidth of 100 kHz, which corresponds to a theoretical resolution of 1500 meters. However, Griffiths showed that effective bandwidth is not 100 kHz with the bandwidth content, but can reach an average of 24.4 kHz for fast tempo jazz music that offers maximum bandwidth [17]. The uncertainty diagram shows the average lobe-to-peak ratio of 30dB - 40dB in the Doppler and the lobe-to-peak ratio of 30dB - 50dB in the Doppler to determine the FM radio waveform performance in PCL. Through practical Doppler resolution, these present that FM based PCL has poor range resolution. Howland reported that the operational radar system from a single FM radio station, as an opportunity illuminator, tracks and monitors targets over distances of 150 kilometers from the receiver [34]. It has also been clarified that the FM-based PLC can be used to identify the Pisces electronic auroral region.

CHAPTER 3

METHODOLOGY

3.1. Bistatic Geometry:

From the term bistatic refers, the geometry of bistatic' is depending on a double transmitters and receivers with diverse locations. Composed with a target and its velocity V as clarified in figure 5.

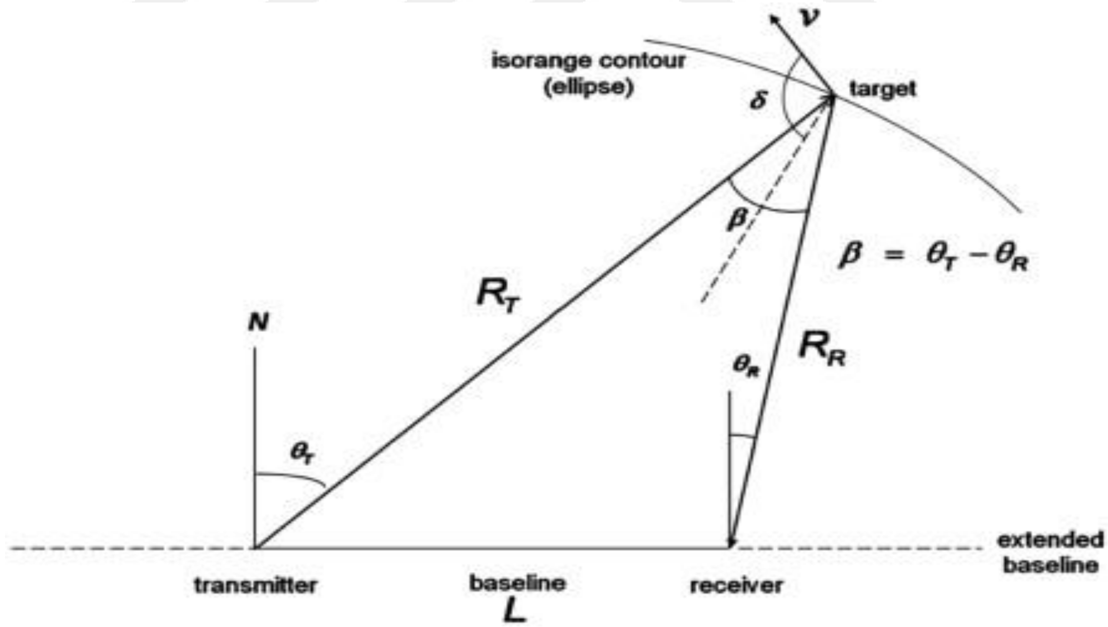


Figure 5. Explanation of bistatic radar geometry.

Bistatic geometry defines the factors that define the performance of the buzzer radar in a fixed-range ellipse, including transmitter (Tx), receiver (Rx), and target at velocity V. The Bistatic Triangle is located at a fixed distance from the oval plane. The distance L is between the transmitter and the receiver, this is called the base distance. The angles θ_R and θ_T are the angles of the receiver and the transmitter, respectively. The velocity vector presented on the desired plane has the magnitude V and the angle property is α . Bistatic angle is $\beta = \theta_T - \theta_R$. All the additional parameters is illustrated in table 2.

Table 2**:** Parameters used in bistatic geometry

Symbol	Meaning
β	Bistatic angle
α	Velocity aspect angle
R_1	Target-receiver distance
R_2	Target-transmitter distance
L	Baseline range
V	Target velocity
θ_T	Transmitter looking angle
θ_R	Receiver looking angle

The bistatic geometry consists a significant basic measurement including Doppler frequency and bistatic range. Bistatic range is defined as a measurement of target locations in the constant range ellipse. **Figure** shows this ellipse that is centered on the transmitter and receiver. R_1/R_2 represent the distance between the target and the receiver/transmitter. L represents the distance. Therefore, it is possible to calculate the location of target in the range ellipse as R_1+R_2 −L. Since the user specifies the positions of transmitter and receiver antennas, L, R_1 and R_2 can be calculated as follows:

$$L = \sqrt{|Tx_x - Rx_x|^2 + |Tx_y - Rx_y|^2} \quad (3.1)$$

$$R_1 = \sqrt{|Tx_x - T\alpha_x|^2 + |Tx_y - T\alpha_y|^2} \quad (3.2)$$

$$R_2 = \sqrt{|Rx_x - T\alpha_x|^2 + |Rx_y - T\alpha_y|^2} \quad (3.3)$$

Where Tx_x and Tx_y represent the transmitter antenna positions, a Rx_x and Rx_y represent receiver antenna positions, $T\alpha_x$and $T\alpha_y$ represent target positions respectively in Cartesian coordinate system. By looking to this geometry, another measurement is Doppler frequency that measures the target velocity. The Doppler frequency which reflected by the target is computed by the following equation:

$$fB = \frac{1}{\lambda}\left[\frac{d}{d_t}(R_1 + R_2)\right] \quad (3.4)$$

Where λ represents the signal wavelength. This equation presents that Doppler frequency is proportional to the ratio of change of the bistatic range. Later, derivatives of $R_1$and R_2 , $\frac{dR_1}{dt}$ and $\frac{dR_2}{dt}$, can be found by projecting the velocity vector onto R1 and R_2. Thus, we can obtain the Doppler frequency fB as follows:

$$fB = \frac{2v}{\lambda}\cos(a)\cos(\frac{\beta}{2}) \quad (3.5)$$

Using Equation 2.3, we can define the term Vϐ as follows:

$$Vϐ = V\ \cos(a)\cos\left(\frac{\beta}{2}\right) \quad (3.6)$$

which is called the projected target velocity. Finally, Doppler frequency can be represented by:

$$fB = 2Vϐ/\ \lambda \quad (3.7)$$

RCS is a function of target material, shape, size, and type of dynamics. In addition, it can be said that the location and location in question depend on it [17]. In addition, this parameter is included in the passive radar equation as described in the next section and is proportional to the received power. RCS can be considered as a feature of the target mirror feature. For example, a stealth aircraft, due to its smooth surfaces, provides low RCS and directs the signal in different directions from the source. As opposite to this, passenger airplanes a high RCS due to the bare material etc. equation of Bistatic radar cross section, σ_B is shown as follows:

$$\sigma_B = 4\frac{\pi A^2}{\lambda^2} \tag{3.8}$$

Where A represents the physical area of cross-sectional. The following equation shows the angular width of the scattered signal vertical or horizontal plane

$$\theta B = \frac{\lambda}{d'} \tag{3.9}$$

Where d' represents the target linear dimension. A range resolution is considered other significant parameter in PBR systems. A target resolution of the bistatic radar is its ability of separating two targets that are very close to each other in a range, Radar range resolution, ΔR can be approximately extracted as follows:

$$\Delta R = \frac{C}{2B} \tag{3.10}$$

Where B represents the signal bandwidth and c represents the speed of the light (3*10^8). This equation displays that if we increase the bandwidth of the reference signal, we may have better range resolution. As clarified in **Table**, a distinctive FM radio inhabits a bandwidth of about B = 100 kHz. Therefore, in our system, the radar range resolution will be equal to ΔR = 1.5 km.

3.2. Linear Frequency Modulation

Frequency modulation (FM) is a modulation technique in which the carrier frequency is changed by the signal to be transmitted. The frequency modulation allows compared to the amplitude modulation a higher dynamic range of the information signal. Furthermore, it is less susceptible to interference. The method was mathematically examined by John Renshaw Carson as early as 1922 [35] . and first put into practice by Edwin Howard Armstrong. The frequency modulation is an angular modulation and related to the phase modulation. Both have an influence on the phase angle $\emptyset_T$.

It should not be confused with the channel coding called digital frequency modulation or Miller code, which is used, for example, in magnetic data carriers for data recording.

Linear frequency modulation (LFM) pulse compression radar simulation, pulse compression radar while increasing the role of the radar range and range resolution. This system uses the width pulse emission in order to improve the average power emitted, to ensure a sufficiently large effective distance accepted when the corresponding pulse compression algorithm to obtain a narrower pulse, in order to improve the distance resolution, the better solution of the radar range and range resolution the contradiction between the rate.

Pulse compression is one of the signal processing techniques used to reduce the peak power of radar pulses using long and specially modulated pulses to maintain amplitude resolution over a longer pulse. Longer pulses are used on the transmitter side, and the output of the radar receiver matching filter output is used on short pulse signals generated by the SNR during pulse compression. This pulse compression is widely used in radars due to its high transmission energy and high resolution. Impact compression techniques provide longer range benefits with the ability to detect longer distances and better resolution of short stroke amplitudes. **Figure 6** shows two pulses with different peak energy and width. The pulse can be modulated in various ways such as linear frequency modulation signals or nonlinear frequency modulation signals and discrete phase code modulation.

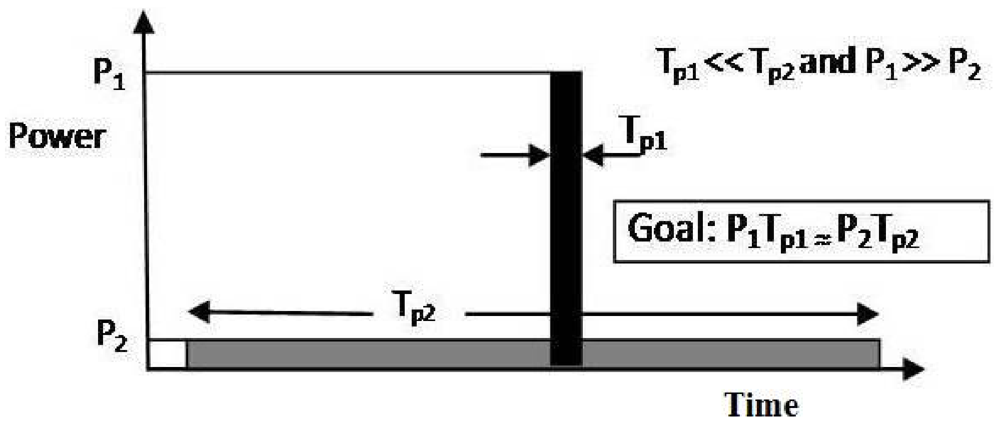


Figure 6. Transmission and receiving signal

Pulse bandwidth is considered for distance resolution, pulse duration is not considered.

$$P = \frac{ct}{2} = \frac{C}{2B} \tag{3.11}$$

Where ρ = resolution range; τ = pulse duration; c = light speed; b = signal bandwidth.

The pulse density (PCR) is as follows:

$$PCR = \frac{WIDTH\ OF\ THE\ PULSE\ BEFORE\ COMPRESSION}{WIDTH\ OF\ THE\ PULSE\ AFTER\ COMPRESSION} \tag{3.12}$$

The block diagram of the impact compression radar system is shown in Figure 7. In the pulse compression method, a short pulse is converted to a long pulse with low peak power tuned to the frequency or phase before transmission. The use of long pulses with limited peak power shows higher amplitude resolution and concentrates on the received signal of all energy in the compressed pulse. The same antenna is used to transmit and receive a transceiver with switching unit. The pulse compression filter corresponds to the transmitted and received waveform spectrum. In this filter, the received signal and the transmitted signal are subjected to correlation processing. The output of the filter receives the signal according to the signal that is transmitted similar to the signal, while the rest of the signal is eliminated.

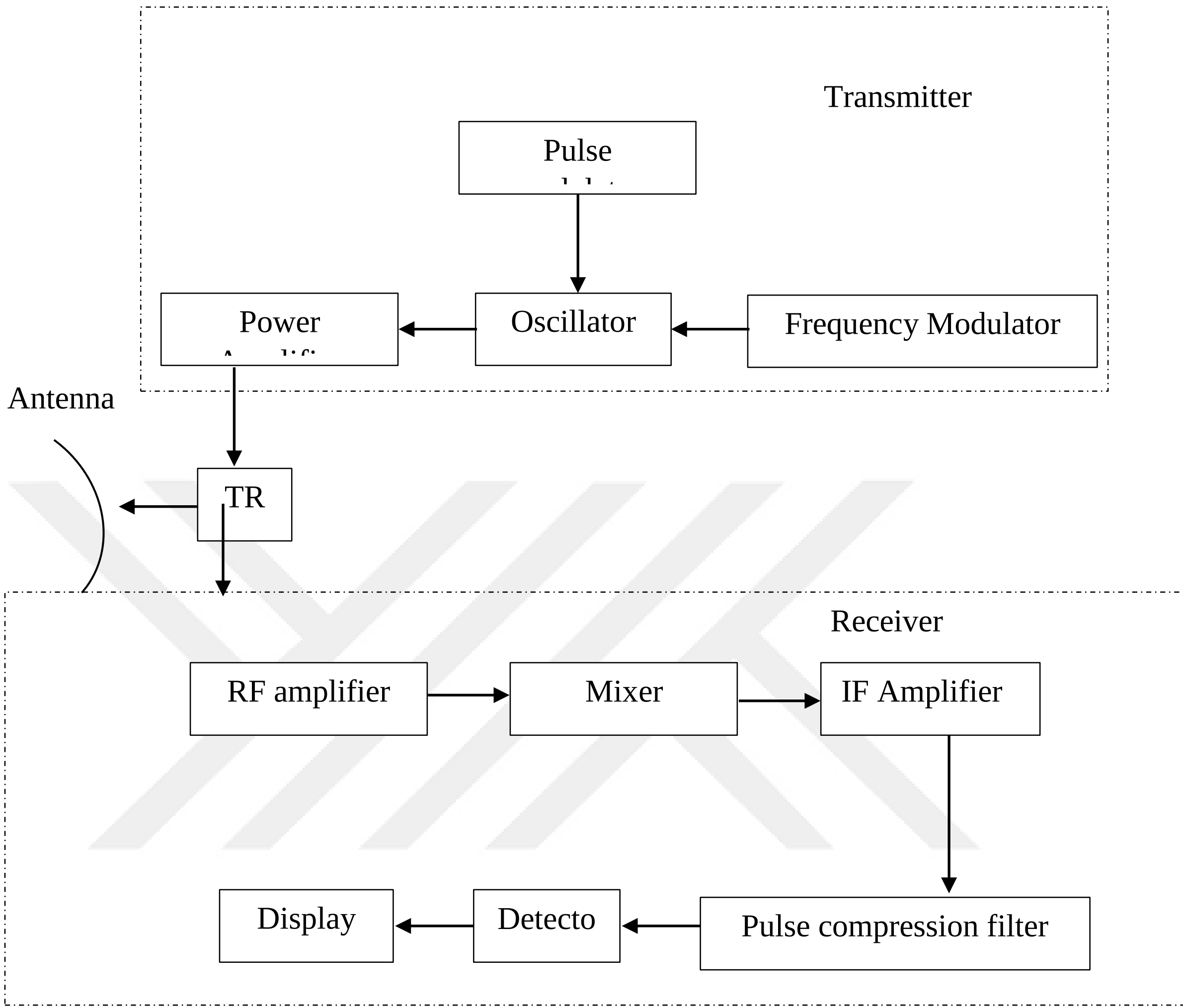


Figure 7. **Pulse Compression Radar**

In radar, the pulse compression algorithm basically consists of two steps. The first generation of filtered pair generation is followed by linear modulation frequency waveforms. In order to generate the LFM waveform, phase-phase and four-phase bandwidth signals are first generated. Then, joining these two waveforms based on the mathematical equation of the chirp signal takes the LFM signal. Here the correlation method is adopted for the pair filter. In filter matching, the LFM signal and its delay version are matched to obtain the results. The flowchart **(Figure 8)** that describes the entire study is shown below.

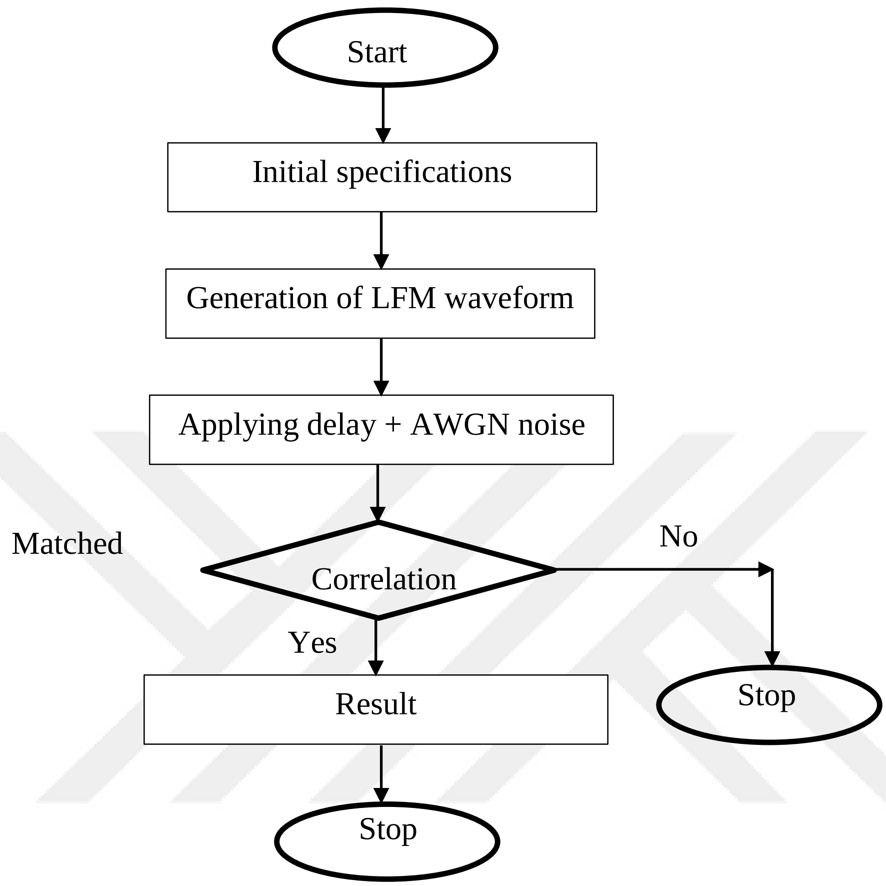


Figure 8. System flow chart

The signal transmitted from the radar is amplified after modulation to increase the amplitude detection and resolution. The signal reflected from the radar not only indicates the presence of the target, but also compares the received echo signal to the transmitted signal to extract different information about the target. The block diagram of the system is shown in figure 9:

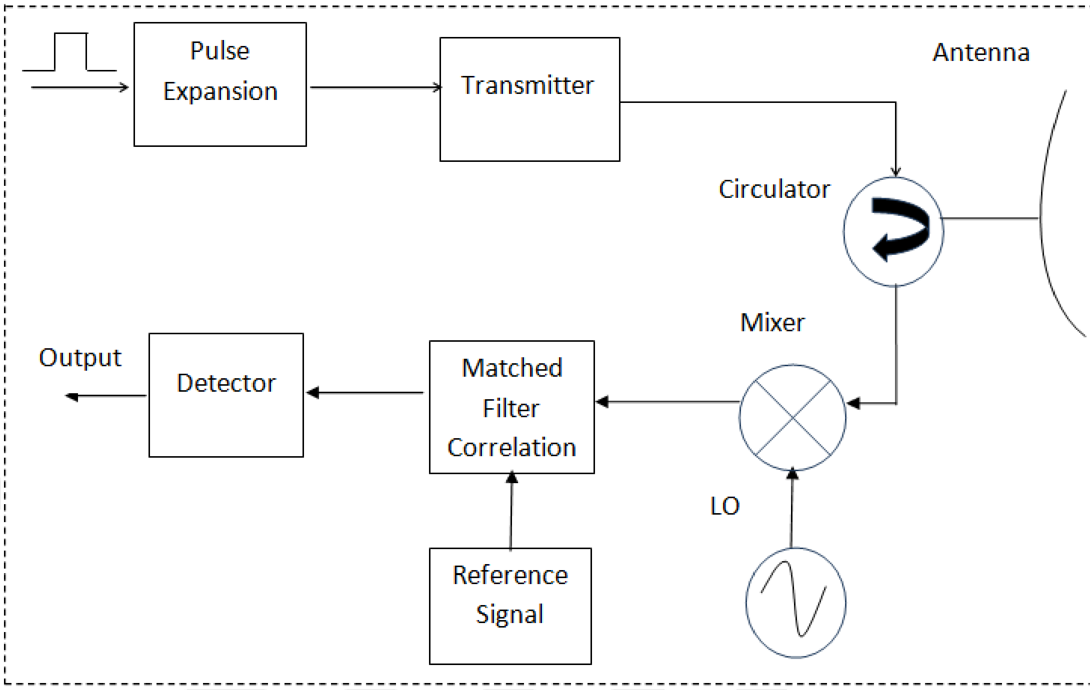


Figure 9. Block system diagram

A correlation operation at the address indicates the existence of an echo received at the radar receiver by compressing the received signal over time using the time correlation properties. Performs filter correlation. One of the popular DSP methods is the correlation method for using pulse-compatible filters. This can be done by multiplying the frequency responses in the frequency response. The signal associated with the two time zones is converted to frequency domain using Fourier transforms. Some signals converted to matching patterns have the same frequency domain signatures. When two frequency field vectors are multiplied, the output of the match will be independent of the time synchronization between the two signals. The matching filter always responds to the reflected energy regardless of the received radar signals. When converting a product vector into a time domain, each target produces latency and amplitude, respectively, with the desired size and distance. The FFT converts the time domain to the signal frequency domain and performs the inverse FFT (IFFT). These two algorithms are key blocks in the impact compression system. **Figure 10** shows the matching filter kernel.

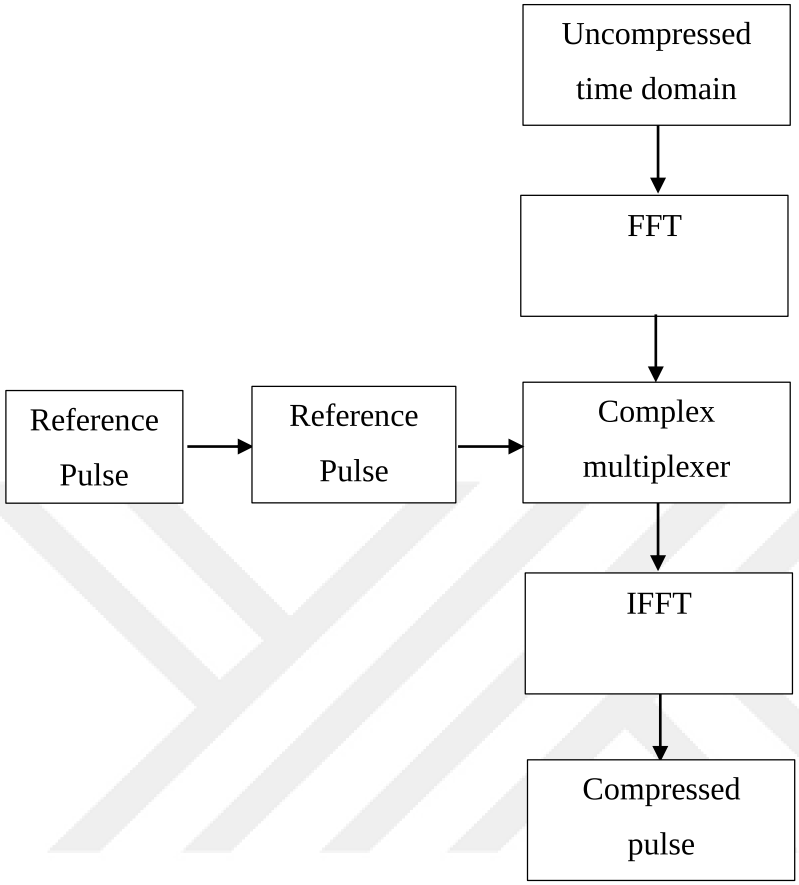


Figure 10. Matched Filtering Core

Linear Frequency Modulation (LFM) radar pulse compression signal can simultaneously improve the amplitude and resolution of the radar amplitude. The system uses wide pulse transmission to increase the average transmission power and create enough working distance. When receiving this, a corresponding pulse compression algorithm is used to improve the amplitude resolution and to achieve narrow pulses to better solve the radar working distance and amplitude resolution between the ratios.

The most common modulation signal of a pulse compression radar is the linear frequency modulation signal. When receiving, a matched filter is used to compress the pulse.

The mathematical expression of the LFM signal (also known as the Chirp signal) is:

$$s(t) = rect(\frac{t}{T})e^{j2\pi(f_c t + \frac{K}{2}t^2)} \tag{3.13}$$

Where f_c is the carrier frequency and $rect(\frac{t}{T})$ is a rectangular signal.

$$rect(\frac{t}{T}) = \begin{cases} 1 \quad , & \left|\frac{t}{T}\right| \leq 1 \\ 0 \quad , & elsewise \end{cases} \tag{3.14}$$

$K = \frac{B}{T}$, which is the frequency modulation slope, so the instantaneous frequency of the signal is $f_c + Kt \ \ (-\frac{T}{2} \leq t \leq \frac{T}{2})$, as shown in Figure 11.

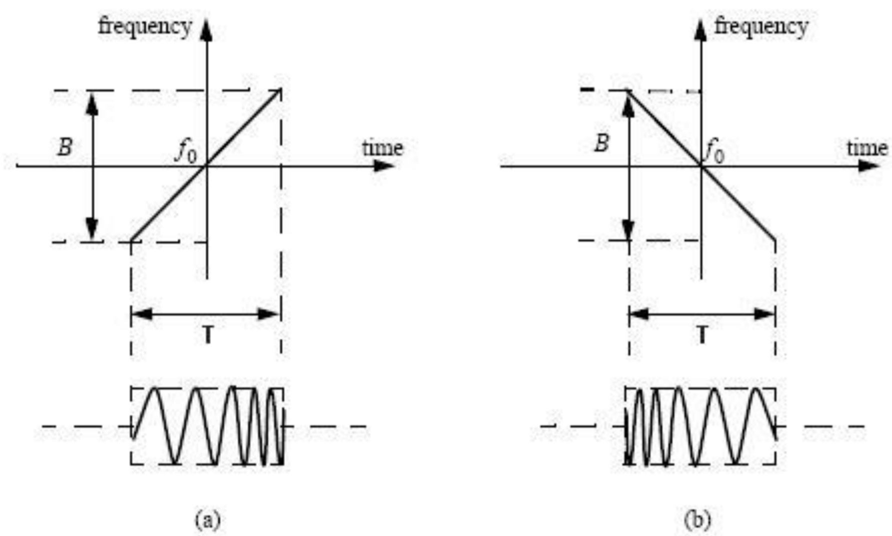


Figure 11: Typical chirp signals,

Rewrite the up-chirp signal in Equation 2.1 as:

$$s(t) = S(t)e^{j2\pi f_c t} \tag{3.15}$$

Where

$$S(t) = rect(\frac{t}{T})e^{j\pi K t^2} \tag{3.16}$$

Is the complex envelope of the signal s(t). Due to the properties of the Fourier transform, S (t) and s (t) have the same amplitude-frequency characteristics, but the center frequency is different. Therefore, only S (t) needs to be considered in MATLAB simulation.

The path followed in the receiver section is followed by the analysis of the result obtained from the graphical model. Signal strength decreases with increasing amplitude. The reduction in range corresponds to this. **Figure 12** shows the transmitted LFM signal.

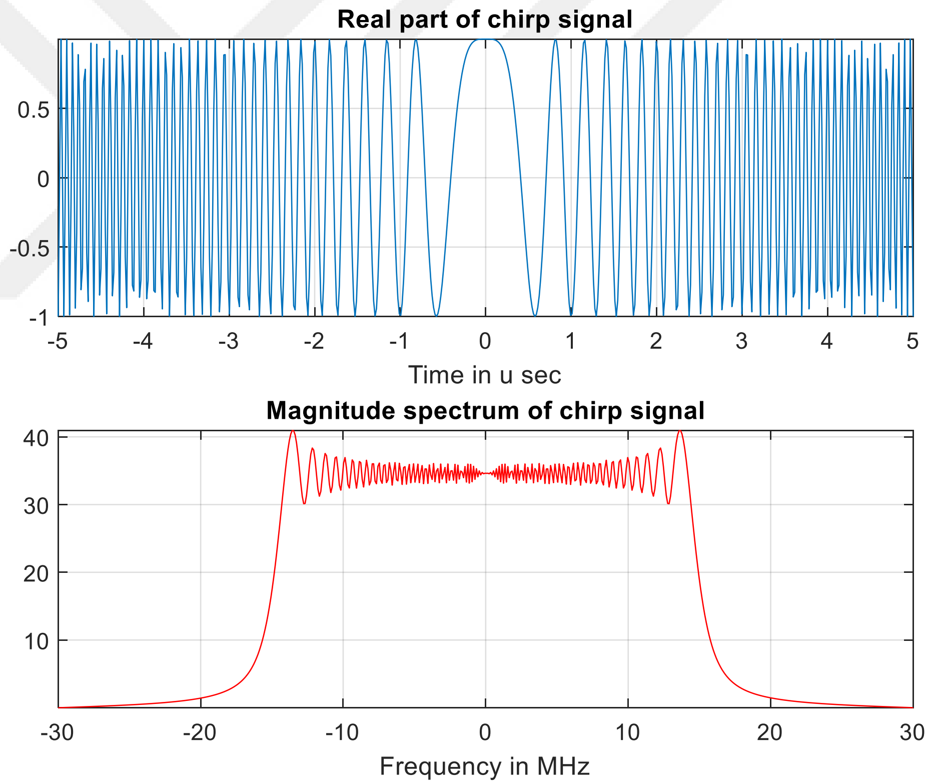


Figure 12. (a) real part of chirp signal that transmitted, (b) magnitude spectrum of chirp signal that transmitted

3.3. Matched filtering of LFM pulses

The time domain impulse response of the matched filter of the signal s (t) is:

The time-domain impulse response of the signal's matched filter is:

$$h(t) = s^*(t_0 - t) \tag{3.17}$$

It is the additional delay that makes the filter physically achievable. In theoretical analysis, we can make = 0 and rewrite formula 3.3,

$$h(t) = s^*(-t) \tag{3.18}$$

Substituting formula 3.1 into formula 3.4 gives:

$$h(t) = rect(\frac{t}{T})e^{-j\pi Kt^2} \times e^{j2\pi f_c t} \tag{3.19}$$

The Matched filtering of LFM signals is shown in figure 13.

Figure 13: Matched filtering of LFM signals

$$s_o(t) = s(t) * h(t) \tag{3.20}$$

$$= \int_{-\infty}^{\infty} s(u)h(t-u)du \ = \int_{-\infty}^{\infty} h(u)s(t-u)du$$

$$= \int_{-\infty}^{\infty} e^{-j\pi Ku^2} rect(\frac{u}{T})e^{j2\pi f_c u} \times e^{j\pi K(t-u)^2} rect(\frac{t-u}{T})e^{j2\pi f_c(t-u)}du$$

When 0≤t≤T,

$$s_0(t) = \int_{t-\frac{T}{2}}^{\frac{T}{2}} e^{j\pi Kt^2}\, e^{-j2\pi Ktu}du$$

$$= e^{j\pi K t^2} \frac{e^{-j2\pi K t u}}{-j2\pi K t}\Bigg|_{t-\frac{T}{2}}^{\frac{T}{2}} \times e^{j2\pi f_c t}$$

$$= \frac{\sin \pi K(T-t)t}{\pi K t} e^{j2\pi f_c t} \tag{3.21}$$

When -T≤t≤0,

$$s_0(t) = \int_{-\frac{T}{2}}^{t+\frac{T}{2}} e^{j\pi K t^2}\, e^{-j2\pi K t u} du$$

$$= e^{j\pi K t^2} \frac{e^{-j2\pi K t u}}{-j2\pi K t}\Bigg|_{-\frac{T}{2}}^{t+\frac{T}{2}} \times e^{j2\pi f_c t}$$

$$= \frac{\sin \pi K(T+t)t}{\pi K t} e^{j2\pi f_c t} \tag{3.22}$$

Combine 3.7 and 3.8

$$s_0(t) = T\frac{\sin \pi K T(1-\frac{|t|}{T})t}{\pi K T t} rect(\frac{t}{2T}) e^{j2\pi f_c t} \tag{3.23}$$

The 3.9 formula is the output of the LFM pulse signal through a matched filter, which is a signal with a fixed carrier frequency fc. When t≤T, the envelope is approximately a sinc function.

$$S_0(t) = TSa(\pi K T t) rect(\frac{t}{2T}) = TSa(\pi B t) rect(\frac{t}{2T}) \tag{3.24}$$

The Matched filtered output signal is shown in figure 14.

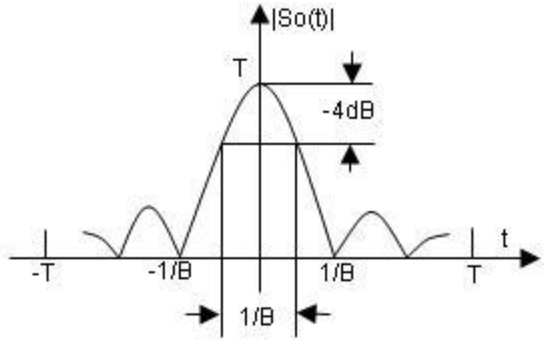


Figure 14: Matched filtered output signal

As shown in Figure 14, when $\pi Bt = \pm\pi$, $t = \pm\frac{1}{B}$ is its first zero coordinate; when $\pi Bt = \pm\frac{\pi}{2}$, $t = \pm\frac{1}{2B}$. By convention, the pulse width at this time is Defined as the compression pulse width.

$$\tau = \frac{1}{2B} \times 2 = \frac{1}{B} \quad (3.25)$$

The ratio of the pulse width T before compression and the pulse width τ after compression of the LFM signal is usually called the compression ratio D,

$$D = \frac{T}{\tau} = TB \quad (3.26)$$

Equation 3.12 shows that the compression ratio is the time-bandwidth product of the LFM signal.

From the formulas 3.1, 3.4, and 3.9, s (t), h (t), and so (t) are all complex signal forms.

The output of matched filter for stationary target is shown in **figure 15**.

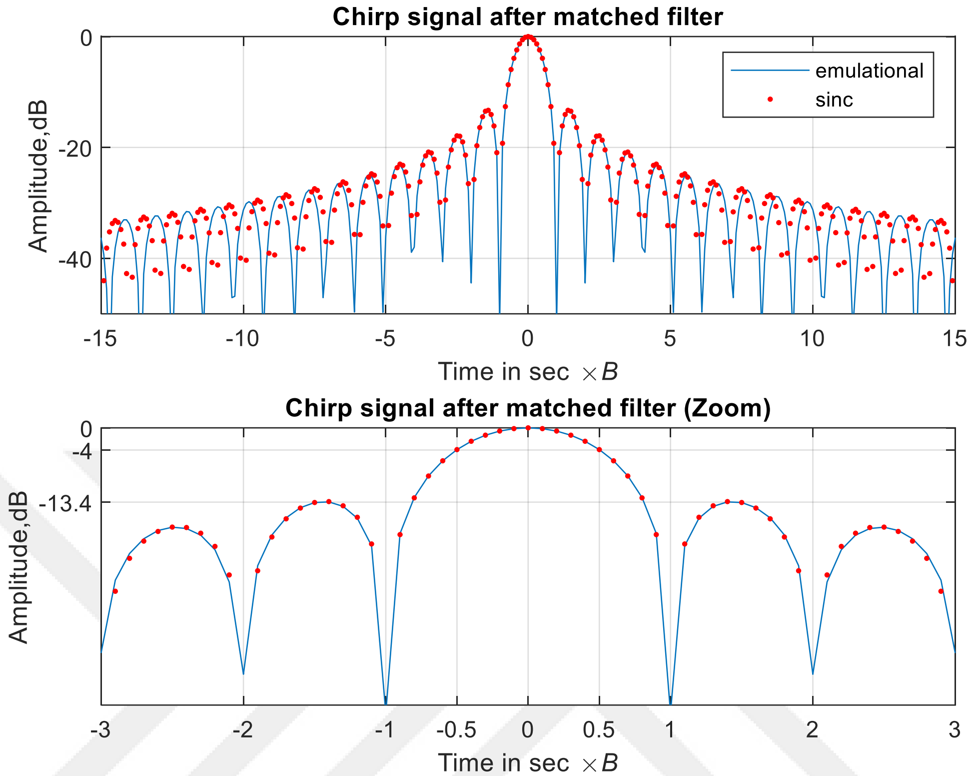


Figure 15. (a) chirp signal after matched filter, (b) chirp signal after matched filter (Zoom view)

CHAPTER 4

SIMULATION RESULT

4.1. Architectures

The experimental results are given below in the graphical model. Practical applications of pulse compression radar matched filter system. In this thesis, the pulse compression filter is used for pulse compression. For testing of the method, the chirp signal is used. The specification of this signal is illustrated in table 3.

Table 3. The parameter is selected for Chirp signal

Parameter	**Value**	**unit**
Pulse duration	10	Micro second
Chirp frequency modulation bandwidth	30	MHz
Chirp slope	3e12	-
Sampling frequency	1.66e-8	-

The Chirp signal is shown in **figure 16**. in this signal the pulse duration is selected 10 μs. For the chirp frequency modulation bandwidth 30 MHz is selected. Also, the sampling frequency was 1.66e-8 Hz. The sample size for this signal is 1500.

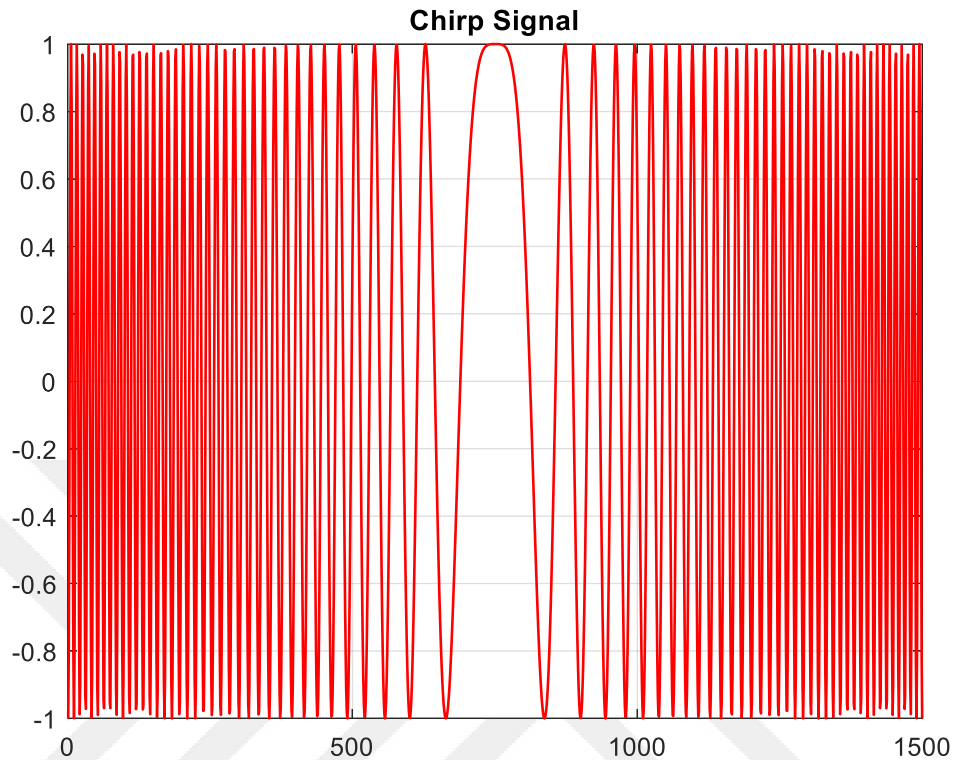


Figure 16. chirp signal

This signal is in time domain. For processing in other step, we need to transform this signal to frequency domain after taking the fast Fourier transform the result is shown in **figure 17**.

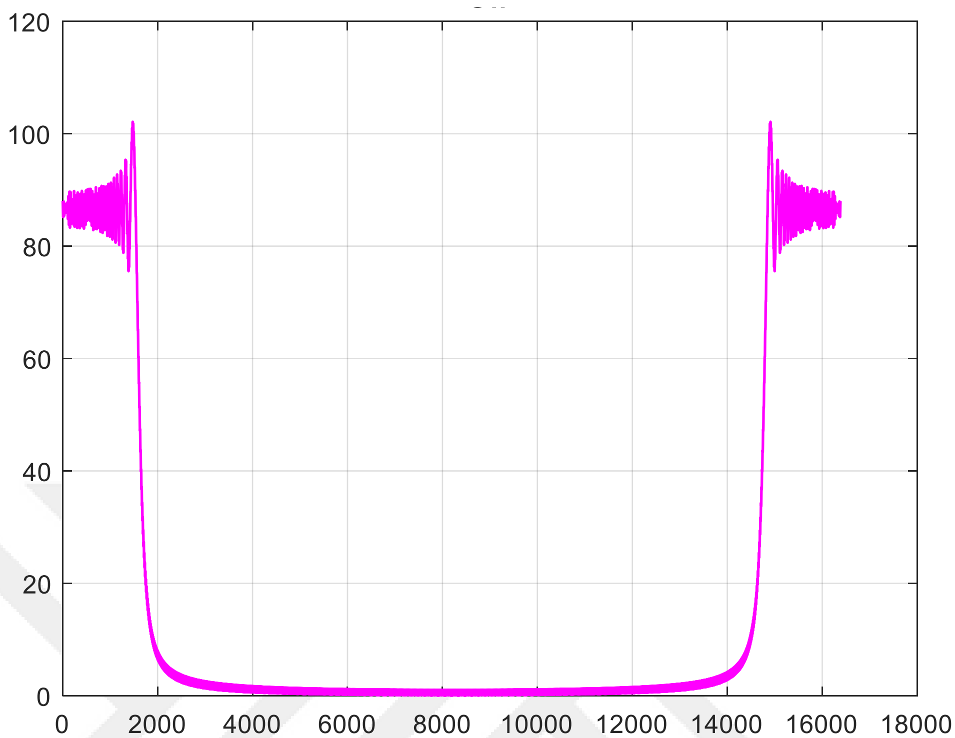


Figure 17. Fast Fourier transformation of chirp signal

For the testing the radar echo without compression the specified parameters are used. These parameters are shown in table 4.

Table 4. Parameters for radar echo

Parameter	value
pulse duration	10e-6 (10μs)
chirp frequency modulation bandwidth	30e6 (30MHz)
range bin	Rmin = 10000;Rmax = 15000;
position of ideal point targets	[10500,11000,12000,12008,13000,13002]
radar cross section	[1 1 1 1 1 1]
propagation speed	3e8
chirp slope	3e12
receive window in meter	5000
receive window in second	3.33e-5
sampling frequency and sampling spacing	150e6
receive window in number	5000

The radar echo from point targets is shown in **figure 18**. In this result for the pulse duration 10μs is selected. The chirp frequency modulation bandwidth is selected 30MHz. For propagation speed we selected 3e8 and for receive window in meter 5000 is selected. For sampling frequency and sampling spacing 150e6 is selected.

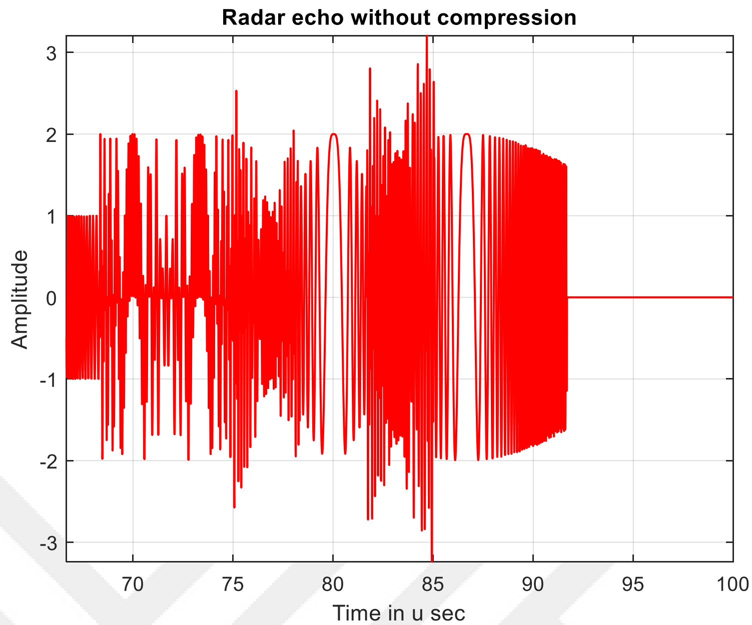


Figure 18. Radar echo without compression

The result for radar echo after compression is shown in **figure 19.**

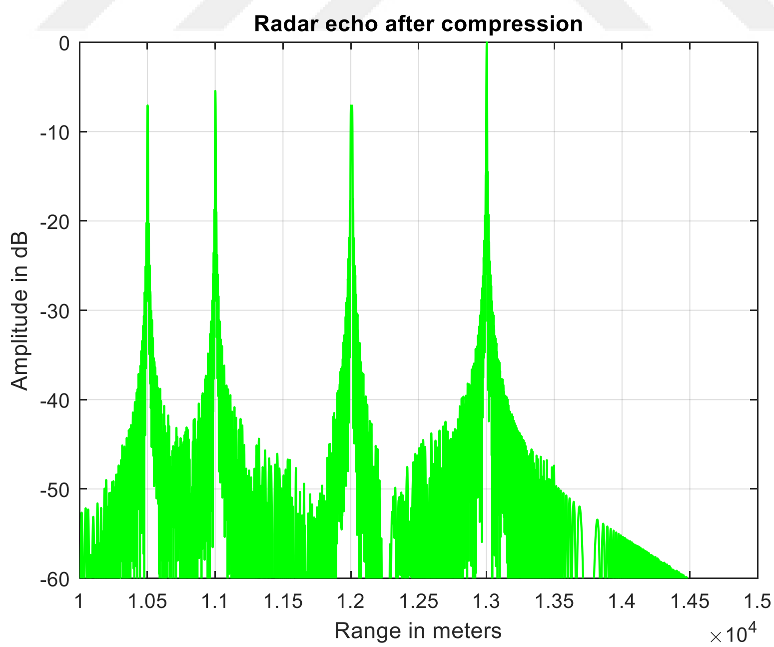


Figure 19. radar echo after compression

The result for signal after pulse compression is shown in **figure 20**.

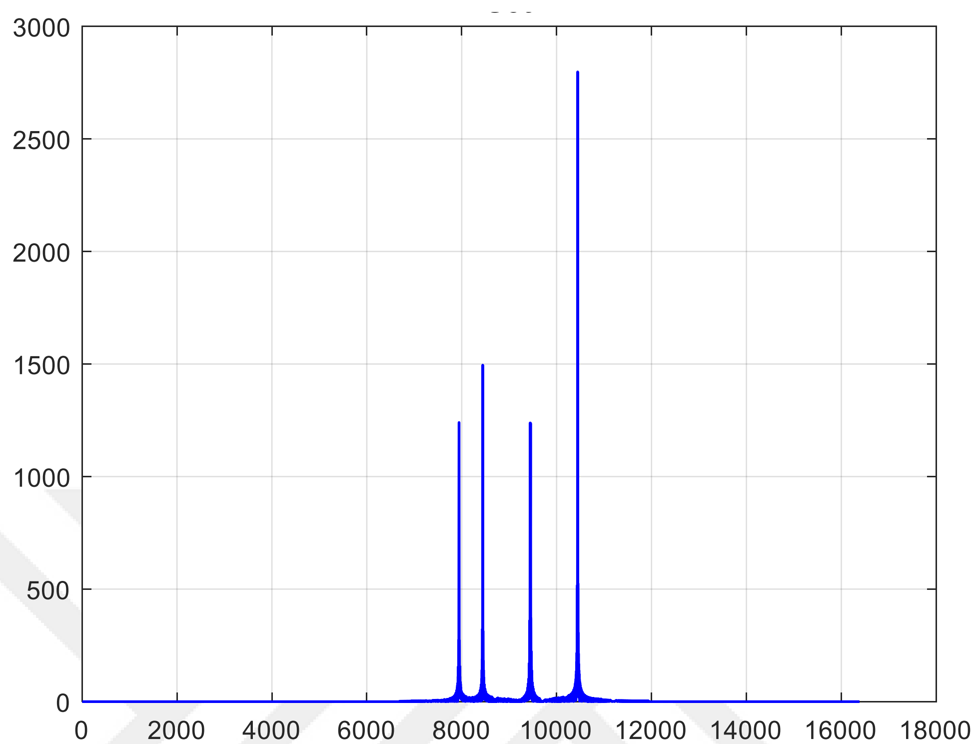


Figure 20. signal after pulse compression

The result of fast Fourier transform for radar echo is shown in **figure 21**.

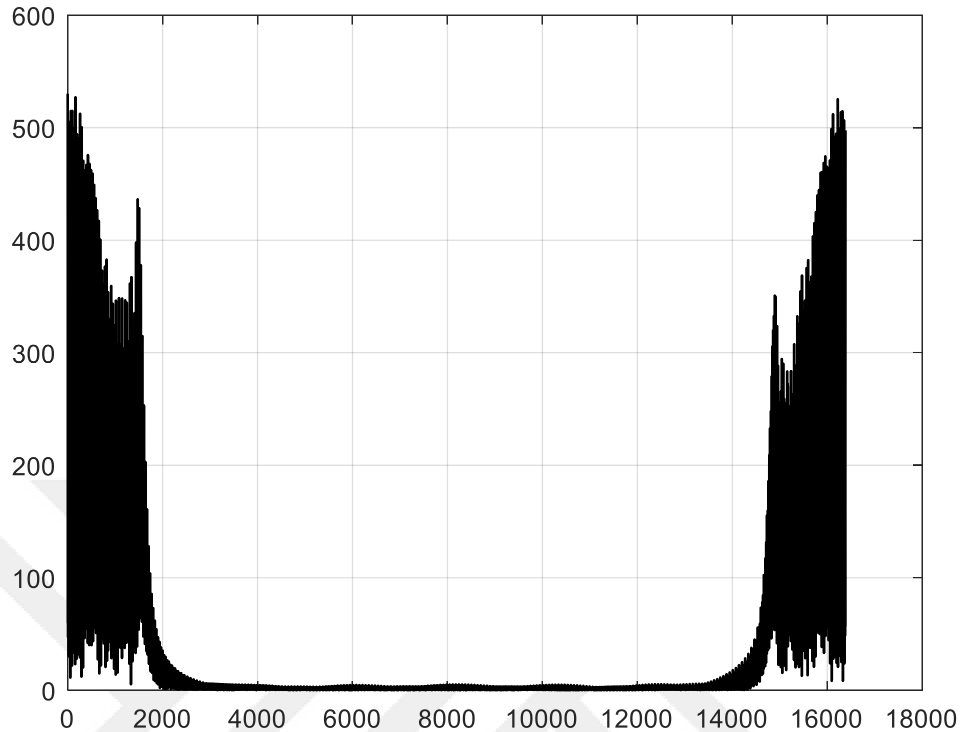


Figure 21. Fast Fourier Transform of radar echo

For other test we selected the pulse function shape. This shape is shown in **figure 22**

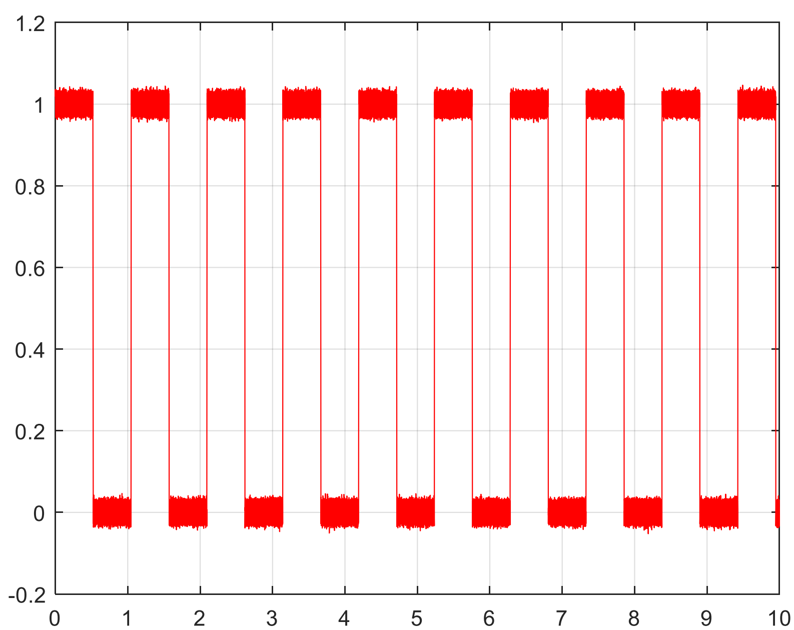


Figure 22. pulse shape signal

The frequency domain analysis of division factor is shown in **figure 23**.

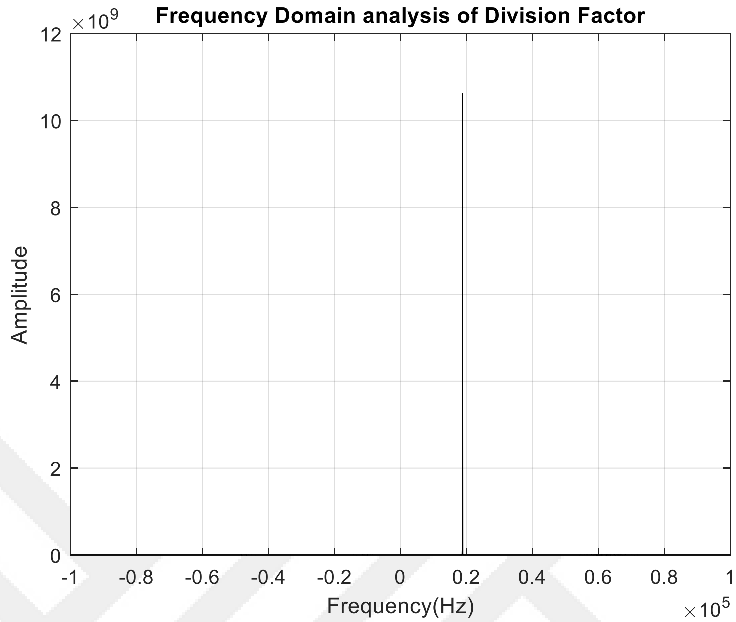


Figure 23. Frequency domain analysis of division factor

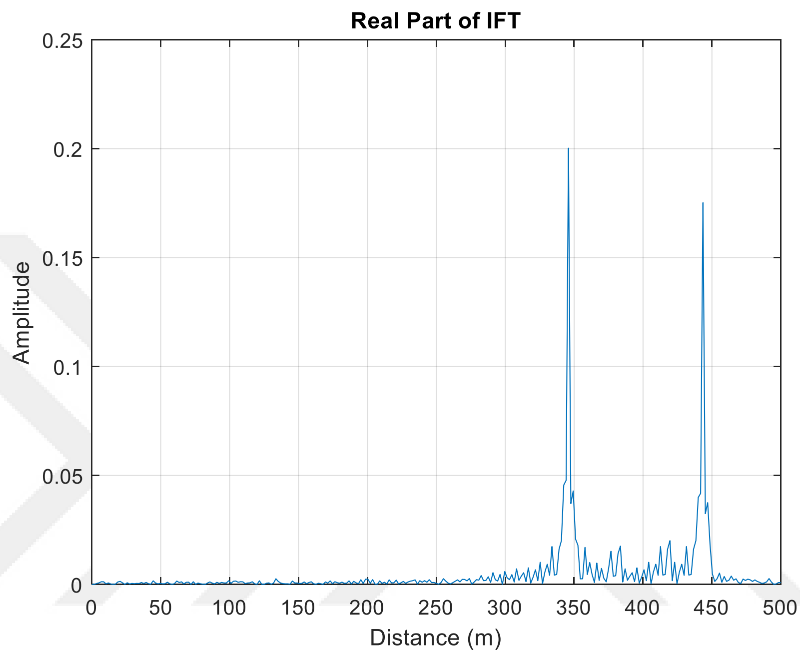
Using the detection algorithm described in Chapter 2, the near-target amplitude resolution is simulated for different FM channels. The carrier frequency of the FM signal is assumed to be an 89 kHz channel. The maximum deviation (.) and sampling frequency are 75 and 200 kHz, respectively.

Simulations were performed to obtain the output of the detection algorithm for two purposes of 48.07, 81.85 and 97.6 m distance. The real part of the signal transmitted from the band filter for two purposes within 97.6 m of the IFT is shown in **Figure 24**. As shown, the horizontal axis of **Figure 24** is in meter. His relationship to his goals can easily be achieved at a light speed.

For this purpose, only one FM channel is busy. As the number of FM channels increases, the performance of the algorithm and the resolution of these two targets increase significantly. Using the three FM channels, the two-target detection method is performed at a distance of 81.85 m from **Figure 25**.

The results of target detection up to 48.07 m using seven FM channels are shown in **Figure 26.** The sensitivity and accuracy of the correlation and cross-correlation performance have been improved by the use of FM channels, so the resolution of the two domains adjacent to the targets is expanded and allows us to better identify them.

The real part of the invers Fourier transform is shown in **figure 24**.



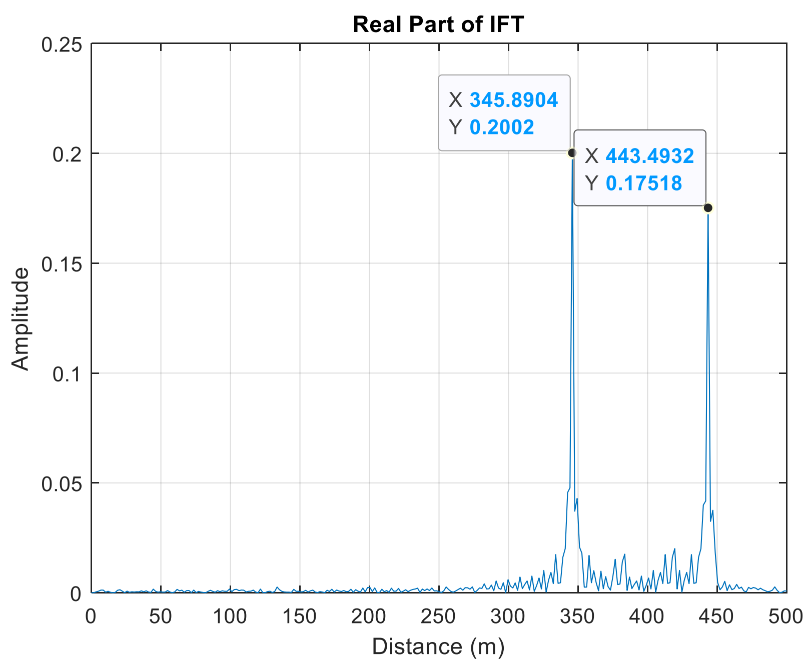
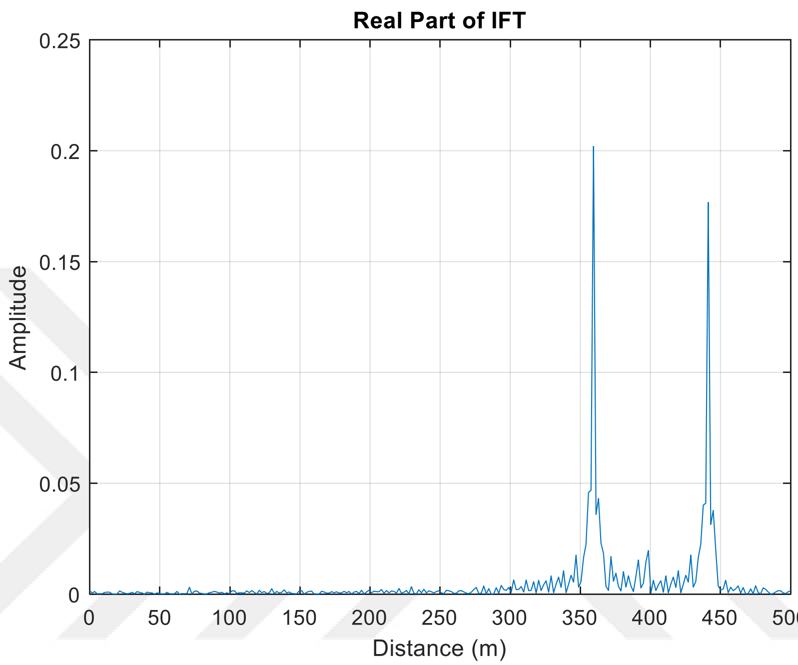


Figure 24. Invers Fourier transforms (Real Part) that passed from the bandpass filter between 2 targets through 345.89m and 443.49m distance

As seen in this figure the distance between two targets is 97.6 meters.



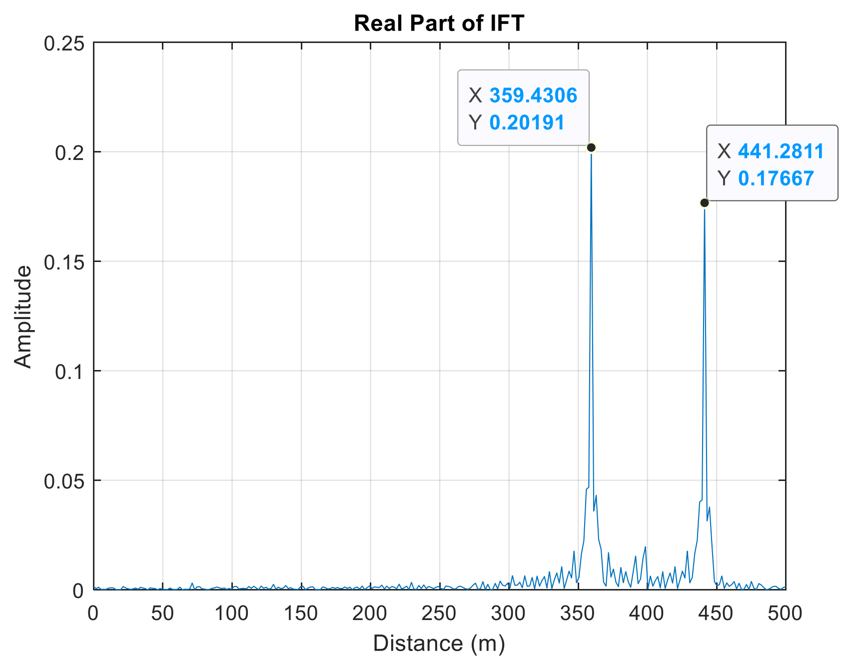


Figure 25. Invers Fourier transforms (Real Part) that passed from the bandpass filter between 2 targets through 441.28m and 359.43m distance

As seen in this figure the distance between two targets is 81.85 meter.

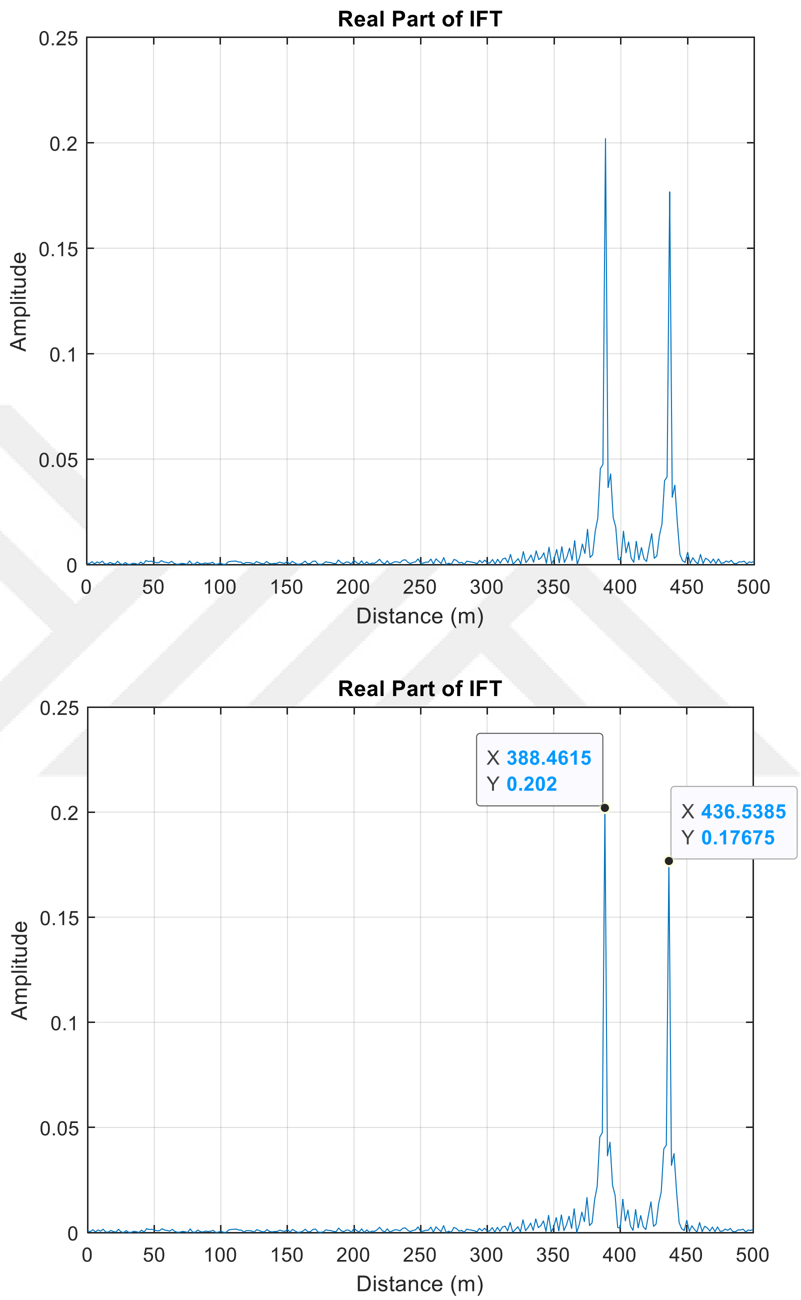


Figure 26. Invers Fourier transforms (Real Part) that passed from the bandpass filter between 2 targets through 436.53m and 388.46m distance

As seen in this figure the distance between two targets is 48.07 meter.

CHAPTER 5

CONCLUSION

In bistatic radar applications, the intensity of each radar signal component often varies greatly, so that in the process of detecting multi-component signals, strong component signals may affect the detection and parameter estimation of weak component signals. Therefore, in the detection and parameter estimation of multi-component signals, certain measures must be taken to suppress the influence of strong component signals on weak component signals. An effective method is to use the Clean method to suppress strong component signals. Assume that each signal component is arranged according to its intensity. According to the spectral peak size of the multi-component signal spectrum, the parameter with the largest peak value, that is, the strongest component signal is detected, and then it is suppressed and removed, and then the peaks of the remaining signals are detected again. In the process, each signal component is detected one by one in order from strong to weak. This process of detecting signals of different intensity components one by one is actually a process of separating each signal component one by one.

In this thesis, the application of pulse compression on radar using FM (or CHIRP) pulse modulation is explained. In this method, the received signal is compared with the correlation process with the transmitted signal to obtain the matching part between the two. Compressed Pulse Width The received pulse has advantages in its amplitude and resolution. Selecting signal processing techniques according to the need for radar performance is one of the most important steps in designing military radars. Today, digital computing offers fast and efficient computing. The best example is the use of FFT and IFFT to perform conversion times (filters). Here we use MATLAB to design a matching filtering algorithm for impact compression radar using LFM. In this thesis, the moving target path is defined to check whether it follows a predetermined path. In this thesis, the clarity of the scope of the two objectives is discussed. Also, an algorithm for close target detection is proposed. By using more FM channels for the transmitted signal, bandwidth and bandwidth are improved. Simulation results confirm that increasing detection accuracy makes close targets better than ever.

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APPENDIX

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WORK EXPERIENCE

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2010/2012	Public Works Company	Engineer of communication and electrical