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Real-time Obstacle Detection System for Needy Using RADAR

Jineshwar Nyamagoud

Design Engineer, Central R & D NxP Semiconductors India Private Limited –Bangalore, India

Abstract: **The main aim is to develop Real-time obstacle detection system using sensors. Environmental information from various sensors is acquired and processed and based on features the obstacles are classified. This unit consists of a Sensor and a Processor to offer an increased detection range of several meters (250 meters). The distance information is conveyed to the user through non-interfering multi-frequency. This unit is also capable of detecting fast/slow moving obstacles. To create a Real-time Algorithm from the combination of the processed information from the different sensing devices, develop Algorithms for real time processing of different environments.**

Keywords: **Real-time obstacle detection system, RADAR, FMCW, FFT, MATLAB, SENSOR.**

I. INTRODUCTION

Objects to be detected in a ruttier scene have a large variety of appearances due to different shapes, sizes, orientation with respect to view's position. Combined with a cluttered background and a range of visibilities under various lighting and weather conditions, the solution for a reliable and accurate algorithm for identifying an obstacle requires complicated system configurations and extensive evaluation. In this urban traffic environment the patterns of obstacle movements are very complicated and not always can be predicted. Another difficulty is that the host vehicle is moving implying background's moving aspects. Strong limitations exist on the computational costs of the methods when considering the speed of the moving vehicle and the necessity of a real time system.

Some of the main characteristics which an obstacle detection system should have are

1) To be in real time

2) To be low price

3) Compact in Size (Portable)

4) To not interfere with other systems

5) The most important requirement is to be 100% safety.

An important aspect of an obstacle detection and classification system from a traffic scene situation is its navigation. Thus an autonomous system is mainly formed by a navigation process based on estimation and an update of the observations (performed at regular time intervals) of the system position related to the ruttier scene. Navigation systems are usually equipped with different sensors that can be used to track the position and describe the area of navigation.

1.1 Obstacle Detection System [9][13]

Radar is the best sensor for obstacle detection (It is described in the section 2.1.2) and FMCW radar is best in among the different radar technologies for obstacle detection so we selected FMCW radar for our application (It is described in the section 2.2.4). In the last years, a number of efforts have been spent to develop automotive radars in the 76–81-GHz frequency range for autonomous cruise control or collision warning, Radar band 76GHZ – 81GHz is worldwide harmonized for obstacle detection system application. The advantage of the FMCW radar architecture is simplicity in both the analog and digital implementation. On the analog side, the transmitter can be implemented using a direct digital synthesizer (DDS) with a standard reference crystal. The DDS generates an analog frequency ramp reference for the phased-locked loops (PLL) to generate the desired transmit frequency modulation. For example, if the PLL has a divider of 1000, then in our example, the reference would be centered at 77 GHz, with desire frequency ramp [9].

This analog ramp signal drives the reference of a PLL, which disciplines a 77 GHz oscillator. The oscillator output of the circuit is amplified and produces the continuous wave (CW) signal ramping up and down over 1 GHz with a center frequency of 77 GHz. Filtering and matching circuits at 77 GHz can be accomplished using passive components etched into high-epsilon R dielectric circuit cards, minimizing the components required. Figure 1.1 illustrates an analog circuit block diagram.

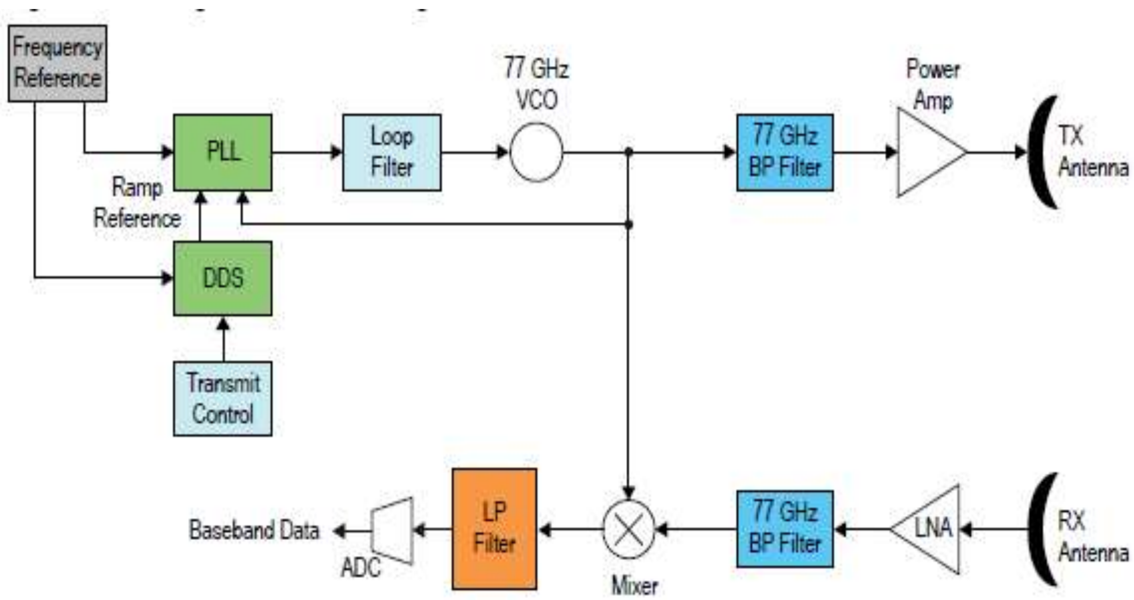


Figure 1.1 An analog circuit block diagram of FMCW RADAR [13]

In the receiver, the front end requires filtering and a low-noise amplifier (LNA), followed by an analog mixer. The mixer down converts the 77 GHz receive signal with the ramping transmit signal, outputting a baseband signal that contains the difference between the transit and receive waveforms at any given instant. The ramping is cancelled out, as we see fixed frequencies depending upon the range and Doppler shift of the target returns. Again, the high-frequency filtering at 77 GHz can be implemented using etched passive components. The output of the mixer will be at low frequency, up to □ 10 MHz at maximum range. Therefore, traditional passive components and operational amplifiers can be used to provide anti-aliasing low-pass filtering prior to the ADC.

Alternately, an intermediate frequency (IF) architecture could be used, but would require an offset receives LO generation circuit. Note that complex down conversion is not required. The baseband signal is composed of frequencies, either all positive (during negative frequency ramp) or all negative (during positive frequency ramp), so a mixer followed by a single low-pass filter and ADC is sufficient [13][14].

1.2 Thesis Outline

The project report is organized as follows. Chapter 2 discusses various obstacle detection technology used for obstacle detection. We also describe the (section 2.1) obstacle detection sensor, (section 2.2) different Radar technologies and (section 2.3) different signal processing methods used in this project. Chapter 3 gives a detailed explanation of the obstacle detection system that was developed for obstacle detection. In Chapter 4 we discusses about tools used for simulation.Chapter 5 gives a detailed explanation of the algorithm implementation. Chapter 6 presents the simulation results of the obstacle detection system. Chapter 7 concludes the project with suggestions for future work.

II. OBSTACLE DETECTION TECHNOLOGY

2.1 Sensors for Obstacle Detection [4]

A sensor may be defined as a device which measures some attribute of the world, then a classification of the sensors type can be according to the type of measurement information they give as output. Therefore, information provided from proprioceptive (measure an attribute regarding their own state) and exteroceptive (measure an attribute of an external object present in the scene) sensors can be mixed together in order to give a better perception of the environment.

2.1.2 Comparison of Sensors

We have considered different types of obstacle detection sensors and have discussed some of their advantages and disadvantages separately. Now we will compare each sensor side-by-side for our application. Given the farming environment we can set few criteria for selecting the best obstacle detection sensor operation in any weather, operation in any light, detection out to at least 1-100 meters, fast response time, and cost that is significantly less than that of the existing systems. Ideally the best sensor will meet our criteria, but if this is not possible the one that comes closest will be selected.

2.1.2.1 Weather

The environment brings out the whole spectrum where weather is concerned. The sensor must be able to handle dust, rain, and snow, all of which can be blowing and swirling at any given time. Because of this the camera, sonar, and scanning laser can give false readings. The only suitable detection sensor is the millimeter wave radar.

2.1.2.2 Light

The day starts in the darkness of the morning and then gradually the light gets more intense as the day goes on until the noon day peak. At this point the light recedes much as it started as the day winds down. If, however, the weather changes throughout the day the amount of light may also change. This means that our detection sensor must operate in any light. From the start this excludes the CCD cameras. They function on ambient light and any changes in the lighting can affect the interpretation of their data. Sonar, scanning laser, and millimeter wave radar are relatively unaffected by changing light conditions and would be good choices for dealing with changing light conditions.

2.1.2.3 Detection Distance

For obstacle detection system that travels at 3 m/sec to 30 m/sec. it only takes 4 seconds- 40 seconds for the travel to travel 10 m-100m. The obstacle detection sensor must determine the presence of an obstacle and the avoidance algorithm must calculate an avoidance heading in under 4seconds preferably well under 4 seconds. This means that the detection sensor must be able to detect obstacles soon enough that avoidance is performed safely. With this limitation we determined that the obstacle detection sensor used on the system must have a maximum detectable range of at least 10 meters. This gives plenty of time for obstacle identification and avoidance heading calculations. This requirement excludes most ultrasonic sensors, which have a maximum range of about 5 meters. CCD cameras, scanning laser, 3D scanning laser, and millimeter wave radar all have maximum detectable ranges of at least 15 meters or more.

2.1.2.4 Response Time

In order for a detection sensor to be adequate the time required to see and obstacle and cause the system respond is critical. In the case of the 3D-scanning laser the time required to scan one image in front of the vehicle is 80 seconds, which is obviously unacceptable for a real-time system. Sonar can determine fast enough if an obstacle is present, but sonar can only see a short distance. That is, the system will already be too close to an obstacle before the sonar can sense an obstacle. A CCD camera’s response time depends on the image processing speeds and capabilities. With faster computers this is not a problem and camera’s response time is fast enough to detect obstacles at a safe distance. 2D-scanning lasers have a very fast response time, on the order of 17 ms to 1 s depending on the resolution and the speed that data are being output. This allows scanning lasers to detect obstacles at a safe distance, allowing for proper obstacle detection and avoidance. Millimeter wave radar also has a fast enough response time. As with cameras, the higher speed computers allow for fast computation of the radar signal. Radar can detect obstacles at safe distances.

2.1.2.5 Cost

For most research projects cost of sensors may not be a prime issue, but with the system already existing there is a desire to keep cost down because of possible future production considerations. If the cheapest detection sensor were the only issue then hands down the sonar or CCD cameras would be the choice. The 2D scanning laser costs significantly more than the sonar and the CCD camera, but it would not break the bank to put it on a production type system. The 3D scanning laser, on the other hand, costs as much if not more than most systems and would not be feasible. The millimeter wave radar also has a high cost, while not as much as the 3D-scanning laser, it is still significant enough to warrant the choice of a cheaper technology.

2.1.2.6 Strengths and Weakness of Sensors for obstacle detection

Table 2.1 Comparison of different Sensors for obstacle detection [4][24]

Sensor Type	Conventional Camera	Wide FOV Camera	IR	RADAR	LASER	SONAR
Field of View	Medium	Large	Large	Small	Large	Medium
Detection Range	Medium	Small	Medium	Large	Medium	Small
Angular Resolution	Large	Medium	Large	Small	Medium	Small
Range Resolution	Medium	Small	Medium	Large	Large	Large
Illumination	Passive reflective, Needs light source	Passive reflective, Needs light source	Passive/ Active, works in dark	Active, works in dark, rain, fog.	Active, works in dark	Active, works in dark
Hardware Cost	Low	Medium	Medium	Medium	High	Medium
Complexity	High	High	Medium	Medium	Medium	Low

2.1.3 Sensors used on Obstacle Detection System

After examining the few criteria we must settle for the optimum sensor. Because radar is the only sensor that works well in all weather conditions it would be a natural choice. The maximum detection range is 100 meters &more, the response time is adequate, and the cost for a unit is justifiable. The comparisons of each sensor with the few criteria are shown graphically in table. 2.1.2. In this section we have discussed different sensors used for obstacle detection. We investigated research that uses each of the different sensors and we listed their advantages and disadvantages.

Finally we set forth few criteria that the detection sensor needed to meet in order to be used on the system. With each sensor evaluated against these few criteria we decided that radar was the optimum sensor at the present time for the autonomous system.

2.2 Comparisons of Various Radar Technologies for Obstacle Detection

Table 2.2 Comparison of different radar technologies for obstacle detection [[1][3][17]

Characteristics	CW Radar	FMCW Radar	Pulse Compression Radar	UWB Pulse Radar
Range Resolution	No Range Information	Good (if use Wideband)	Good	Good
Detection Range	Long	Long	Marginal	Marginal
Doppler Ambiguity	No Range Information	PRT	PRT	PRT
Easy to separate T/R capability	No	No	Yes	Yes
Separate Multipath propagations	Poor	Poor	Good	Good
Data Acquisitions	Simpler	Marginal	Marginal	Hard
System Complexity	Simpler	High	High	Marginal
Signal Processing Complexity	Low	High	High	Low
Cost	Low	High	High	Marginal

2.2.1 RADAR Technology used for Obstacle Detection

After examining the few criteria we must settle for the optimum radar technology. FMCW radar is the only technology that has good range resolution, long detection range, data acquisition, signal processing complexity and cost is marginal so it would be a natural choice.

The comparisons of each sensor with the few criteria are shown graphically in table. 2.2. In this section we have discussed different radar technologies used for obstacle detection. We investigated research that uses each of the different radar technologies and we listed their advantages and disadvantages. Finally we set forth few criteria that the radar technology needed to meet in order to be used for the system. With each technology evaluated against these few criteria we decided that FMCW radar was the optimum technology at the present time for the autonomous system.

III. OBSTACLE DETECTION SYSTEM

3.1 FMCW RADAR block diagram [13] [14] [15]

The advantage of the FMCW radar architecture is simplicity in both the analog and digital implementation. Figure 3.1 illustrates FMCW RADAR block diagram.

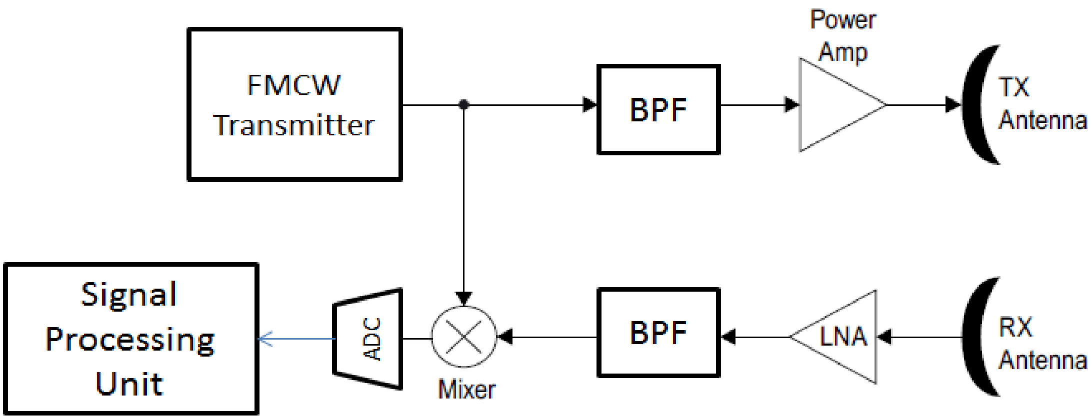


Figure 3.1 FMCW RADAR block diagram [12][13]

In the receiver, the front end requires filtering and a low-noise amplifier (LNA), followed by an analog mixer. The mixer down converts the 77 GHz receive signal with the ramping transmit signal, outputting a baseband signal that contains the difference between the transit and receive waveforms at any given instant. The ramping is cancelled out, as we see fixed frequencies depending upon the range and Doppler shift of the target returns. Again, the high-frequency filtering at 77 GHz can be implemented using etched passive components. The output of the mixer will be at low frequency, up to □ 10 MHz at maximum range.

Therefore, traditional passive components and operational amplifiers can be used to provide anti-aliasing low-pass filtering prior to the ADC. Alternately, an intermediate frequency (IF) architecture could be used, but would require an offset receives LO generation circuit. Note that complex down conversion is not required. The baseband signal is composed of frequencies, either all positive (during negative frequency ramp) or all negative (during positive frequency ramp), so a mixer followed by a single low-pass filter and ADC is sufficient.

3.2 FMCW Transmitter

FMCW Transmitter involves transmitting a signal whose frequency changes periodically. It is possible to transmit complicated frequency patterns (like in noise radar) with the periodic repetition occurring at most at a time in which no ambiguous echoes are expected. However, in the simplest case basic ramp or triangular modulation is used, which of course will only have a relatively small unambiguous measurement range. By using FMCW, there is no amplitude modulation, and the transmitter only varies in frequency. Use of FM allows for the transmit circuit to operate in saturation, which is the most efficient mode for any RF amplifier.

Up down chirp

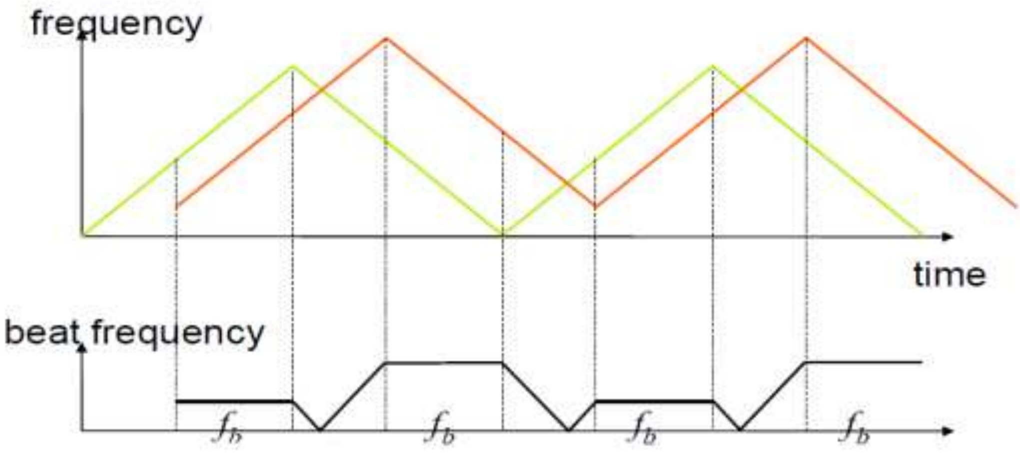


Figure 3.2 up down chirp [13]

3.3 RF power amplifier

An RF power amplifier is a type of electronic amplifier used to convert a low-power radio-frequency signal into a larger signal of significant power, typically for driving the antenna of a transmitter. It is usually optimized to have high efficiency, high output Power compression, good return loss on the input and output, good gain, and optimum heat dissipation.

3.4 Low-noise amplifier (LNA)

Low-noise amplifier (LNA) is an electronic amplifier used to amplify possibly very weak signals (for example, captured by an antenna). It is usually located very close to the detection device to reduce losses in the feed line.This active antenna arrangement is frequently used in microwave systems like GPS, because coaxial cable feed line is very lossy at microwave frequencies, e.g. a loss of 10% coming from few meters of cable would cause a 10% degradation of the signal-to-noise ratio (SNR).Using an LNA, the effect of noise from subsequent stages of the receive chain is reduced by the gain of the LNA, while the noise of the LNA itself is injected directly into the received signal. Thus, it is necessary for an LNA to boost the desired signal power while adding as little noise and distortion as possible, so that the retrieval of this signal is possible in the later stages in the system.

3.5 Frequency Mixer

In electronics a mixer or frequency mixer is a nonlinear electrical circuit that creates new frequencies from two signals applied to it. In its most common application, two signals at frequencies f_1 and f_2 are applied to a mixer, and it produces new signals at the sum $f_1 + f_2$ and difference $f_1 - f_2$ of the original frequencies. Other frequency components may also be produced in a practical frequency mixer. Mixers are widely used to shift signals from one frequency range to another, a process known as heterodyning, for convenience in transmission or further signal processing.

For example, a key component of a super heterodyne receiver is a mixer used to move received signals to a common intermediate frequency. Frequency mixers are also used to modulate a carrier frequency in radio transmitters.

3.6 Band-pass filter

A band-pass filter is a device that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. These filters can also be created by combining a low-pass filter with a high-pass filter. Band pass is an adjective that describes a type of filter or filtering process, which is to be distinguished from pass band, which refers to the actual portion of affected spectrum. Hence, one might say "A dual band pass filter has two pass bands." A band pass signal is a signal containing a band of frequencies not adjacent to zero frequency, such as a signal that comes out of a band pass filter.

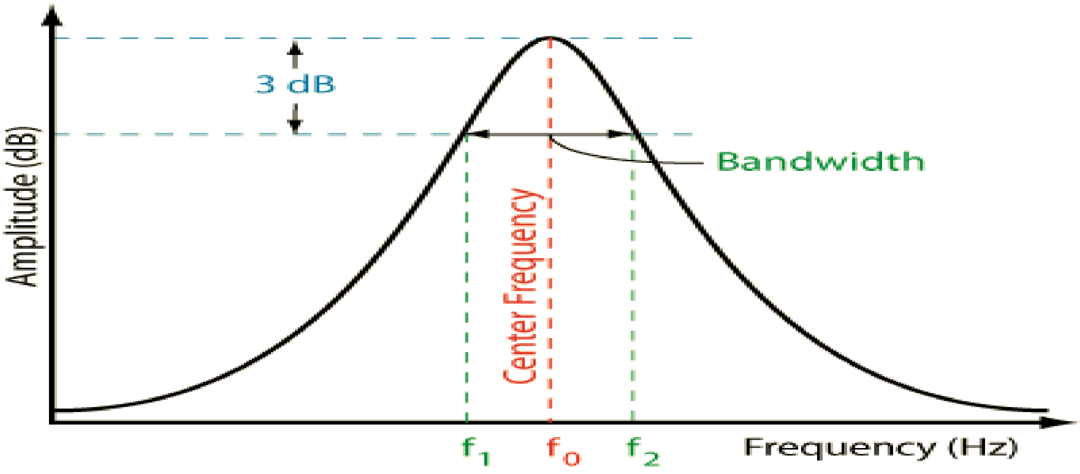


Figure 3.3 Band pass filter charactestics[24]

An ideal band pass filter would have a completely flat pass band (e.g. with no gain/attenuation throughout) and would completely attenuate all frequencies outside the pass band. Additionally, the transition out of the pass band would be instantaneous in frequency. In practice, no band pass filter is ideal.

The filter does not attenuate all frequencies outside the desired frequency range completely; in particular, there is a region just outside the intended pass band where frequencies are attenuated, but not rejected. This is known as the filter roll-off, and it is usually expressed in dB of attenuation per octave or decade of frequency. Generally, the design of a filter seeks to make the roll-off as narrow as possible, thus allowing the filter to perform as close as possible to its intended design. Often, this is achieved at the expense of pass-band or stop-band ripple.

The bandwidth of the filter is simply the difference between the upper and lower cutoff frequencies. The shape factor is the ratio of bandwidths measured using two different attenuation values to determine the cutoff frequency, e.g., a shape factor of 2:1 at 30/3 dB means the bandwidth measured between frequencies at 30 dB attenuation is twice that measured between frequencies at 3 dB attenuation.

3.7 Analog-to-Digital Converter (ADC)

Most signals of practical interest, such as speech, biological signals, seismic signals, radar signals, sonar signals, and various communications signals such as audio and video signals, are analog. To process analog signals by digital means, it is first necessary to convert them into digital form, that is, to convert them to a sequence of numbers having finite precision.

This procedure is called analog-to-digital conversion, and the corresponding devices are called converters (ADCs).Conceptually, we view *AD* conversion as a three-step process. This process is illustrated in figure 3.4.

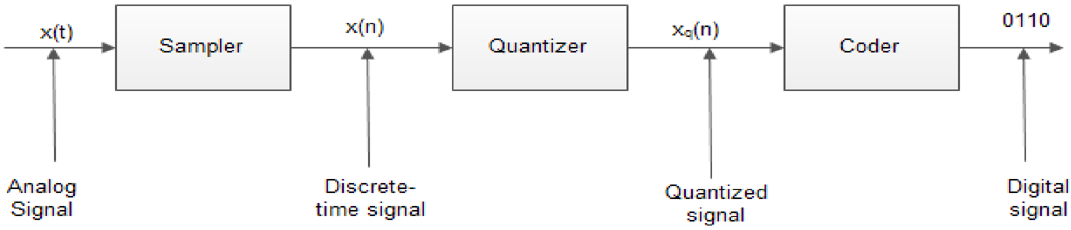


Figure 3.4 Analog to Digital Converter

Sampling

This is the conversion of a continuous-time signal into a discrete time signal obtained by taking samples of the continuous-time signal at discrete-time instants. Thus, if x (t) is the input to the sampler, the output is x, (nT) r x (n), where T is called the sampling interval.

Quantization

This is the conversion of a discrete-time continuous-valued signal into a discrete-time, discrete-valued (digital) signal. The value of each signal sample is represented by a value selected from a finite set of possible values. The difference between the unquantized sample s (n) *and* the quantized output x (n) is called the quantization error.

Coding

In the coding process, each discrete value x (n) is represented by a b-bit binary sequence. Although we model the AID converter as a sampler followed by a quantizer and coder, in practice the AID conversion is performed by a single device that takes x(t) and produces a binary-coded number.

The operations of sampling and quantization can be performed in either order but in practice sampling is performed before quantization. Since computers only process digital information, they require digital input. Therefore, if an analog input is sent to a computer, an analog-to-digital converter (ADC) is required. This device can take an analog signal, such as an electrical current, and digitize it into a binary format that the computer can understand.

A common use for an ADC is to convert analog video to a digital format. The accuracy of the audio conversion depends on the sampling rate used in the conversion process. Higher sampling rates provide a better estimation of the analog signal, and therefore produce a higher-quality result. While ADCs convert analog inputs into a digital format that computers can recognize, sometimes a computer must output an analog signal. For this type of conversion, a digital-to-analog converter (DAC) is used.

3.8 Signal processing unit

3.8.1 Using Difference Method

The ADC for baseband input must operate at a minimum of 20 MSPS to meet the Nyquist criterion. The next step of signal processing is to perform frequency discrimination using a difference method.

Using difference method frequency change converted into amplitude changes from amplitude the beat frequency is calculated and finally range is calculated. Figure 3.5 illustrates a signal processing block diagram

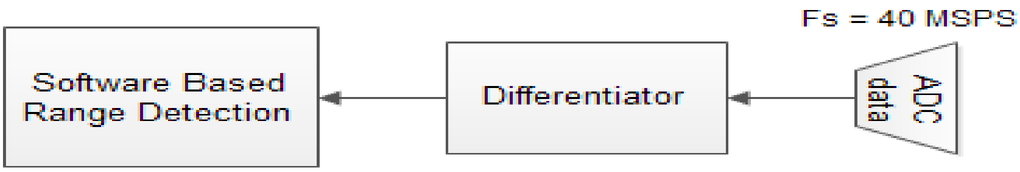


Figure 3.5 Signal processing unit using differentiator

3.8.2 Using Fast Fourier transform (FFT)

The ADC for baseband input must operate at a minimum of 20 MSPS to meet the Nyquist criterion. The digital filter can operate at a 204 MHz rate using 12 bit input samples, outputting samples at 40 MHz The next step of signal processing is to perform frequency discrimination using an FFT.The nature of FFTs is to have growth in the data precision as it proceeds through the processing stages. For our case, we will assume a 1,024 point FFT, which can potentially require avoiding any loss of data. Finally range is calculated using formula from fft spectrum. Figure 3.6 illustrates a signal processing block diagram.

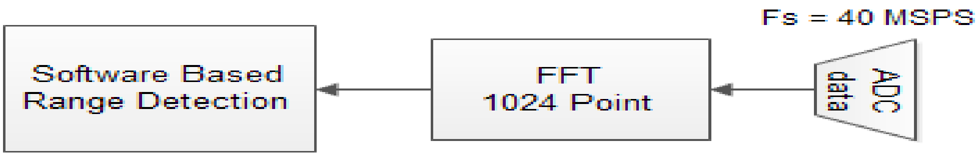


Figure 3.6 Signal processing unit using 1024 FFT

3.8.3 Using Fast Fourier transform (FFT) with decimation

The ADC for baseband input must operate at a minimum of 20 MSPS to meet the Nyquist criterion. If, instead, an 8x sampling frequency of 40 MSPS is used, followed by an 8:1 digital decimation filter, then approximately 2 MHz beat frequency can be achieved. The digital filter can operate at a 204 MHz rate using 12 bit input samples, outputting samples at 5 MHz. The next step of signal processing is to perform frequency discrimination using an FFT. The nature of FFTs is to have growth in the data precision as it proceeds through the processing stages. For our case, we will assume a 128 point FFT, which can potentially require avoiding any loss of data. Finally range is calculated using formula from fft spectrum. Figure 3.7 illustrates a signal processing block diagram

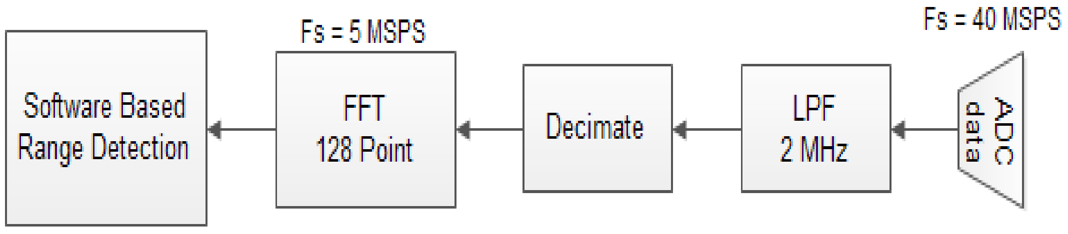


Figure 3.7 Signal processing unit using FFT and decimator

IV. TOOLS USED

4.1 MATLAB [20]

MATLAB Version: 8.0.0.783 (R2012b)

4.1.1 Product Description

The Language of Technical Computing

MATLAB® is a high-level language and interactive environment for numerical computation, visualization, and programming. Using MATLAB, you can analyze data, develop algorithms, and create models and applications. The language, tools, and built-in math functions enable you to explore multiple approaches and reach a solution faster than with spreadsheets or traditional programming languages, such as C/C++ or Java™. You can use MATLAB for a range of applications, including signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology. More than a million engineers and scientists in industry and academia use MATLAB, the language of technical computing.

Key Features

- High-level language for numerical computation, visualization, and application development
- Interactive environment for iterative exploration, design, and problem solving
- Mathematical functions for linear algebra, statistics, Fourier analysis, filtering, optimization, numerical integration, and solving ordinary differential equations
- Built-in graphics for visualizing data and tools for creating custom plots
- Development tools for improving code quality and maintainability and maximizing performance
- Tools for building applications with custom graphical interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET, and Microsoft® Excel®

V. IMPLEMENTATION OF ALGORITHMS

5.1 Algorithm using finite difference method

Steps for finding range of target

1) Generation of Transmitted signal
2) Generation of Received signal
3) Generation of Mixed signal
4) Band pass filtering
5) Analog to digital conversion
6) Calculating amplitude of digital signal using peak detector
7) Differentiator output signal
8) Calculating amplitude of differentiator output signal using peak detector
9) Calculating Beat frequency, Round trip delay and range of target.

Chirp signal formula = A * sin (2*pi*f*t+ (kf*t^2)/2)

Where A→Amplitude of chirp signal

F→frequency of chirp signal

t →time period of chirp signal

Kf →sweep frequency →(fmax-fmin) / t →(Bandwidth / t)

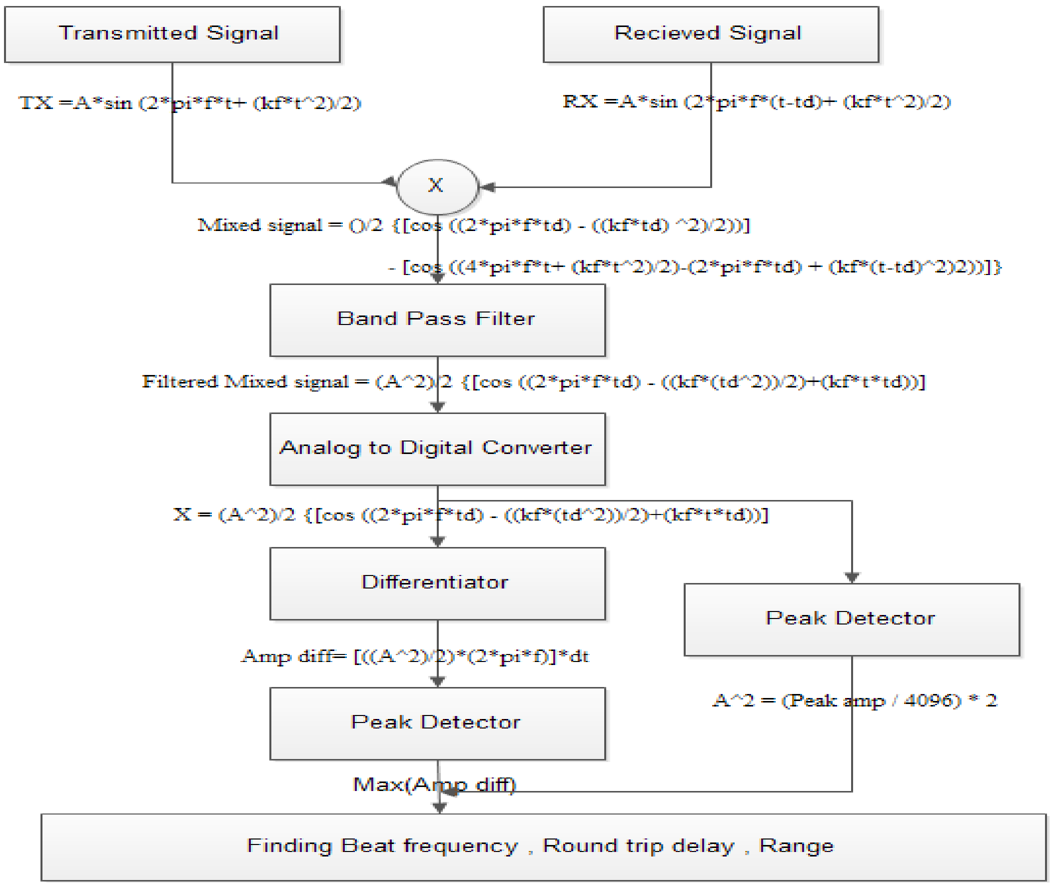


Figure 5.1 Flowchart for Signal processing using difference method.

Steps for finding range of target

1) Generation of Transmitted signal is given as

TX = A * sin (2 * pi * f * t + (kf * t^2) / 2)

2) Generation of Received signal is given as

RX = A * sin (2 * pi * f * (t – td) + (kf * $(t - td)^2$) / 2)

3) Generation of Mixed signal (Mixer output)

Now multiplying TX and RX we get,

Mixed signal = TX * RX

Mixed signal = [A * sin (2 * pi * f * t+ (kf * t^2) / 2)] * [A * sin (2 * pi * f * (t-td) + (kf * $(t - td)^2$) / 2)]

By using formula 2 * SIN A SIN B = COS (A-B) - COS (A+B)

Mixed signal = $(A^2)/$ 2 { [cos ((2 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * (t - td) + (kf * $(t - td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * (t - td) + (kf * $(t - td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((~~2 * pi * f * t~~ + (~~kf * t^2) / 2~~) - ~~(2 * pi * f * t)~~ + (2 * pi * f * td) - (~~kf~~ * ($~~t~~ - td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * t) - (2 * pi * f * td) + (kf * $(t - td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td) ^2) / 2) + kf * t * td)] – [cos ((4 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * td) + (kf * $(t - td)^2$)/ 2))] }

By using Band pass filter, filtering the mixed signal we get filtered mixed signal as,

Filtered Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td^2) / 2) + kf * t * td)] ~~– [cos ((4 * pi * f * t + (kf * t^2) / 2) (2 * pi * f * td) + (kf $(t - td)^2$ ^2) / 2))] }~~ → High frequency component

4) Analog to digital conversion (ADC)

5) Calculating Amplitude of digital signal

Find peak amplitude of ADC output signal by using Peak detector signal

Considering Positive cycle, the dynamic range of ADC i.e. 2^12=4096

So ADC output has amplitude of =(PA_ADC/4096)

As we know the ADC output will have amplitude of (A^2/2)

Now A = sqrt (PA_ADC * 2 / 4096)

6) Differentiator output signal

Now taking difference between present sample and previous sample

(f(t+dt)-f(t)) / dt

Filtered Mixed Signal

x= (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td^2) / 2) + kf * t * td)]

Differentiation of filtered mixed signal finds the difference between present sample and previous sample

dx / dt = { [(A^2) / 2] * (2 * pi * f – kf * td) * [cos ((2 * pi * f * td) – ((kf * td^2) / 2) + kf * t * td)] }

Taking amplitude content term from above equation we get

Amplitude difference = [((A^2) / 2) * (2 * pi * f)] * dt

7) Calculating amplitude of differentiator output signal using peak detector

Comparing the all Amplitude difference (AD) values and finding the maximum value by using Peak detector.

8) Calculating Beat frequency, Round trip delay and range of target

Now taking Amplitude difference equation from above state we have

Amplitude difference = [((A^2) / 2) * (2 * pi * f)] * dt

Amplitude difference = [((A^2) / 2) * (2 * pi * f)] * N / fs

since dt → N / fs

Finding beat frequency from above equation we will get,

Beat frequency = (Amplitude difference *fs)/ (((A^2)/ ~~2)*2~~*pi)

Beat frequency = (Amplitude difference * fs) / (A^2 * pi * N)

Now finding round trip delay from beat frequency

We know that f = rate of change of frequency = kf * td

Beat frequency = kf * round trip delay

Round trip delay = Beat frequency / kf

Round trip delay = (Amplitude difference * fs) / (A^2*pi*kf * N)

Now finding range of target from round trip delay

We know that,

Range →R = c * round trip dalay/2

From above equation we get R as,

Range = c * round trip delay / 2

5.2 Algorithm using Fast Fourier transform (FFT)

Steps for finding range of target

1) Generation of Transmitted signal
2) Generation of Received signal
3) Generation of Mixed signal
4) Band pass filtering
5) Analog to digital conversion
6) Frequency discrimination using a 1024 point FFT
7) Calculating Beat frequency from FFT magnitude spectrum
8) Calculating Round trip delay and range of target.

Chirp signal formula = A * sin (2*pi*f*t+ (kf*t^2)/2)

Where A→Amplitude of chirp signal

F→frequency of chirp signal

t →time period of chirp signal

kf →sweep frequency →(fmax-fmin) / t→(Bandwidth / t)

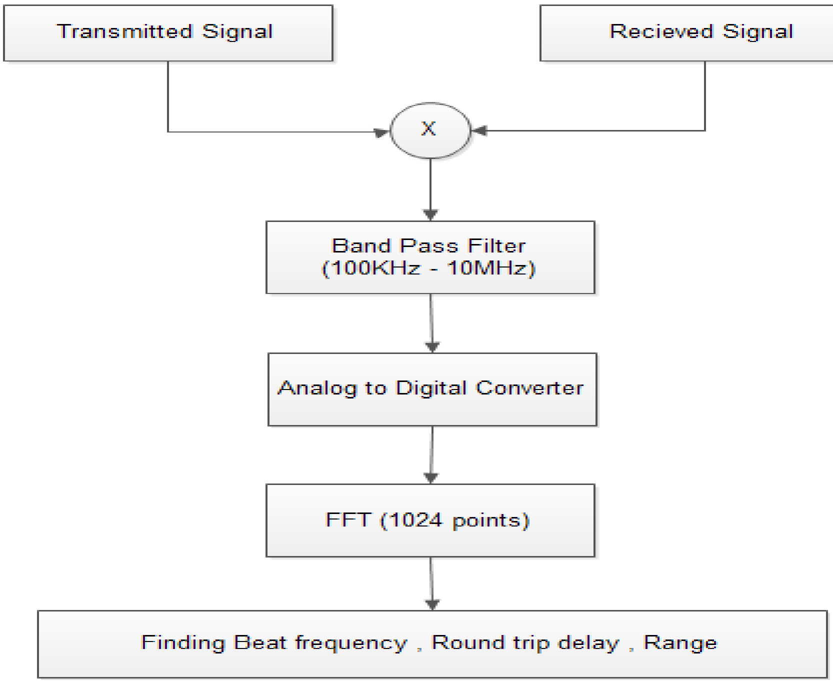


Figure 5.2 Flowchart for signal processing using FFT

1) Generation of Transmitted signal is given as

TX = A * sin (2 * pi * f * t + (kf * t^2) / 2)

2) Generation of Received signal is given as

RX = A * sin (2 * pi * f * (t – td) + (kf * $(t-td)^2$) / 2)

3) Generation of Mixed signal (Mixer output)

Now multiplying TX and RX we get,

Mixed signal = TX * RX

Mixed signal = [A * sin (2 * pi * f * t+ (kf * t^2) / 2)] * [A * sin (2 * pi * f * (t-td) + (kf * $(t-td)^2$) / 2)]

By using formula 2 * SIN A SIN B = COS (A-B) - COS (A+B)

Mixed signal = (A^2)/ 2 { [cos ((2 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * (t - td) + (kf * $(t-td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * (t - td) + (kf * $(t-td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((~~2 * pi * f * t~~ + (~~kf * t^2) / 2~~) - ~~(2 * pi * f * t)~~ + (2 * pi * f * td) - (~~kf~~ * (t − $td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * t) - (2 * pi * f * td) + (kf * $(t-td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td) ^2) / 2) + kf * t * td)] – [cos ((4 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * td) + (kf * $(t-td)^2$)/ 2))] }

4) By using Band pass filter, filtering the mixed signal we get filtered mixed signal as,

Filtered Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td^2) / 2) + kf * t * td)] ~~– [cos ((4 * pi * f * t + (kf * t^2) / 2) (2 * pi * f * td) + (kf $(t-td)^2$ ^2) / 2))] }~~ →High frequency component

5) Analog to digital conversion (ADC)

6) Frequency discrimination using a 1024 point FFT

7) Calculating Beat frequency from FFT magnitude spectrum

- Beat frequency = Max (peak frequency)

8) Calculating Round trip delay and range of target.

- Round trip delay = Beat frequency / (bandwidth / chirp time)
- Range = (Round trip delay *speed of light(c)) / 2

5.3 Algorithm using **Fast Fourier transform (FFT) with decimate**

Steps for finding range of target

1) Generation of Transmitted signal
2) Generation of Received signal
3) Generation of Mixed signal
4) Band pass filtering
5) Analog to digital conversion
6) Low pass filtering (2MHz)
7) Decimate by 8 times
8) Frequency discrimination using a 128 point FFT
9) Calculating Beat frequency from FFT magnitude spectrum
10) Calculating Round trip delay and range of target.

Chirp signal formula = A * sin (2*pi*f*t+ (kf*t^2)/2)

Where A→Amplitude of chirp signal

F→frequency of chirp signal

t →time period of chirp signal

kf →sweep frequency →(fmax-fmin) / t→(Bandwidth / t)

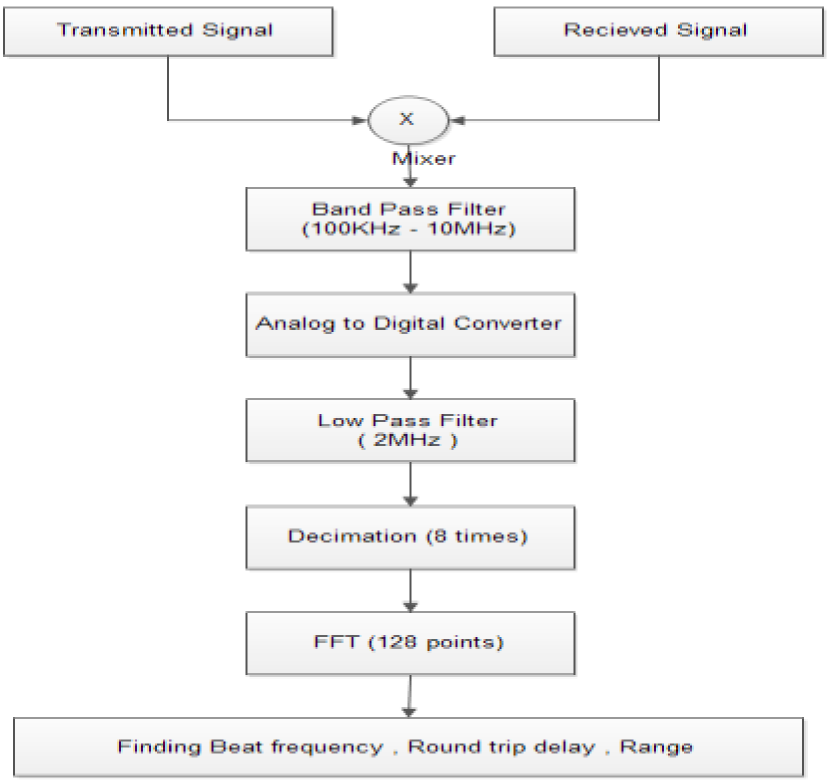


Figure 5.3 Flowchart for signal processing using FFT with decimation

1) Generation of Transmitted signal is given as

TX = A * sin (2 * pi * f * t + (kf * t^2) / 2)

2) Generation of Received signal is given as

RX = A * sin (2 * pi * f * (t – td) + (kf * $(t-td)^2$) / 2)

3) Generation of Mixed signal (Mixer output)

Now multiplying TX and RX we get,

Mixed signal = TX * RX

Mixed signal = [A * sin (2 * pi * f * t+ (kf * t^2) / 2)] * [A * sin (2 * pi * f * (t-td) + (kf * $(t-td)^2$) / 2)]

By using formula 2 * SIN A SIN B = COS (A-B) - COS (A+B)

Mixed signal = $(A^2)/$ 2 { [cos ((2 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * (t - td) + (kf * $(t-td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * (t - td) + (kf * $(t-td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((~~2 * pi * f * t~~ + (~~kf * t^2) / 2~~) - ~~(2 * pi * f * t)~~ + (2 * pi * f * td) - (~~kf~~ * (~~t~~ $-td)^2$) / 2))] - [cos ((2 * pi * f * t + (kf * t^2) / 2) + (2 * pi * f * t) - (2 * pi * f * td) + (kf ∗ $(t-td)^2$) / 2))] }

Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td) ^2) / 2) + kf * t * td)] – [cos ((4 * pi * f * t + (kf * t^2) / 2) - (2 * pi * f * td) + (kf * $(t-td)^2$)/ 2))] }

4) By using Band pass filter, filtering the mixed signal we get filtered mixed signal as,

Filtered Mixed signal = (A^2) / 2 { [cos ((2 * pi * f * td) – ((kf * td^2) / 2) + kf * t * td)] ~~– [cos ((4 * pi * f * t + (kf * t^2) / 2) (2 * pi * f * td) + (kf $(t-td)^2$ ^2) / 2))] }~~ →High frequency component

5) Analog to digital conversion (ADC)

6) Low pass filtering (2MHz)

- Only 2 MHz intermediate frequencies are passed for FFT processing.

7) Decimate by 8 times

- Intermediate frequencies above 2 MHz are filtered by LPF so for required beat frequency and range resolution requires 128 point fft instead of 1024
- So IF signal is decimated by 8 times to get 128 points

8) Frequency discrimination using a 128 point FFT

9) Calculating Beat frequency from FFT magnitude spectrum

- Beat frequency = Max (peak frequency)

10) Calculating Round trip delay and range of target.

- Round trip delay = Beat frequency / (bandwidth / chirp time)
- Range = (Round trip delay *speed of light(c)) / 2

VI. SIMULATION RESULTS

6.1 Single target detection

6.1.1 Test Case 1

Input values

Minimum Distance = 0.5 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz

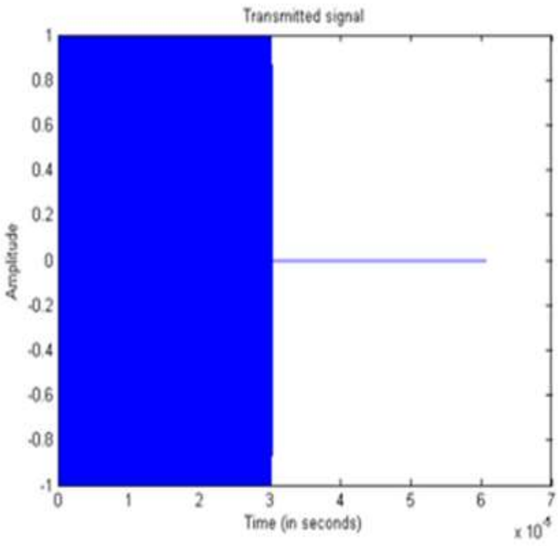
Min Frequency = 77 GHz
Max Frequency = 77.910 GHz
Total Chirp time = 60.67 usec

Decimation Factor = 8
Time delay 1 = 55 nsec

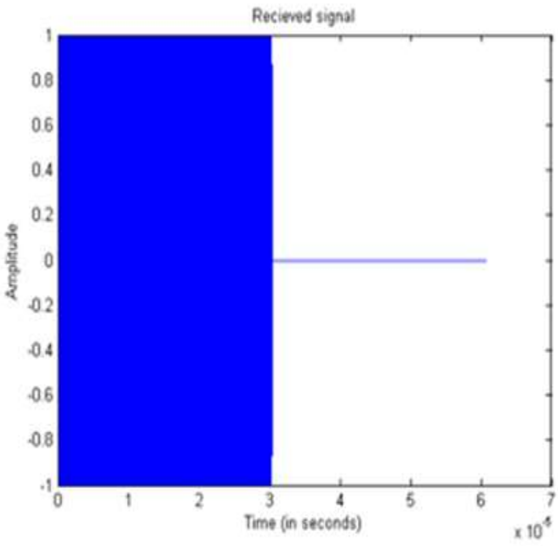
Output values
Maximum distance of target = 50 m
Minimum round trip delay = 3.3 nsec
Maximum round trip delay = 333.3333 nsec
Up chirp time = 30.33 usec
Bandwidth = 910 MHz
No samples = 1024

No of samples after decimation = 128
Range resolution = 0.2 m

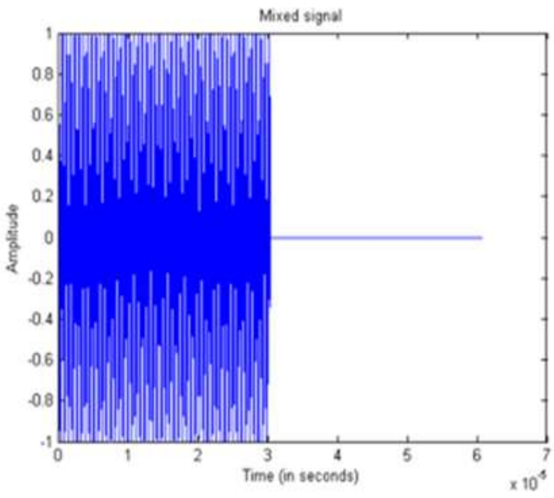
Generation of Transmitted signal



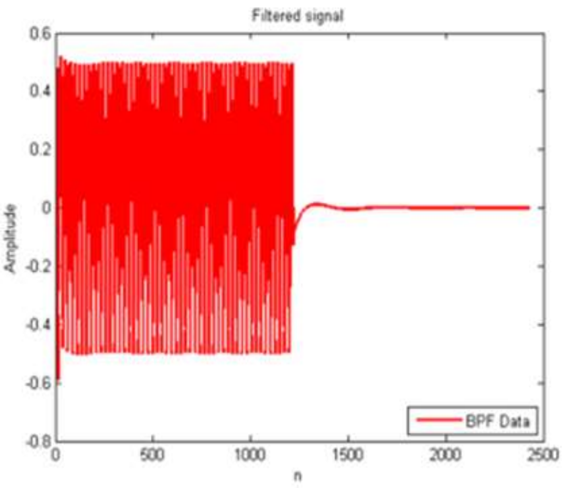
Generation of Received signal



Mixed signal



Band pass filtered signal



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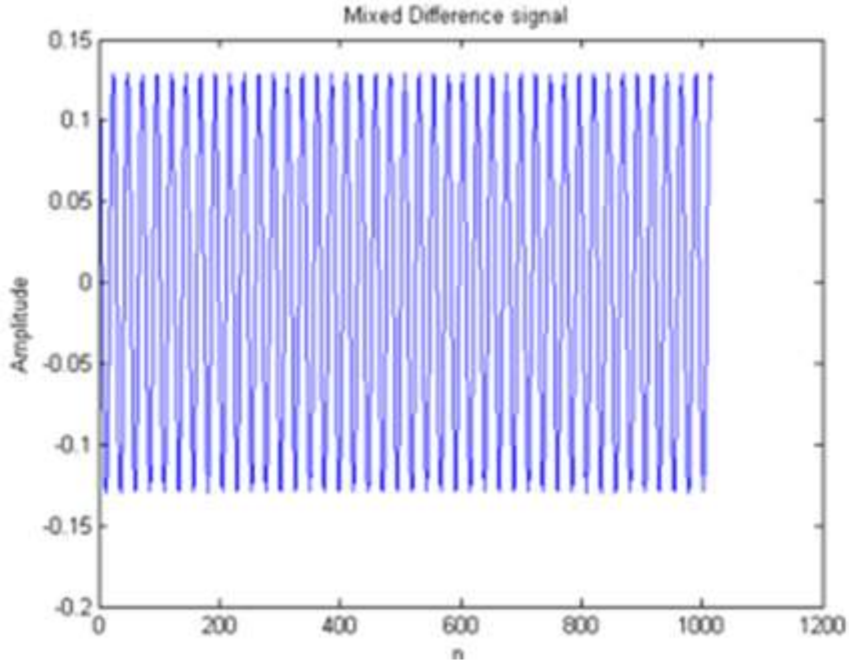
Difference Method

Differentiator Output



Output Results

Target 1

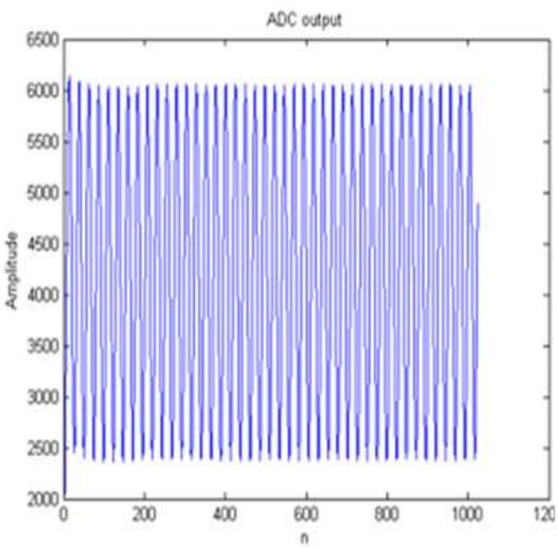
Beat Frequency 1 = 1.78 MHz

Round Trip Delay 1 = 59.48 nseconds

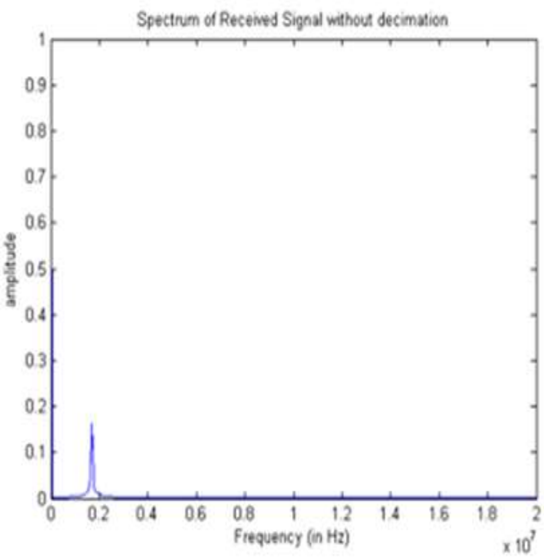
Target at distance = 8.9 meters

FFT Method

ADC output



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 1.68 MHz

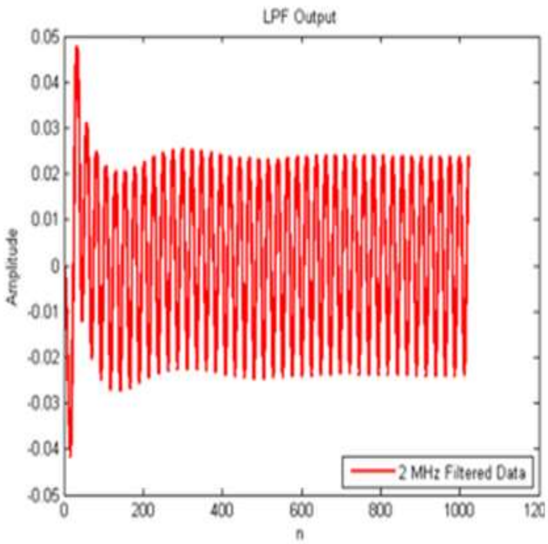
Round Trip Delay 1 = 55.99 nseconds

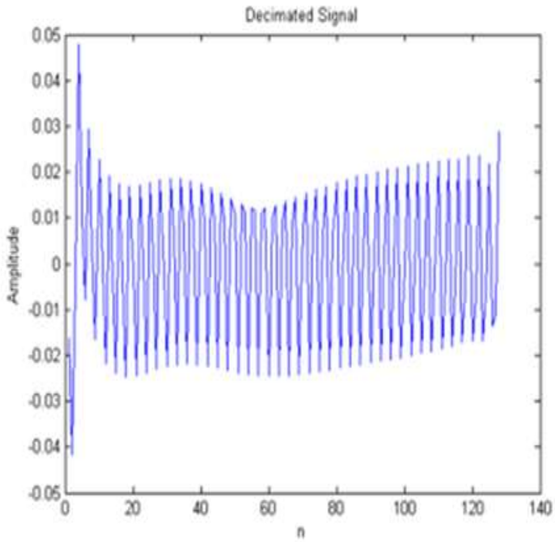
Target at distance = 8.40 meters

FFT Method with decimation

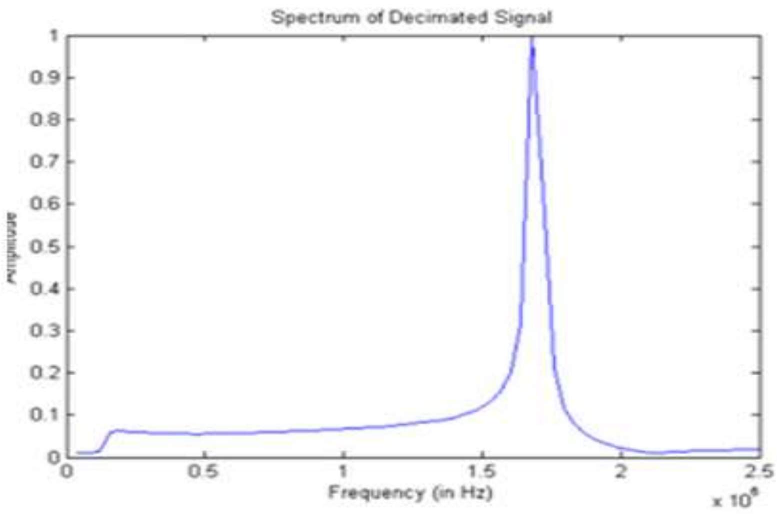
LPF Signal

Decimated signal





Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 1.68 MHz

Round Trip Delay 1 = 55.99 nseconds

Target at distance = 8.40 meters

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6.1.2 Test Case 2

Input values

Minimum Distance = 1 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz
Min Frequency = 77 GHz
Max Frequency = 77.460 GHz
Total Chirp time = 61.33 usec

Decimation Factor = 8

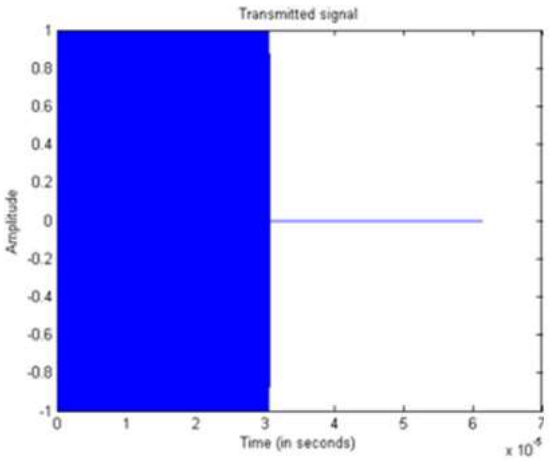
Time delay 1 = 100 nsec

Output values

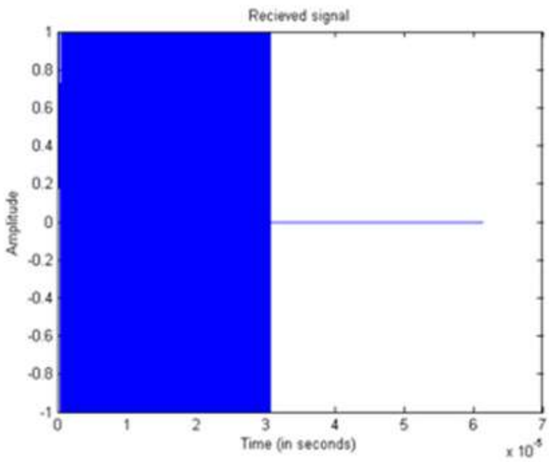
Maximum distance of target = 100 m
Minimum round trip delay = 6.6 nsec
Maximum round trip delay = 666.67 nsec
Up chirp time = 30.67 usec
Bandwidth = 460 MHz
No samples = 1024

No of samples after decimation = 128

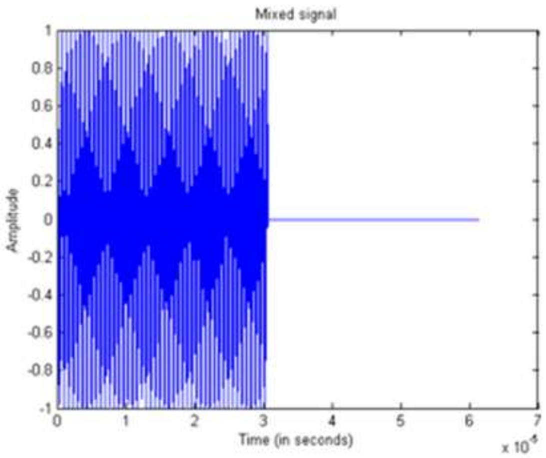
Generation of Transmitted signal



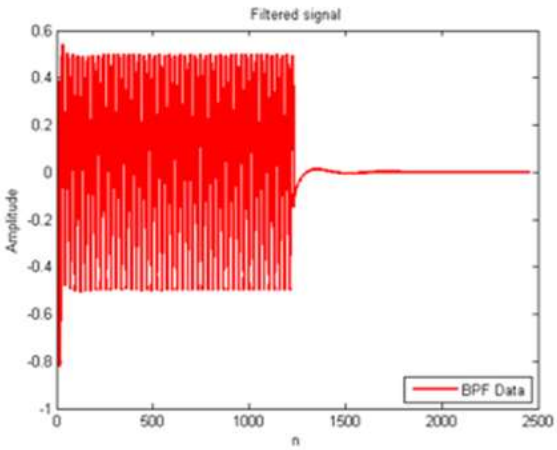
Generation of Received signal



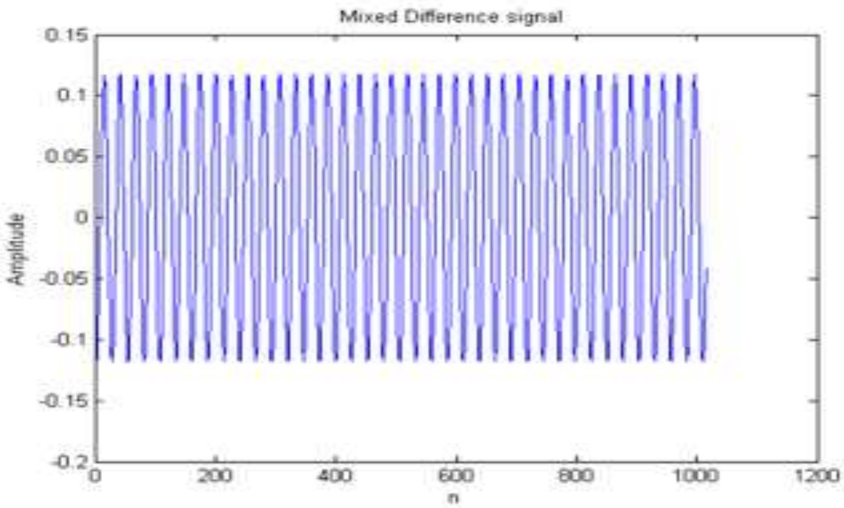
Mixed signal



BPF signal



Difference Method



Differentiator Output

Output Results

Target 1

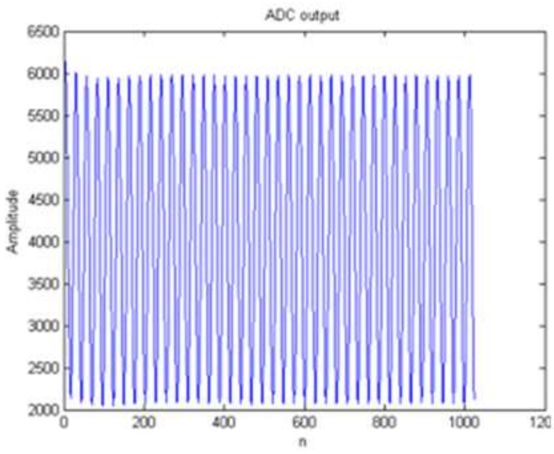
Beat Frequency 1 = 1.43 MHz

Round Trip Delay 1 = 95.77 nseconds

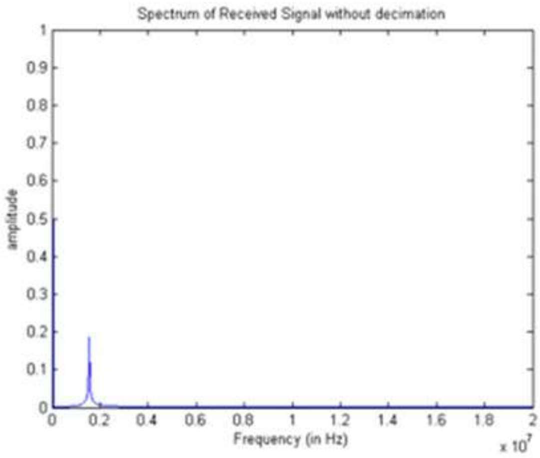
Target at distance = 14.3 meters

FFT Method

ADC output



Magnitude Spectrum



Output Results

Target 1

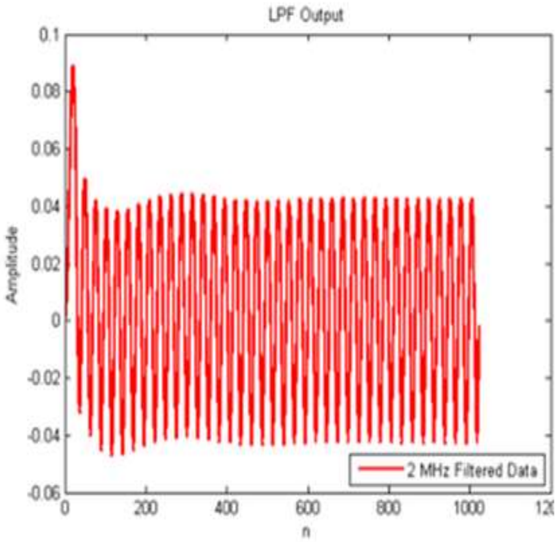
Beat Frequency 1 = 1.52 MHz

Round Trip Delay 1 = 101.56 nseconds

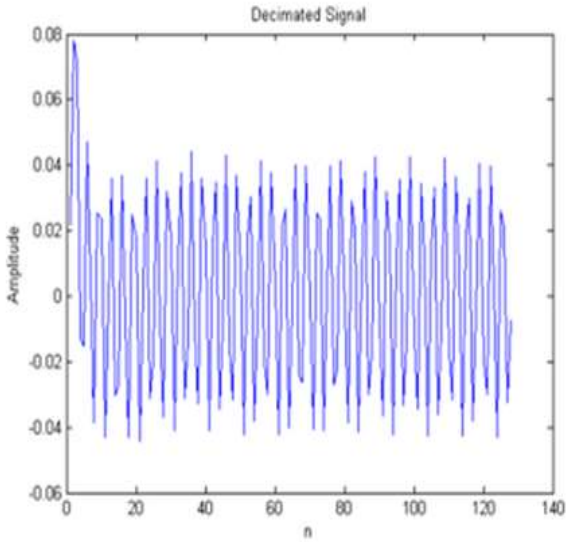
Target at distance =15.2 meters

FFT Method with decimation

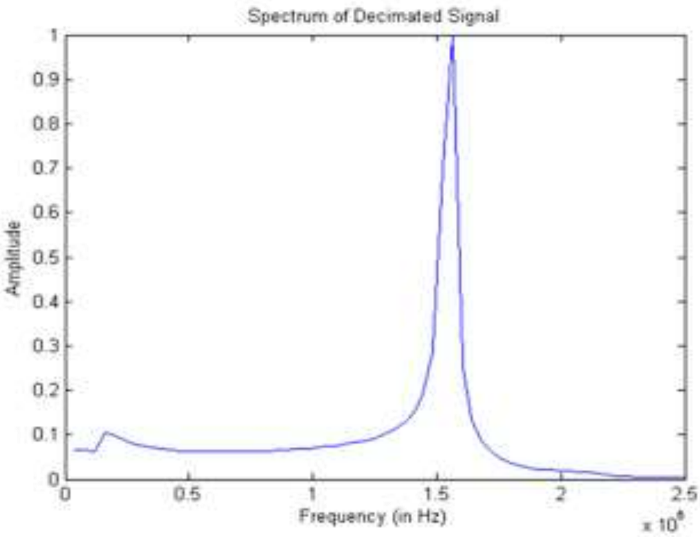
LPF Signal



Decimated Signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 =1.52 MHz

Round Trip Delay 1 = 101.56 nseconds

Target at distance = 15.2 meters

6.1.3 Test Case 3

Input values

Minimum Distance = 2.5 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz
Min Frequency = 77 GHz

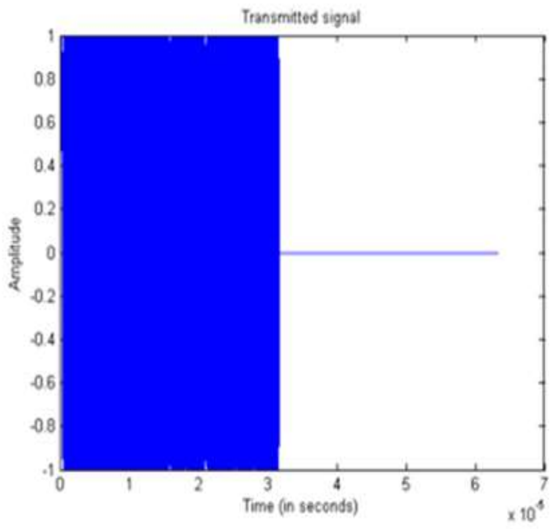
Max Frequency = 77.190 GHz
Total Chirp time = 63.33 usec

Decimation Factor = 8
Time delay 1 = 300 nsec

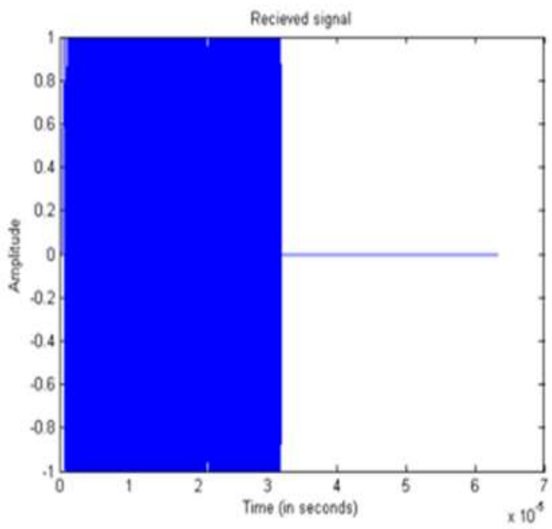
Output values
Maximum distance of target = 250 m
Minimum round trip delay = 16.67 nsec
Maximum round trip delay = 1666.67 nsec
Up chirp time = 31.67 usec
Bandwidth = 190 MHz
No samples = 1024

No of samples after decimation = 128

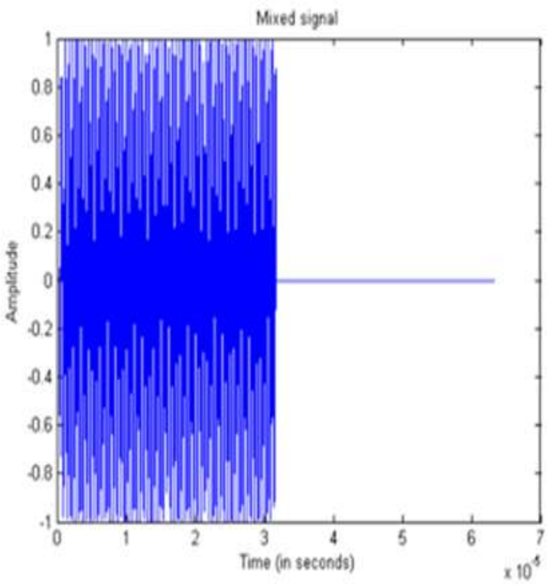
Generation of Transmitted signal



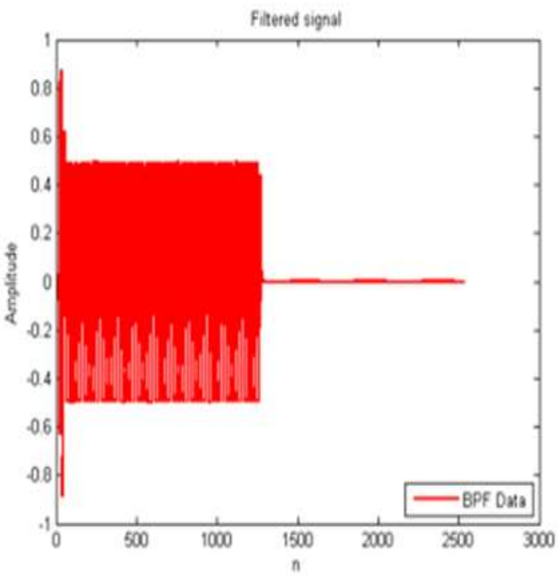
Generation of Received signal



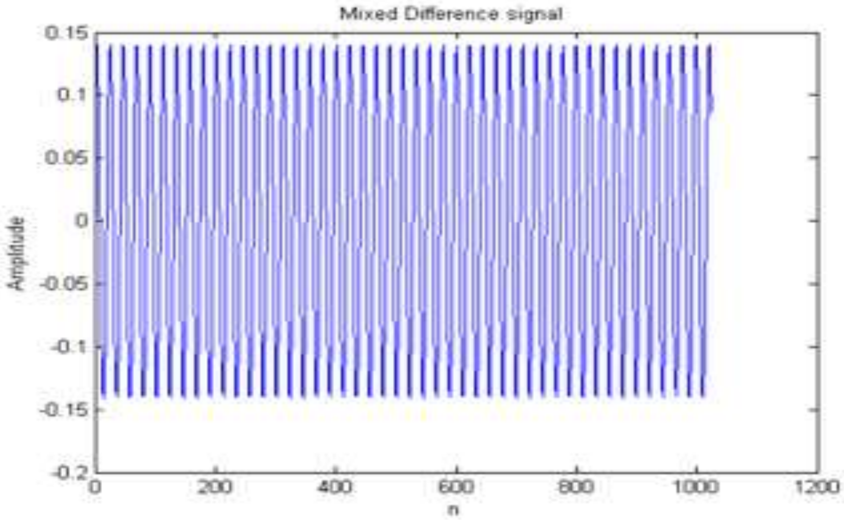
Mixed signal



BPF signal



Difference Method



Differentiator Output

Output Results

Target 1

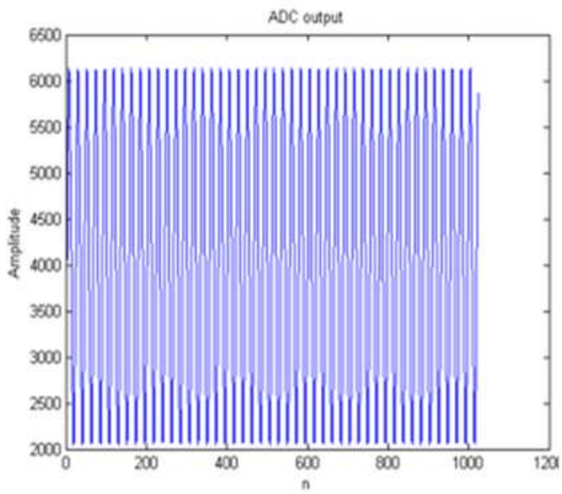
Beat Frequency 1 = 1.79 MHz

Round Trip Delay 1 = 299.06 nseconds

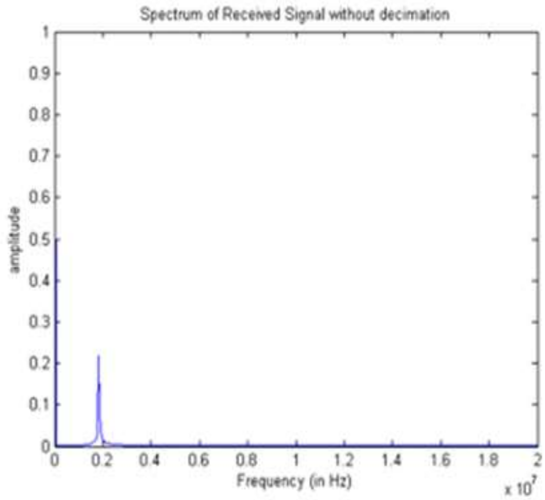
Target at distance = 44.8 meters

FFT Method

ADC output



Magnitude Spectrum



Output Results

Target 1

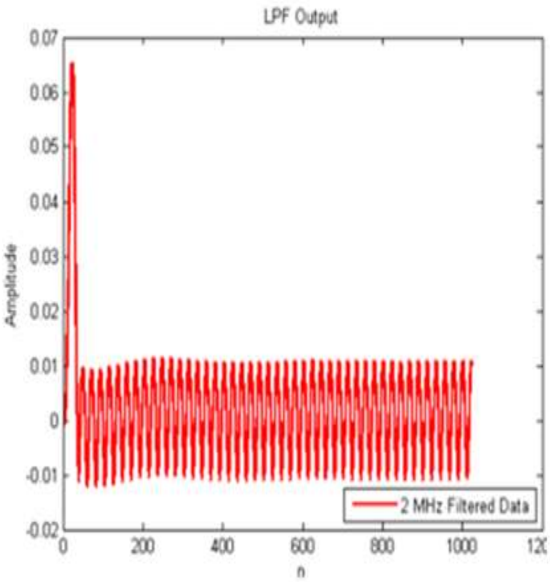
Beat Frequency 1 = 1.79 MHz

Round Trip Delay 1 = 299.47 nseconds

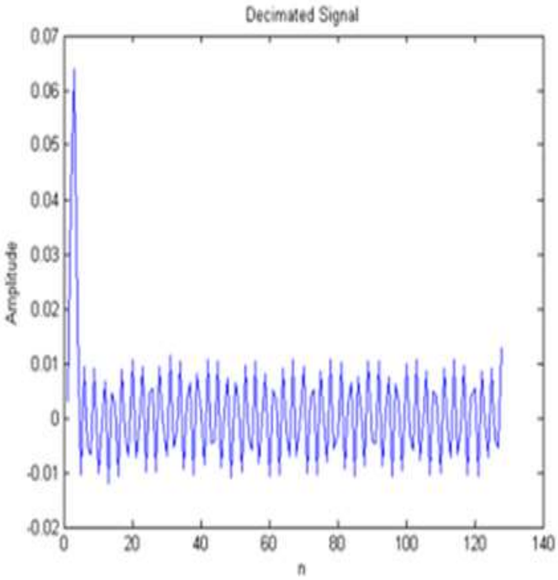
Target at distance = 44.9 meters

FFT Method with decimation

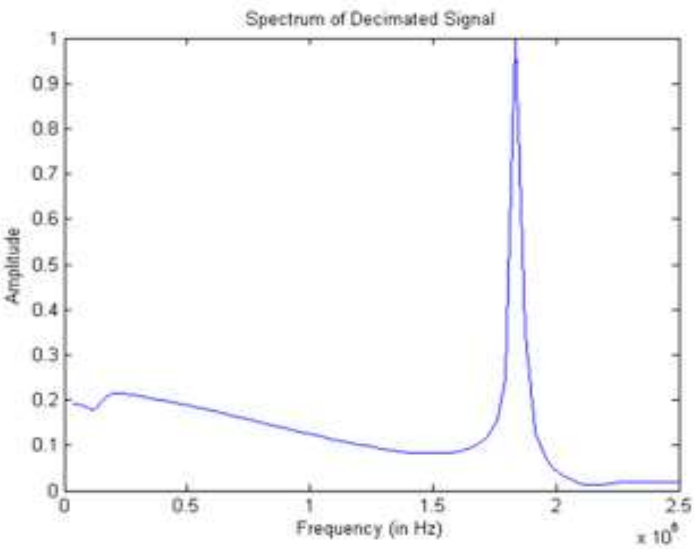
LPF Signal



Decimated Signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 1.79 MHz

Round Trip Delay 1 = 299.47 nseconds

Target at distance = 44.9 meters

6.1.4 Comparison of Different method results

From the simulation results in the previous section, the results for different signal processing methods and test cases are tabulated as shown below. The test cases 1, 2 and 3 are for different ranges of the target, 0.5 m to 50 m, 1 m to 100 m and 2.5 m to 250 m respectively.

Table 6.1 Detected range using single target detection algorithm.

Signal Processing Method	Test Case 1	Test Case 2	Test Case 3
Actual Range	8.25 m	15 m	45 m
Using Difference Method	8.90 m	14.3 m	44.8 m
Using FFT Method	8.40 m	15.2 m	44.9 m
Using FFT with Decimate	8.40 m	15.2 m	44.9 m

Table 6.2 Accuracy error using single target detection algorithm

Signal Processing Method	Accuracy Error(TC-1)	Accuracy Error(TC-2)	Accuracy Error(TC-3)
Using Difference Method	0.65 m	0.7 m	0.2 m
Using FFT Method	0.15 m	0.2 m	0.1 m
Using FFT with Decimate	0.15 m	0.2 m	0.1 m

From Accuracy error table for Test case 1 using FFT and FFT with decimate method we got 0.15 m error but it is well within the range resolution (0.2 m) so both methods given accurate result but in difference method the error is 0.65 m which is outside the range resolution. In Test case 1 difference method's range output is not accurate as other methods.

Similarly for Tests case 2, using FFT and FFT with decimate method we got 0.2 m error but it is same as the range resolution (0.2 m) so both methods given accurate result but in difference method the error is 0.7 m which is outside the range resolution. In Test case 2 also difference method's range output is not accurate as other methods.

In Test case 3, using FFT and FFT with Decimate method we got 0.1 m error but it is half of the range resolution (0.2 m) so both methods given accurate result but in Difference method the error is 0.2 m it is equal to range resolution (0.2 m). In Test case 3 all methods gave accurate results.

Table 6.3 Performance comparison for single target detection

Signal Processing Method	Using FFT(1024 point) Method	Using FFT(128 point) with decimate
Processing Time	More	20 % Less compared to FFT method
Hardware Requirement	More	More
Complexity	O(N*log(N))	O(N/8*log(N/8))

N - Number of samples

From accuracy error table and from the above discussion on Test cases 1, 2 and 3 we can conclude that both FFT and FFT with decimate method gives accurate results of range. The processing time, hardware requirement and complexity are more for FFT method compared to FFT with decimate which has less processing time and less complexity so we can conclude that Signal processing using FFT with decimate is the best algorithm for obstacle detection system in our use case.

6.2 Multiple target detection

6.2.1 Test case 4

Input values

Minimum Distance = 0.5 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz
Min Frequency = 77 GHz
Max Frequency = 77.910 GHz
Total Chirp time = 60.67 usec

Decimation Factor = 8
Time delay 1 = 40 nsec

Time delay 2 = 31.25 nsec

Time delay 3 = 22 nsec

Time delay 4 = 330 nsec

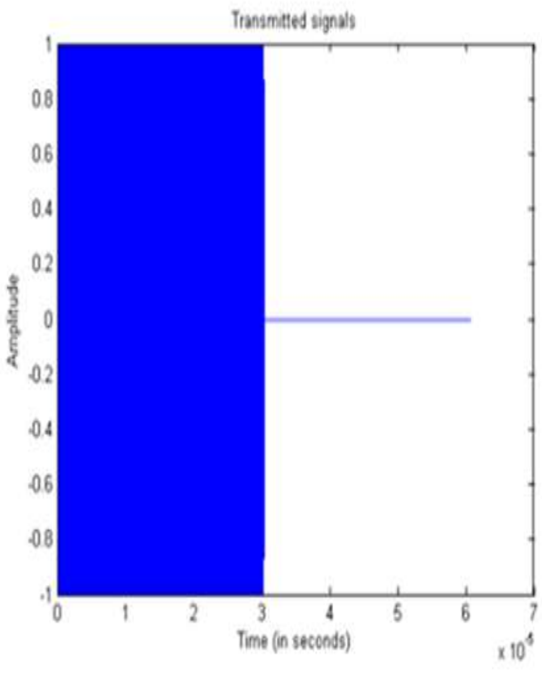
Time delay 5 = 450 nsec

Output values

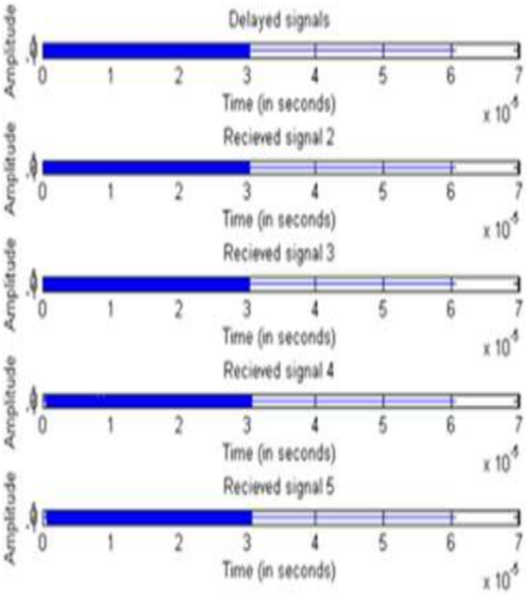
Maximum distance of target = 50 m
Minimum round trip delay = 3.3 nsec
Maximum round trip delay = 333.3333 nsec
Up chirp time = 30.33 usec
Bandwidth = 910 MHz
No samples = 1024

No of samples after decimation = 128
Range resolution = 0.2 m

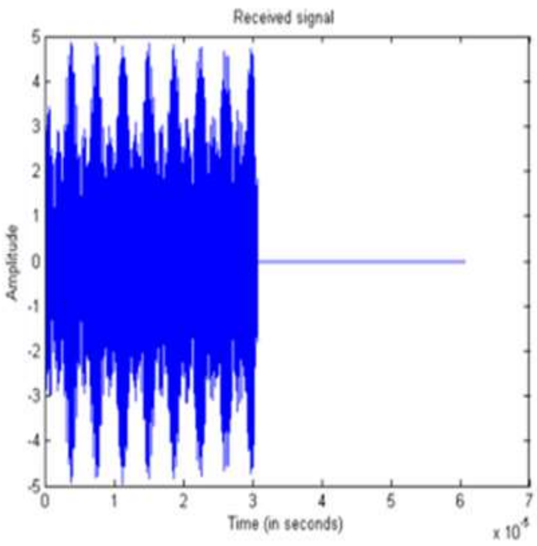
Generation of Transmitted signal



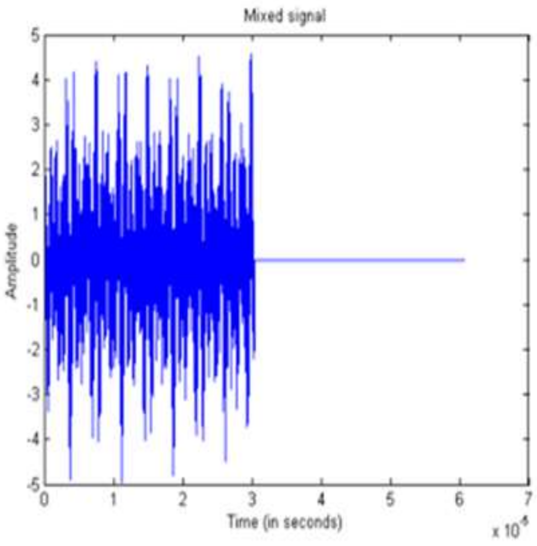
Generation of Received signal



Combined of Received signal

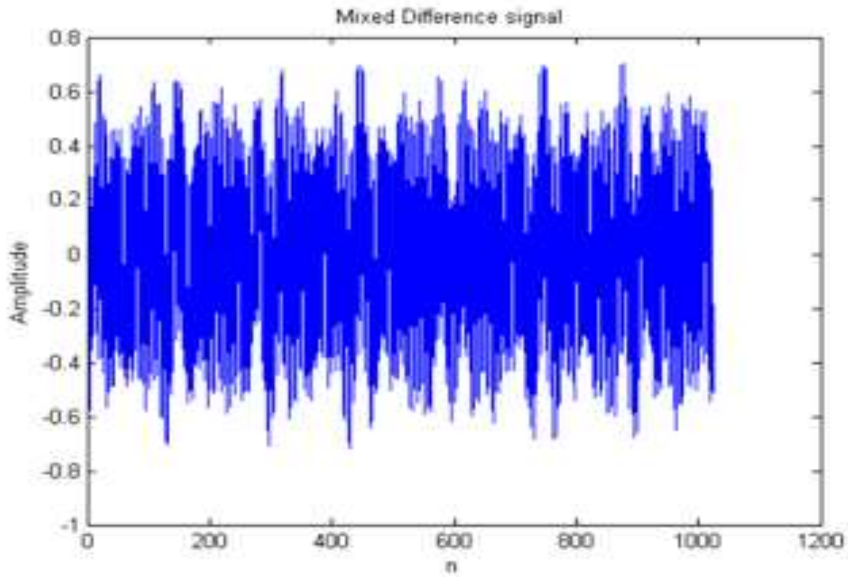


Mixed signal



Difference Method

Differentiator Output



Output Results

Target 1

Beat Frequency 1 = 1 MHz

Round Trip Delay 1 = 33.39 nseconds

Target 1 at distance = 5 meters

Target 2

Beat Frequency 2 = 0.99 MHz

Round Trip Delay 2 = 33 nseconds

Target 2 at distance = 4.9 meters

Target 3

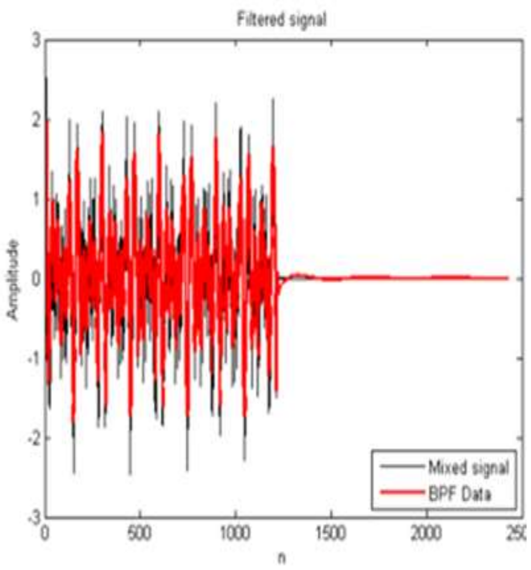
Beat Frequency 3 = 1.7 MHz

Round Trip Delay 3 = 56.56 nseconds

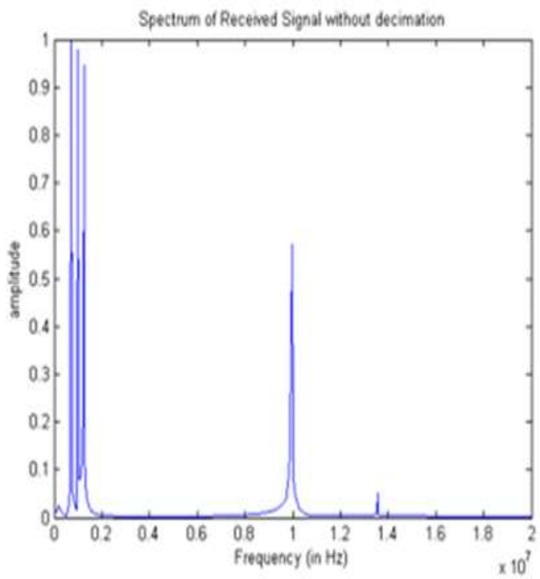
Target 3 at distance = 8.5 meters

FFT Method

BPF signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.70 MHz

Round Trip Delay 1 = 23.43 nseconds

Target 1 at distance = 3.5 meters

Target 2

Beat Frequency 2 = 0.98 MHz

Round Trip Delay 2 = 32.55 nseconds

Target 2 at distance = 4.9 meters

Target 3

Beat Frequency 3 = 1.25 MHz

Round Trip Delay 3 = 41.6 nseconds

Target 3 at distance = 6.2 meters

Target 4

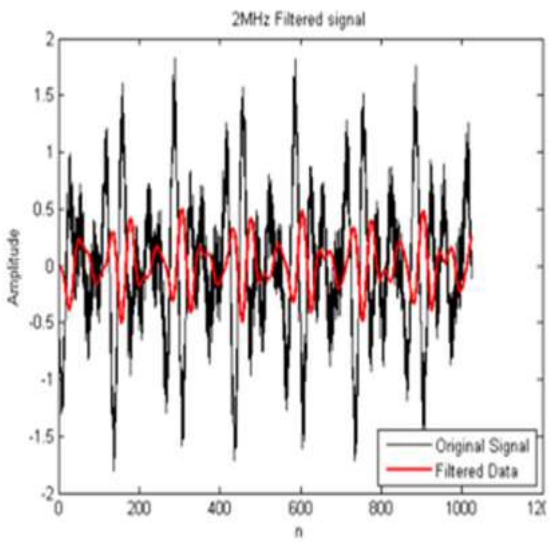
Beat Frequency 4 = 9.96 MHz

Round Trip Delay 4 = 332 nseconds

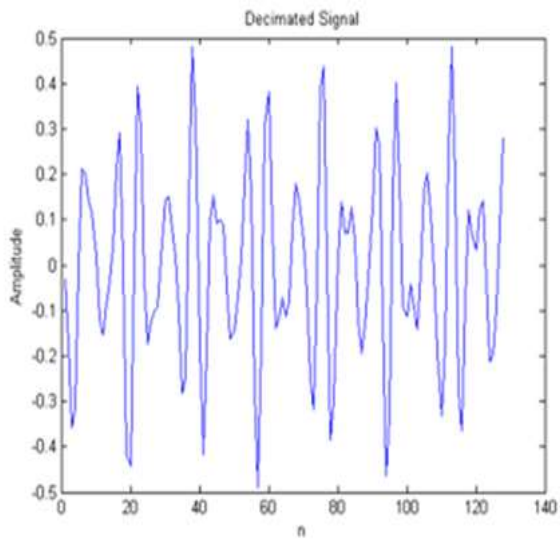
Target 4 at distance = 49.7 meters

FFT Method with decimation

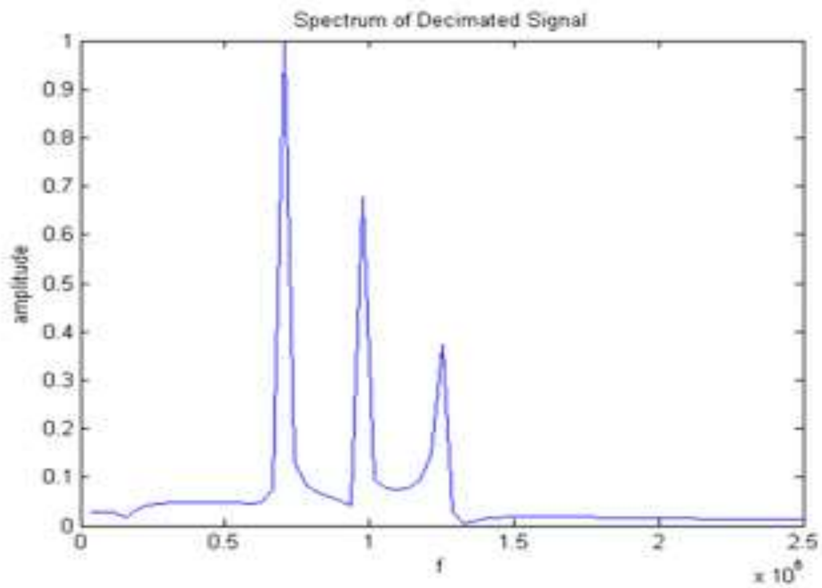
LPF Signal



Decimated Signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.70 MHz

Round Trip Delay 1 = 23.43 nseconds

Target 1 at distance = 3.5meters

Target 2

Beat Frequency 2 = 0.98 MHz

Round Trip Delay 2 = 32.55 nseconds

Target 2 at distance = 4.9 meters

Target 3

Beat Frequency 3 = 1.25 MHz

Round Trip Delay 3 = 41.6 nseconds

Target 3 at distance = 6.2 meters

6.2.2 Test Case 5

Input values

Minimum Distance = 1 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz
Min Frequency = 77 GHz
Max Frequency = 77.460 GHz
Decimation Factor = 8
Time delay 1 = 40 nsec

Time delay 2 = 31.25 nsec

Time delay 3 = 60 nsec

Time delay 4 = 330 nsec

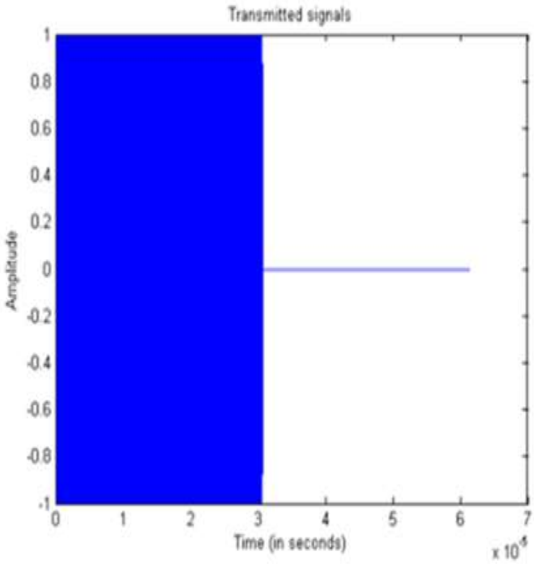
Time delay 5 = 450 nsec

Output values

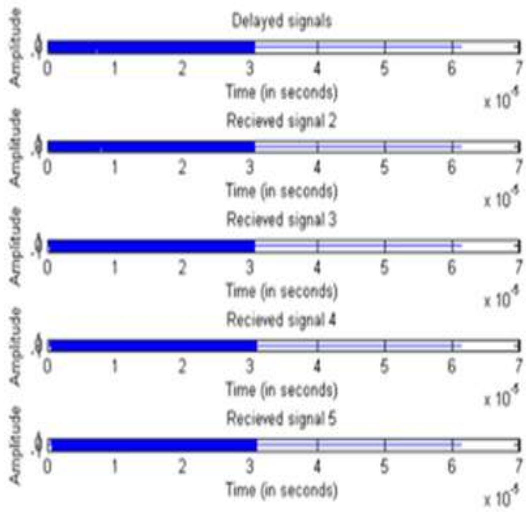
Maximum distance of target = 100 m
Minimum round trip delay = 6.67 nsec
Maximum round trip delay = 666.67 nsec
Up chirp time = 30.67 usec
Bandwidth = 460 MHz
No samples = 1024

No of samples after decimation = 128
Range resolution = 0.4 m

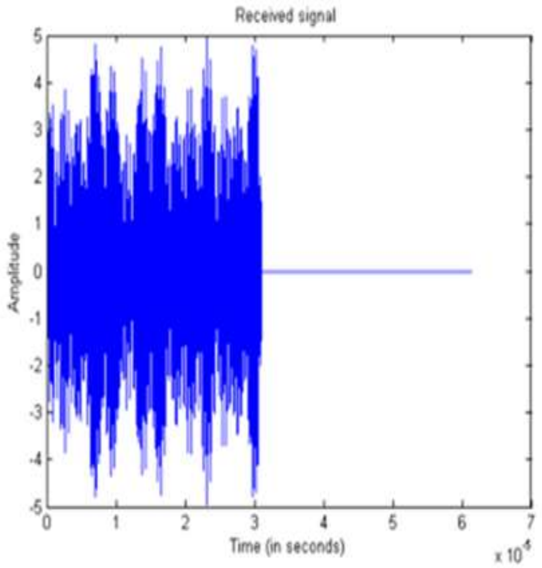
Generation of Transmitted signal



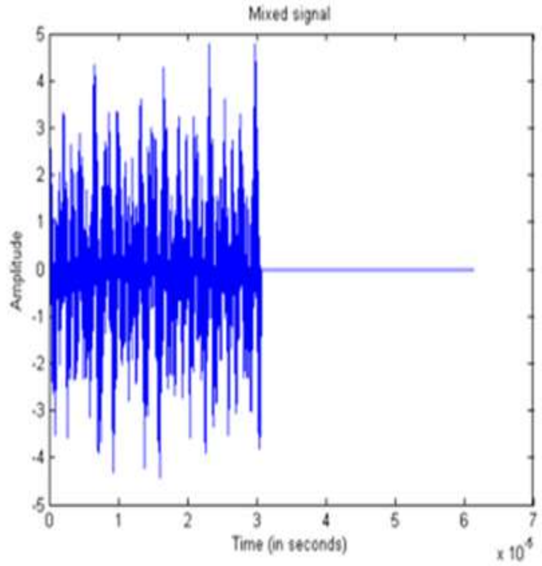
Generation of Received signal



Combined of Received signal

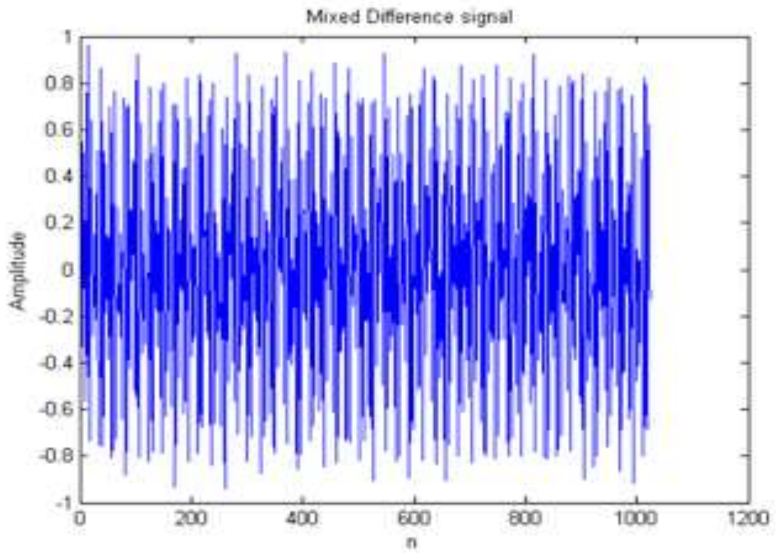


Mixed signal



Difference Method

Differentiator Output



Output Results

Target 1

Beat Frequency 1 = 1.5 MHz

Round Trip Delay 1 = 99.3 nseconds

Target 1 at distance = 14.9 meters

Target 2

Beat Frequency 2 = 1.36 MHz

Round Trip Delay 2 = 90.7 nseconds

Target 2 at distance = 13.6 meters

Target 3

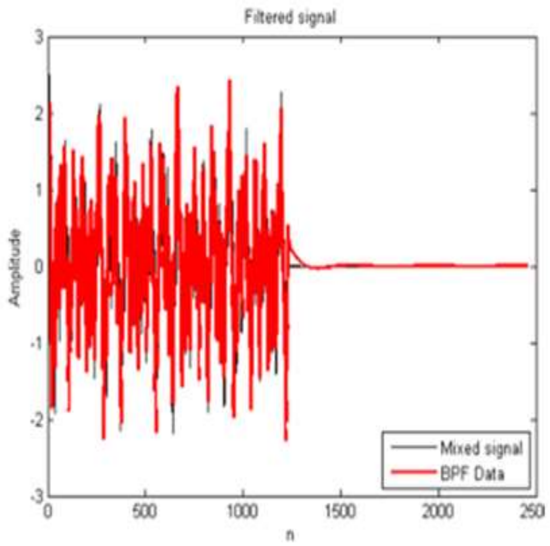
Beat Frequency 3 = 2.61 MHz

Round Trip Delay 3 = 174.3 nseconds

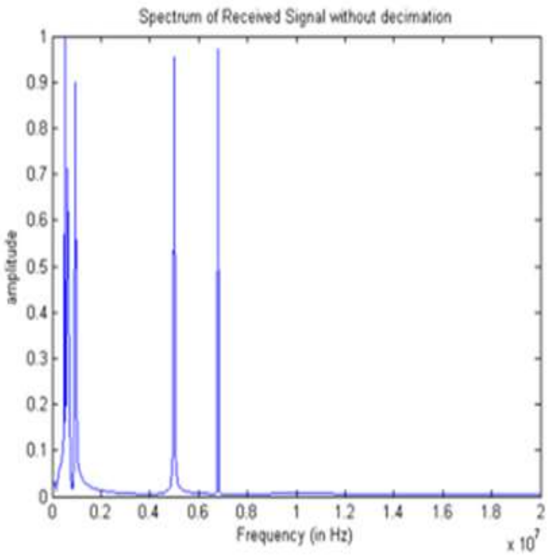
Target 3 at distance = 26.1 meters

FFT Method

BPF signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.51 MHz

Round Trip Delay 1 = 33.81 nseconds

Target 1 at distance = 5.1 meters

Target 2

Beat Frequency 2 = 0.63 MHz

Round Trip Delay 2 = 41.67 nseconds

Target 2 at distance = 6.3 meters

Target 3

Beat Frequency 3 = 0.94 MHz

Round Trip Delay 3 = 62.5 nseconds

Target 3 at distance = 9.3 meters

Target 4

Beat Frequency 4 = 4.99 MHz

Round Trip Delay 4 = 332 nseconds

Target 4 at distance = 49.9 meters

Target 5

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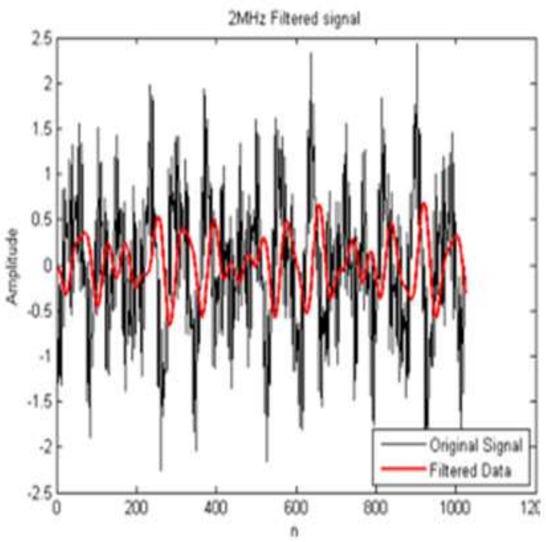
Beat Frequency 5 = 6.76 MHz

Round Trip Delay 5 = 452.87 nseconds

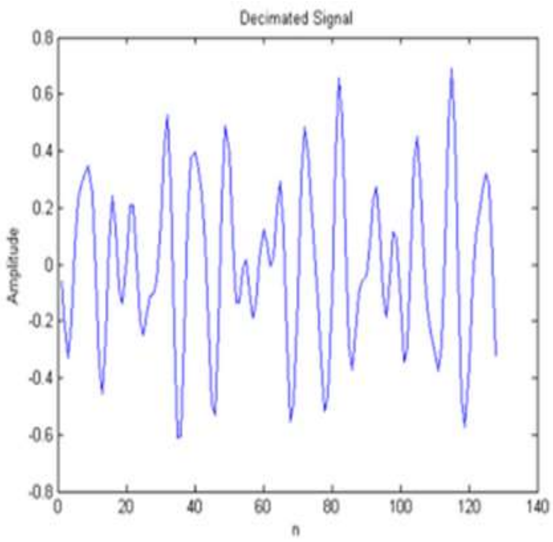
Target 5 at distance = 67.9 meters

FFT Method with decimation

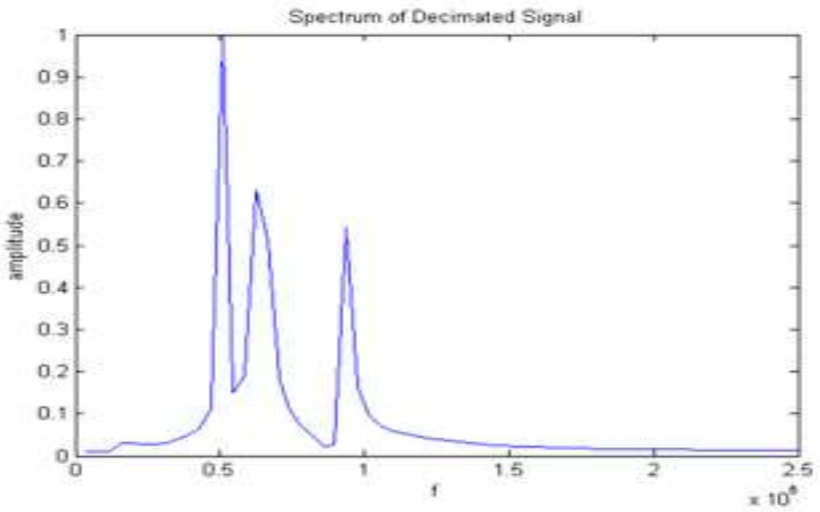
LPF Signal



Decimated Signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.51 MHz

Round Trip Delay 1 = 33.83 nseconds

Target 1 at distance = 5.1 meters

Target 2

Beat Frequency 2 = 0.63 MHz

Round Trip Delay 2 = 41.67 nseconds

Target 2 at distance = 6.3 meters

Target 3

Beat Frequency 3 = 0.94 MHz

Round Trip Delay 3 = 62.5 nseconds

Target 3 at distance = 9.3 meters

6.2.3 Test Case 6

Input values

Minimum Distance = 2.5 m
Band pass filter cutoff frequency = 100 KHz -10 MHz
Low pass filter cutoff frequency = 2 MHz
Min Frequency = 77 GHz
Max Frequency = 77.190 GHz
Total Chirp time = 63.33 usec

Time delay 1 = 40 nsec

Time delay 2 = 90 nsec

Time delay 3 = 60 nsec

Time delay 4 = 330 nsec

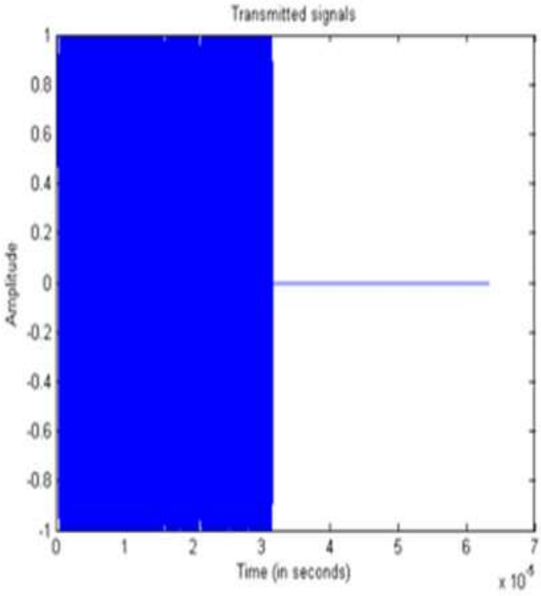
Time delay 5 = 450 nsec

Output values

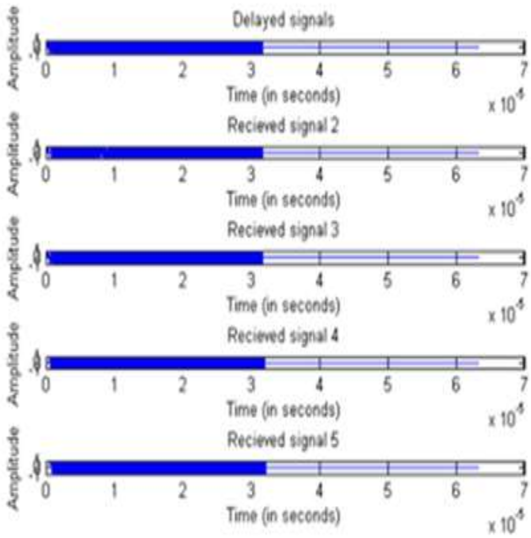
Maximum distance of target = 250 m
Minimum round trip delay = 16.67 nsec
Maximum round trip delay = 1666.67 nsec
Up chirp time = 31.67 usec
Bandwidth = 190 MHz
No samples = 1024

No of samples after decimation = 128

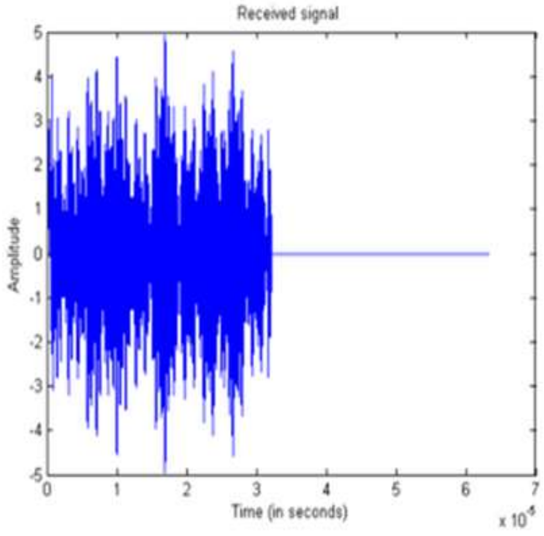
Generation of Transmitted signal



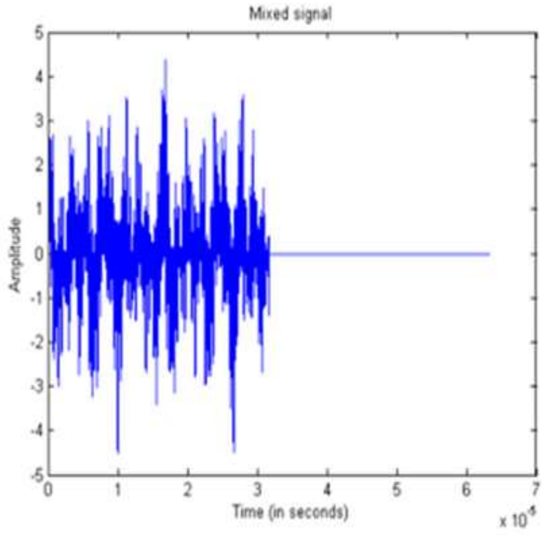
Generation of Received signal



Combined Received Signal

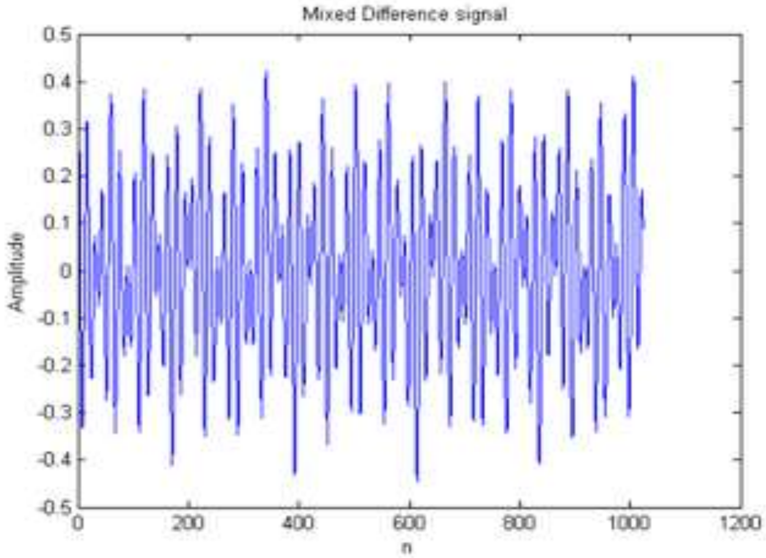


Mixed signal



Difference Method

Differentiator Output



Output Results

Target 1

Beat Frequency 1 = 0.99 MHz

Round Trip Delay 1 = 165.72 nseconds

Target 1 at distance = 24.8 meters

Target 2

Beat Frequency 2 = 1.02 MHz

Round Trip Delay 2 = 171.52 nseconds

Target 2 at distance = 25.7 meters

Target 3

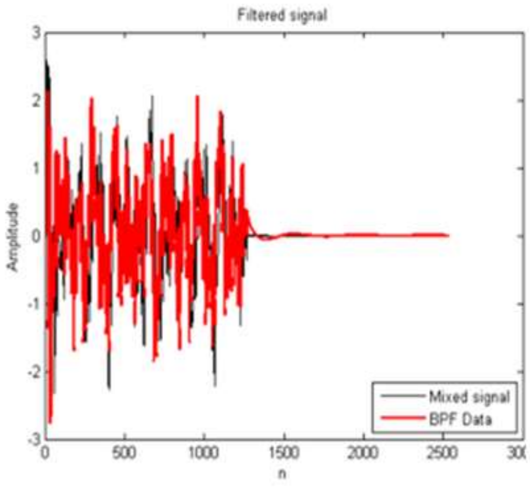
Beat Frequency 3 = 0.24 MHz

Round Trip Delay 3 = 39.93 nseconds

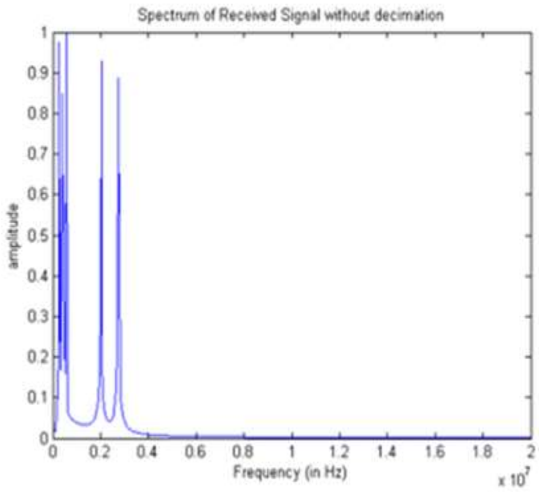
Target 3 at distance = 6 meters

FFT Method

BPF signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.27 MHz

Round Trip Delay 1 = 45.57 nseconds

Target 1 at distance = 6.8 meters

Target 2

Beat Frequency 2 = 0.39 MHz

Round Trip Delay 2 = 65.1 nseconds

Target 2 at distance = 9.7 meters

Target 3

Beat Frequency 3 = 0.52 MHz

Round Trip Delay 3 = 96.66 nseconds

Target 3 at distance = 14.3 meters

Target 4

Beat Frequency 4 = 2.03 MHz

Round Trip Delay 4 = 338.5 nseconds

Target 4 at distance = 50.7 meters

Target 5

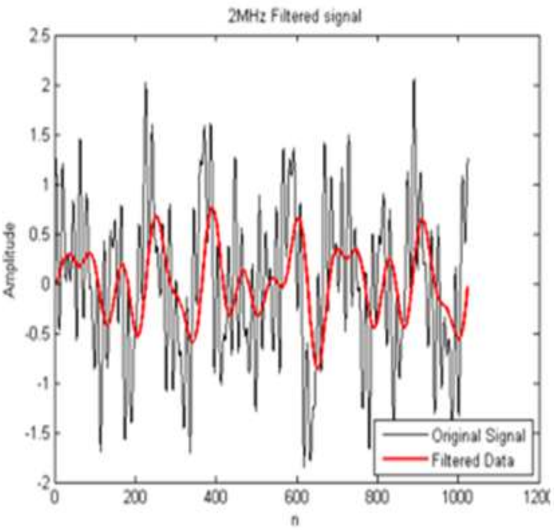
Beat Frequency 5 = 2.73 MHz

Round Trip Delay 5 = 455.7 nseconds

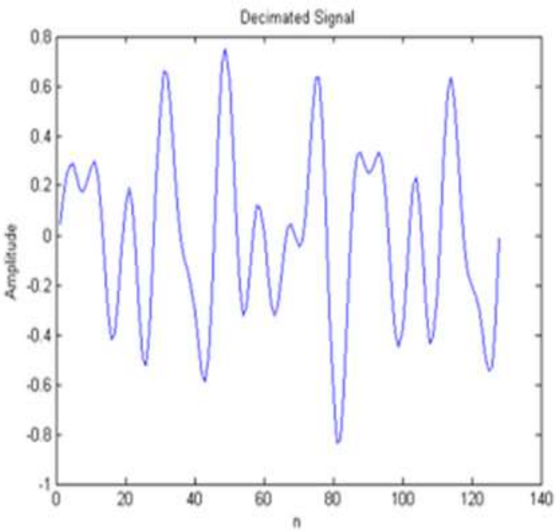
Target 5 at distance = 68.3 meters

FFT Method with decimation

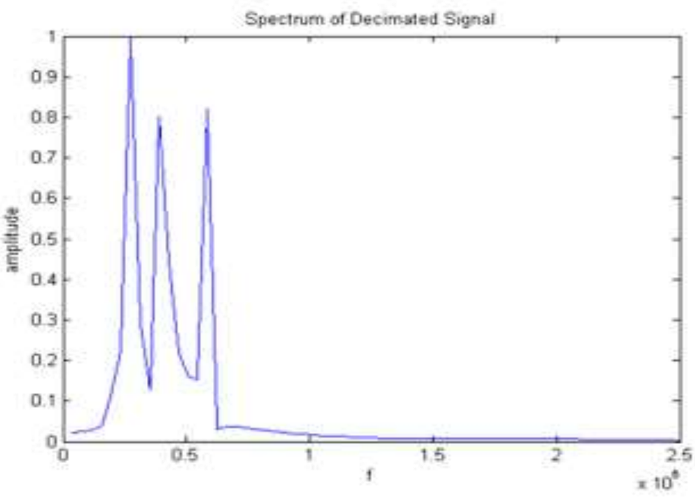
LPF Signal



Decimated Signal



Magnitude Spectrum



Output Results

Target 1

Beat Frequency 1 = 0.27 MHz

Round Trip Delay 1 = 45.57 nseconds

Target 1 at distance = 6.8 meters

Target 2

Beat Frequency 2 = 0.39 MHz

Round Trip Delay 2 = 65.1 nseconds

Target 2 at distance = 9.7 meters

Target 3

Beat Frequency 3 = 0.52 MHz

Round Trip Delay 3 = 96.65 nseconds

Target 3 at distance = 14.3 meters

6.2.4 Comparison of Different method results

From the simulation results in the previous section, the results for different signal processing methods and test cases are tabulated as shown below. The test cases 4, 5 and 6 are for different ranges of the target, 0.5 m to 50 m, 1 m to 100 m and 2.5 m to 250 m respectively.

Test Case 4

Table 6.4 Detected range using multiple target detection algorithms for Test case 4

Signal Processing Method/Target	Target 1	Target 2	Target 3	Target 4	Target 5
Actual Range	3.3 m	4.7 m	6 m	49.5 m	67.5 m
Difference Method	4.9 m	5 m	8.5 m	-	-
FFT Method	3.5 m	4.9 m	6.2 m	49.7 m	OR
FFT with Decimate Method	3.5 m	4.9 m	6.2 m	OR	OR

OR – Out of Range

Table 6.5 Accuracy error using multiple target detection algorithms for Test case 4

Signal Processing Method/Target	Accuracy Error (Target 1)	Accuracy Error (Target 2)	Accuracy Error (Target 3)	Accuracy Error (Target 4)	Accuracy Error (Target 5)
Difference Method	1.6 m	0.3 m	2.5 m	-	-
FFT Method	0.2 m	0.2 m	0.2 m	0.2 m	-
FFT with Decimate Method	0.2 m	0.2 m	0.2 m	-	-

From Accuracy error table for Test case 4 using FFT and FFT with decimate method we got 0.2 m accuracy error for target 1,target 2 ,target 3,target 4.But accuracy error is equal to the range resolution (0.2 m) so it won't affect range of target with actual range. Both methods gave accurate results. In difference method the error is 1.6 m, 0.3 m and 2.5 m for target 1, target 2 and target 3 respectively which is outside of range resolution (0.2 m). In Test case 4 difference method's range output is not accurate due to coupling of amplitudes at the receiving end. In FFT with decimate method target 4 is not detected because target 4 is at distance 49.5 meters, it is rejected by low pass filter .In our example low pass filter passes the signal with distance maximum of 10 meters. Similarly target 5 is at distance of 67.5 meters which is rejected by band pass filter because the band pass filter passes signal of range 0.5 meters to 50 meters.

Test Case 5

Table 6.6 Detected range using multiple target detection algorithms for Test case 5

Signal Processing Method/Target	Target 1	Target 2	Target 3	Target 4	Target 5
Actual Range	4.7 m	6 m	9 m	49.5 m	67.5 m
Using Difference Method	13.6 m	14.9 m	26.1 m	-	-
Using FFT Method	5.1 m	6.3 m	9.3 m	49.9 m	67.9 m
Using FFT with Decimate Method	5,1 m	6.3 m	9.3 m	OR	OR

Table 6.7 Accuracy error using multiple target detection algorithms for Test case 5

Signal Processing Method/Target	Accuracy Error (Target 1)	Accuracy Error (Target 2)	Accuracy Error (Target 3)	Accuracy Error (Target 4)	Accuracy Error (Target 5)
Using Difference Method	8.9 m	8.6 m	16.8 m	-	-
Using FFT Method	0.4 m	0.3 m	0.3 m	0.4 m	0.4 m
Using FFT with Decimate Method	0.4 m	0.3 m	0.3 m	-	-

From Accuracy error table for Test case 5 using FFT and FFT with decimate method we got 0.4 m, 0.3 m , 0.3 m and 0.3 m accuracy error for target 1,target 2 ,target 3 and target 4 respectively. But accuracy error 0.4 m and 0.3 m are within the range resolution (0.4 m) so it won't affect range of target with actual range. Both methods gave accurate results. In difference method the error is 8.9 m, 8.6 m and 16.8 m for target 1, target 2 and target 3 respectively which is outside of range resolution (0.4 m). In Test case 5 difference method's range output is not accurate due to coupling of amplitudes at the receiving end. In FFT with decimate method target 4 is not detected because target 4 is at distance 49.5 meters it is rejected by low pass filter .In our example low pass filter passes the signal with distance maximum of 20 meters.

Test Case 6

Table 6.8 Detected range using multiple target detection algorithms for Test case 6

Signal Processing Method/Target	Target 1	Target 2	Target 3	Target 4	Target 5
Actual Range	6 m	9 m	13.5 m	49.5 m	67.5 m
Using Difference Method	6 m	24.8 m	25.7 m	-	-
Using FFT Method	6.8 m	9.7 m	14.3 m	50.2 m	68.3 m
Using FFT with Decimate Method	6.8 m	9.7 m	14.3 m	OR	OR

OR – Out of Range

Table 6.9 Accuracy error using multiple target detection algorithms for Test case 6

Signal Processing Method/Target	Accuracy Error (Target 1)	Accuracy Error (Target 2)	Accuracy Error (Target 3)	Accuracy Error (Target 4)	Accuracy Error (Target 5)
Difference Method	0 m	15.1 m	11.4 m	-	-
FFT Method	0.8 m	0.7 m	0.8 m	0.7 m	0.8 m
FFT with Decimate Method	0.8 m	0.7 m	0.8 m	-	-

From Accuracy error table for Test case 6 using FFT and FFT with Decimate method we got 0.8 m, 0.7 m , 0.8 m ,0.7 , accuracy error for target 1,target 2 ,target 3,target 4 respectively within the range resolution (0.9 m) so it won.t affect range of target with actual range. Both methods gave accurate results. In difference method the error is 0 m, 15.1 m and 11.4 m for target 1, target 2 and target 3 respectively .For target 2 and target 3 range errors are outside of range resolution (0.8 m). In Test case 6 also difference method's range output is not accurate due to coupling of amplitudes at the receiving end.

Table 6.10 Comparison between FFT and Difference method (for N samples)

Operation	FFT Method	Difference Method
Memory storage	(N*12) bits	2*(N*12) bits
Multiplication	(N/2)*log N	NILL
Addition / Subtraction	N*log N	N-1
Comparator	NILL	(N-1)
Peak Detector	Required	Required
Complexity	O(N*log(N))	O(N-1)

Table 6.11 Performance comparison for multiple target detection

Signal Processing Method	Using FFT(1024 point) Method	Using FFT(128 point) with decimate
Processing Time	More	20% Less compared to 1024 FFT method
Hardware Requirement	More	Less
Complexity	O(N*log(N))	O(N/8*log(N/8))

N - Number of samples

From accuracy error table and from above discussion on different Test cases we can conclude that both FFT and FFT with decimate method gives accurate results of range. FFT method uses 1024 point FFT, the processing time is more and the hardware complexity is too high. Hence not a feasible solution. Leading to the FFT with decimate signal processing method which gives the same accuracy as the FFT method but reducing the hardware complexity and processing time so we can conclude that Signal processing using FFT with decimate is the best algorithm for obstacle detection system in our use case.

VII. CONCLUSION

The signal processing algorithm was implemented successfully for the real time obstacle detection system using radar. As discussed there are three different types of signal processing algorithms for the obstacle detection system and finding range of the obstacle.

Difference method which works on amplitude modulation has a disadvantage of amplitude variation of the signal depending on the type of target, hence providing inaccurate results.

FFT method finds the beat frequency depending upon the range of the target, hence giving accurate range. Since it is a 1024 point FFT, the processing time is more and the hardware complexity is too high and hence not a feasible solution. **FFT with Decimate** signal processing method gives the same accuracy as the FFT method but reducing the hardware complexity and processing time, as the 1024 samples is decimated by 8 times resulting in 128 samples. This detection algorithm could also be used in other obstacle detection research, such as the car parking assistant application. The algorithm would have to be adapted to the specific robot function, but the basis for the algorithm stays the same.

The signal processing unit can be improved by adding information of velocity and direction. The signal processing algorithm is specific to the obstacle detection, specifically slow moving vehicles that don’t need velocity information. In order to improve this algorithm the velocity and direction finding part needs to be added.

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