A THESIS FOR THE DEGREE OF MASTER OF SCIENCE

Detection Performance of 24GHz UWB Short Range Radar Receivers in Vehicular Clutter Environment

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Abstract

High range resolution ultra wideband radars attract considerable attention as short range automotive radar for target detection and ranging. The 24GHz short range radar (SRR) in automotive sector is the recent hot research topic with an idea to avoid collision and increase road safety. The demand for short range radar sensor which is used for the target detection has been increased fabulously in automotive sector. The range resolution is the key specification that the 24-GHz sensor is required to fulfill in all the applications. The precise measurement of object movements is essential for the prediction of trajectories and the prevention of false alarms.

Radar signal reflected from a target often contains unwanted echoes called as clutter, so the detection of target is difficult with clutter echoes. Therefore, it is important to investigate the radar detector performance for the better detection of the reflected signals. In this thesis the optimal detector is obtained for various log-normal distributional parameters in log-normal clutter environment. The detectors we used are square law detector, linear detector and logarithmic detector. The detection performance of non-coherent logarithmic detector in log normal and weibull clutter environment is also analyzed. The detection probability of the detector is obtained with different mean and variance value in log normal clutter environment, and with different shape parameter and scale parameter values in weibull clutter environment at system bandwidths of 1GHz, 500MHz and 100MHz.The performance of the detectors are compared in log-normal and weibull clutter environment and a suitable detector is determined for automotive short range radar applications.

Keywords: Square law detector, linear detector, logarithmic detector, clutter, log-normal clutter, weibull clutter, Coherent and non-coherent integration.

국문초록

초광대역 레이더는 고해상도를 갖고 있어서 목표물을 검출하고 거리를 측정하는 목적으로 단거리 차량용 레이더로 각광 받고 있다. 차량용으로 사용하고 있는 24GHz 대역의 단거리 레이더는 차량 사고를 방지하고 운전자의 안전을 보장하기 위해 고안된 아이디어로 최근 많은 관심을 받고 있는 연구 주제이다. 특히, 초광대역 레이더의 가 장 큰 장정은 매우 높은 거리 해상도라고 볼 수 있다. 따라서 움직이는 목표물의 정확한 거리를 측정할 수 있다는 것은 추적과 잘못 된 검출을 방지하는데 필요한 필수 요건이다.

목표물에서 반사된 레이더 수신 신호는 “클러터(clutter)”라고 하는 원하지 않는 반사 신호를 포함하게 되며, 이로 인해 원하는 목표물을 검출하는데 어려움을 갖게 된다. 특히, 클러터는 레이더 수신기의 성능에 영향을 미치는 검출 확률과 오류 확률에 큰 영향을 끼치게 된다. 그러므로, 본 논문에서는 로그-노말 클러터 환경에서 다양한 로그-노말 파라메타에 따른 최적의 검출기를 획득하였다. 검출기는 자승 검출기, 선형 검출기, 로그 검출기를 사용한다. 또한, 로그-노말 및 weibull 환경에서 비동기 방식 로그 검출기의 검출 확률을 얻었다. 검출기의 검출 확률은 다음과 같은 환경을 고려하였다. 우선, 로그-노말 환경에서 다양한 클러터의 평균과 분산값을 사용하였다. 둘째, weibull 환경에서 다양한 파라메타를 고려하여 다양한 환경을 가정하였다. 마지막으로, 신호의 펄스 대역폭은 1GHz, 500MHz, 100MHz 를 고려하였다. 컴퓨터 시뮬레이션을 통해 다양한 로그-노말 및 weibull 환경에서 성능을 비교하여 단거리용 차량용 레이더에 적합한 검출기를 제시하였다.

Keywords: 자승 검출기, 선형 검출기, 로그 검출기, 클러터, 로그-노말 클러터, 웨이블 클러터, 동기 및 비동기 누적

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1. Introduction

The first RADAR (radio detection and ranging) system was invented by Christian Hülsmeyer (1881-1957) in 1904 to avoid vessel collisions on the river Rhine even in bad weather conditions. The first radar application in road traffic situations was started intensively in the early 1970s. The main idea is to avoid vehicle collisions in traffic density and to increase driving comfort and passenger’s security. Unlike airbag systems which react when an accident already happened, a radar system can even detect collisions before they happen and react very early to avoid an accident or minimize the consequences. Systems at the very early stage of development in the 1970s exceeded the acceptable geometrical product size for a passenger car, the target price for one unit and had a performance which was not convincing enough. So in 1999, a leading car manufacturer came up with a 77GHz pulse radar system that satisfied all the key parameters like small cost at large volume production, size and performance. The 77GHz narrow beam long range pulse radar system are capable of measuring even targets of small radar cross section up to 150m in front of the vehicle. The customers accept the functionality of an adaptive cruise control (ACC) system as a security and comfort system but the requirements for additional and future automotive radar applications like parking aid, pre-crash, stop & go cannot be fulfilled by these typical ACC radars. These radar systems can monitor only very narrow section of the car and have some system limitations in angular coverage, range accuracy and range resolution. For this reason a completely new automotive radar system development has been started based on high powerful short range pulse radar sensors in the 24 GHz domain.

The 24GHz short range radar (SRR) in automotive sector is the recent hot research topic with an idea to avoid collision and increase road safety. The demand for short range radar sensor which is used for the target detection has been increased fabulously in automotive sector. The range resolution is the key specification that the 24-GHz sensor is required to fulfill in all the applications. The accuracy of time information and the ability to precisely determine an object’s location is inversely proportional to the signal bandwidth. The precise measurement of object movements is essential for the prediction of trajectories and the prevention of false alarms.

The source for target detection is the radar signals reflected by the target. The reflected signal in the radar receiver is a mixture of atmospheric noise, reflected signal from the target and also the objects surrounding the target. The signals reflected back from the objects surrounding the target are often referred as clutter signals (clutter echoes). In the UWB automotive short range radar the clutter echoes are the echoes reflected from buildings, trees and other objects on the side of the road environment. So the detection of target is difficult with clutter echoes. Therefore, it is important to investigate the performance of the radar receiver for the better detection of the target reflected signals and precise range measurement. The purpose of this thesis is to analyze the radar receiver's performances using detection probability and false alarm probability through computer simulation results and also to determine a suitable receiver that can be used in UWB short range radar vehicular applications.

2. Radar System

Radar systems use modulated waveforms and directive antennas to transmit electromagnetic energy into a specific volume in space to search for targets. Objects (targets) within a search volume will reflect portions of this energy (radar returns or echoes) back to the radar. These echoes are then processed by the radar receiver to extract target information such as range, velocity, angular position, and other target identifying characteristics.

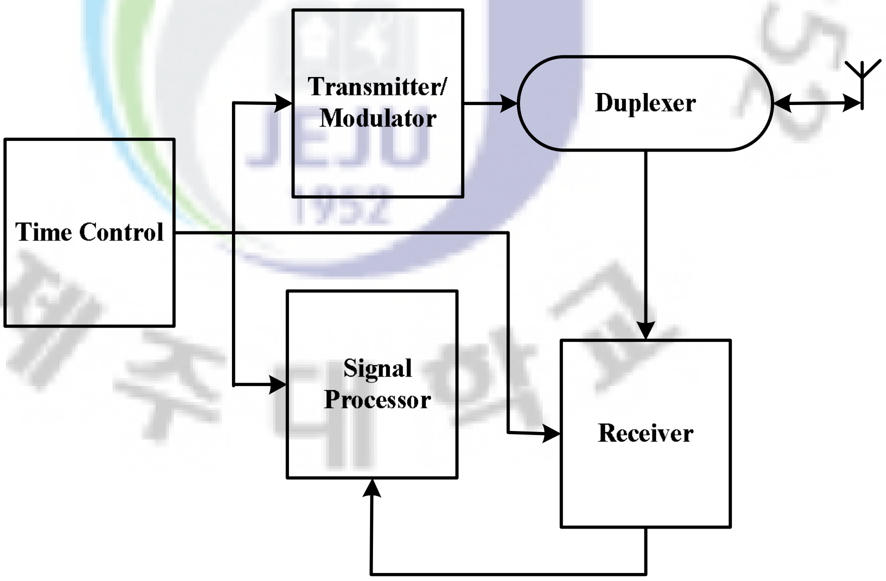


Figure.1. Radar System Block Diagram

2.1 Radar Classifications:

Radars can be classified as ground based, airborne, space borne, or ship based radar systems. They can also be classified into numerous categories based on the specific radar characteristics, such as the frequency band, antenna type, and waveforms utilized. Radar can operate in various modes by radiating different frequencies, with different polarizations. The frequency spectrums are given different designation based on the application by International Telecommunications Union (ITU) for radiolocation, or radar.

Band Designation	Nominal Frequency Range
HF	3-30MHz
VHF	30-300MHz
UHF	300-1000MHz
L	1-2GHz
S	2-4GHz
C	4-8GHz
X	8-12GHz
K_u	12-18GHz
K	18-27GHz
K_a	27-40GHz
V	40-75GHz
W	75-110GHz
mm	110-300GHz

Table.I. IEEE standard radar-frequency letter-band nomenclature

Each frequency band has its own particular characteristics that make it better for certain applications than for others. In the following, the characteristics of the various portions of the electromagnetic spectrum at which radars have been or could be operated are described. The divisions between the frequency regions are not as sharp in practice as the precise nature of the nomenclature.

2.1.1 HF (3 to 30 MHz):

Although the first operational radars installed by the British just prior to World War II were in this frequency band, it has many disadvantages for radar applications. Large antennas are required to achieve narrow beam widths, the natural ambient noise level is high, the available bandwidths are narrow and these portions of the electromagnetic spectrum is widely used and restrictively narrow. In addition, the long wavelength means that many targets of interest might be in the Rayleigh region, where the dimensions of the target are small compared with the wavelength; hence, the radar cross section of targets small in size compared with the (HF) wavelength might be lower than the cross section at microwave frequencies.

The British used this frequency band, even though it had disadvantages, because it was the highest frequency at which reliable, readily available high-power components were then available. Ranges of 200 mi were obtained against aircraft. These were the radars that provided detection of hostile aircraft during the battle of Britain and were credited with allowing the limited British fighter resources to be effectively used against the attacking bomber aircraft. They did the job that was required. Electromagnetic waves at HF have the important property of being refracted by the ionosphere so as to return to the earth at ranges from about 500 to 2000nmi, depending on the actual condition of the ionosphere. This allows the over the horizon detection of aircraft and other targets. The long over-the-horizon ranges that are possible make the HF region of the spectrum quite attractive for the radar observation of areas (such as the ocean) not practical with conventional microwave radar.

2.1.2 VHF (30 to 300 MHz):

Most of the early radars developed in the 1930s were in this frequency band. Radar technology at these frequencies represented a daring venture that pushed to the edge of technology known in the thirties. These early radars served quite well the needs of the time and firmly established the utility of radar. Like the HF region, the VHF (very high frequency) region is crowded, bandwidths are narrow, external noise can be high, and beam widths are broad. However, the necessary technology is easier and cheaper to achieve than at microwave frequencies. High power and large antennas are readily practical. The stable transmitters and oscillators required for good MTI are easier to achieve than at higher frequencies, and there is relative freedom from the blind speeds that limit the effectiveness of MTI as the frequency is increased. Reflections from rain are not a problem. With horizontal polarization over a good reflecting surface (such as the sea), the constructive interference between the direct wave and the wave reflected from the surface can result in a substantial increase in the maximum range against aircraft (almost twice the free-space range). However, a consequence of this increase in range due to constructive interference is that the accompanying destructive interference results in nulls in the coverage at other elevation angles and less energy at low angles. It is a good frequency for lower cost radars and for long-range radars such as those for the detection of satellites. It is also the frequency region where it is theoretically difficult to reduce the radar cross section of most types of airborne targets.

In spite of its many attractive features, there have not been many applications of radar in this frequency range because its limitations do not always counterbalance its advantages.

2.1.3 UHF (300 to 1000 MHz):

Much of what has been said regarding VHF applies to UHF. However, natural external noise is much less of a problem, and beam widths are narrower than at VHF. Weather effects usually are not a bother. With a suitably large antenna, it is a good frequency for reliable long range surveillance radar, especially for extraterrestrial targets such as spacecraft and ballistic missiles. It is well suited for AEW (airborne early warning), e.g., airborne radar that uses AMTI for the detection of aircraft. Solid-state transmitters can generate high power at UHF as well as offer the advantages of maintainability and wide bandwidth.

2.1.4 L Band (1.0 to 2.0 GHz):

This is the preferred frequency band for land based long-range air surveillance radars, such as the 200-nmi radars used for en route air traffic control [designated ARSR by the U.S. Federal Aviation Administration (FAA)]. It is possible to achieve good MTI performance at these frequencies and to obtain high power with narrow beam width antennas. External noise is low. Military 3D radars can be found at L band, but they also are at S band. L band is also suitable for large radars that must detect extraterrestrial targets at long range.

2.1.5 S Band (2.0 to 4.0 GHz):

Air surveillance radars can be of long range at S band, but long range usually is more difficult to achieve than at lower frequencies. The blind speeds that occur with MTI radar are more numerous as the frequency increases, thus making MTI less capable. The echo from rain can significantly reduce the range of S-band radars. However, it is the preferred frequency band for long-range weather radars that must make accurate estimates of rainfall rate. It is also a good frequency for medium-range air surveillance applications such as the airport surveillance radar (ASR) found at air terminals. The narrower beam widths at this frequency can provide good angular accuracy and resolution and make it easier to reduce the effects of hostile main-beam jamming that might be encountered by military radars. Military 3D radars and height finding radars are also found at this frequency because of the narrower elevation beam widths that can be obtained at the higher frequencies.

Long-range airborne air surveillance pulse Doppler radars, such as AWACS (Airborne Warning and Control System) also operate in this band. Generally, frequencies lower than S band are well suited for air surveillance (detection and low-data-rate tracking of many aircraft within a large volume). Frequencies above S band are better for information gathering, such as high data rate precision tracking and the recognition of individual targets. If a single frequency must be used for both air surveillance and precision tracking, as in military air defense systems based on phased array multifunction radar, a suitable compromise might be S band.

2.1.6 C Band (4.0 to 8.0 GHz):

This band lies between the S and X bands and can be described as a compromise between the two. It is difficult, however, to achieve long-range air surveillance radars at this or higher frequencies. It is the frequency where one can find long-range precision instrumentation radars used for the accurate tracking of missiles. This frequency band has also been used for multifunction phased array air defense radars and for medium-range weather radars.

2.1.7 X Band (8 to 12.5 GHz):

This is a popular frequency band for military weapon control (tracking) radar and for civil applications. Shipboard navigation and piloting, weather avoidance, doppler navigation, and the police speed meter are all found at X band. Radars at this frequency are generally of convenient size and are thus of interest for applications where mobility and light weight are important and long range is not. It is advantageous for information gathering as in high-resolution radar because of the wide bandwidth that makes it possible to generate short pulses (or wideband pulse compression) and the narrow beam widths that can be obtained with relatively small-size antennas. X-band radar may be small enough to hold in one's hand or as large as the MIT Lincoln Laboratory Haystack Hill radar with its 120-ft-diameter antenna and average radiated power of about 500 kW. Rain, however, can be debilitating to X-band radar.

2.1.8 Ku, K, and Ka Bands (12.5 to 40 GHz):

The original K-band radars developed during World War II were centered at a wave length of 1.25 cm (24 GHz). This proved to be a poor choice since it is too close to the resonance wavelength of water vapor (22.2 GHz), where absorption can reduce the range of radar. Later this band was subdivided into two bands on either side of the water-vapor absorption frequency.

The lower frequency band was designated K11, and the upper band was designated Ka. These frequencies are of interest because of the wide bandwidths and the narrow beam widths that can be achieved with small apertures. However, it is difficult to generate and radiate high power. Limitations due to rain clutter and attenuation are increasingly difficult at the higher frequencies. Thus not many radar applications are found at these frequencies. However, the airport surface detection radar for the location and control of ground traffic at airports is at Ku band because of the need for high resolution. The disadvantages that characterize this band are not important in this particular application because of the short range.

2.1.9 Millimeter Wavelengths (above 40 GHz):

Although the wavelength of Ka band is about 8.5 millimeters (a frequency of 35 GHz), the technology of Ka band radar is more like that of microwaves than that of millimeter waves and is seldom considered to be representative of the millimeter-wave region. Millimeter-wave radar, therefore, is taken to be the frequency region from 40 to 300 GHz. The exceptionally high attenuation caused by the atmospheric oxygen absorption line at 60 GHz precludes serious applications in the vicinity of this frequency within the atmosphere. Therefore, the 94 GHz frequency region (3 mm wavelength) is generally what is thought of as a "typical" frequency representative of millimeter radar. The millimeter-wave region above 40 GHz has been further subdivided into letter bands in the IEEE Standard, as shown in Table I. Although there has been much interest in the millimeter portion of the electromagnetic spectrum, there have been no operational radars above Ka band. High-power sensitive receivers and low-loss transmission lines are difficult to obtain at millimeter wavelengths, but such problems are not basic. The major reason for the limited utility of this frequency region is the high attenuation that occurs even in the "clear" atmosphere. The so-called propagation window at 94 GHz is actually of greater attenuation than the attenuation at the water-vapor absorption line at 22.2 GHz. The millimeter-wave region is more likely to be of interest for operation in space, where there is no atmospheric attenuation. It might also be considered for short range applications within the atmosphere where the total attenuation is not large and can be tolerated.

2.2 Classifications Based on Functionality of the Radar:

Another classification is concerned with the mission and the functionality of the radar. This includes weather, acquisition and search, tracking, track-while-scan, fire control, early warning, over the horizon, terrain following, and terrain avoidance radars. Radars are most often classified by the types of waveforms they use, or by their operating frequency. Considering the waveforms first, radars can be Continuous Wave (CW) or Pulsed Radars (PR). CW radars are those that continuously emit electromagnetic energy, and use separate transmit and receive antennas. Un-modulated CW radars can accurately measure target radial velocity (Doppler shift) and angular position. Target range information cannot be extracted without utilizing some form of modulation. The primary use of un-modulated CW radars is in target velocity search and track, and in missile guidance. Pulsed radars use a train of pulsed waveforms (mainly with modulation).In this category, radar systems can be classified on the basis of the Pulse Repetition Frequency (PRF), as low PRF, medium PRF, and high PRF radars. Low PRF radars are primarily used for ranging where target velocity (Doppler shift) is not of interest. High PRF radars are mainly used to measure target velocity. Continuous wave as well as pulsed radars can measure both target range and radial velocity by utilizing different modulation schemes.

2.3 Automotive Radar Applications:

Starting with an explanation of future automotive radar applications, the system requirements will be discussed in this chapter.

2.3.1 Why Radar in cars?

The current status of modern commercially available automotive radar systems covers adaptive cruise control applications for highway traffic situations. Numerous automobile manufacturers and automotive part suppliers as well as RF part producers are engaged in this development and try to bring their products to the market or are at least interested in the market development to keep up with their competitors. Large volume production will one day be the future of automotive radar systems which cover many different applications. A multifunctional sensor system is able to detect the complete surrounding of the vehicle as shown in Figure.2. Due to the very wide field of view of the individual sensors, their maximum detection range has to be kept low up to e.g. 20 m.

A multifunctional radar sensor network is able to support parking aid, pre-crash, stop & go applications for example and can also support the long range ACC radar in the near distance area with large angular range. But it is absolutely clear that this radar sensor network should not be seen as a replacement of an ACC radar system due to very different properties.

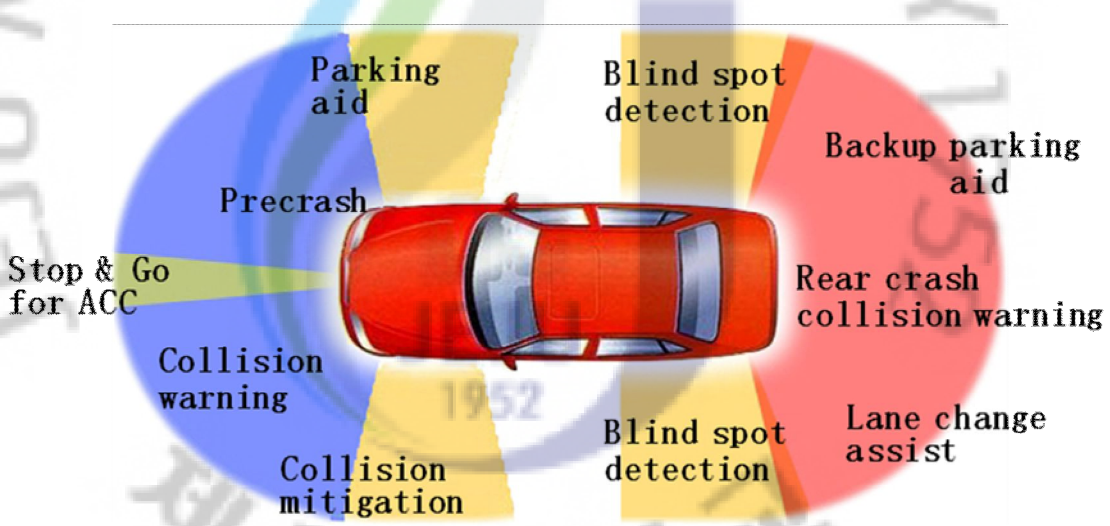


Figure.2. Application of SRR network

Possible applications of a short range radar network are illustrated in Figure.2. The different applications can be characterized as follows:

2.3.2 Parking Aid:

As a comfort application for the driver and to increase security for people walking on the streets the use of a high range resolution radar network for parking aid applications should be mentioned. The demands on system reliability and safety are not high as in the other applications. A replacement of today's ultrasonic sensors by a multifunctional radar sensor network with more potential and better performance is the idea. It is intended to warn the driver in situations at very low vehicle speed. An acoustic warning can be initiated if the distance between the vehicle and an obstacle or human being is below a critical value. An optical display is useful to display direction of an obstacle and exact distance between vehicle and obstacle. Active braking is possible to prevent the vehicle from hitting obstacles or injuring people in parking situations.

2.3.3 Stop & Go:

The warning of or reaction on cut-in collisions is a significant task for adaptive cruise control systems. Vehicles cutting in from adjacent lanes have to be detected very early to reduce speed in time. In very dense traffic situations this application can surely reduce a large amount of accidents. The support of a long range radar sensor for adaptive cruise control and CA (collision avoidance) is possible. Long range radars show limitations e.g. in their angular coverage in azimuth. With such very narrow beam radars it is usually not possible to monitor the vehicle front corners which are also critical directions for accidents. Range accuracy and resolution in the very near range in front of the vehicle are also better if high resolution radars are used.

2.3.4 Blind Spot Surveillance:

Overseeing passing vehicles or vehicles on adjacent lanes by an inattentive driver can be avoided by a blind spot detection function of the sensor network. At least an acoustic warning for the driver in a critical situation would be very helpful.

2.3.5 Rear End Collision Warning:

Rear end collision warning can also be used like all other applications to initiate system reactions early in case of an accident, e.g. activating the airbags inside the vehicle or the brakes if a collision with a fast vehicle from the back cannot be avoided. This application can be seen as a special case of a complete pre-crash system monitoring only the rear of the car.

2.3.6 Pre-Crash:

Last but not least the application of a radar sensor network surrounding the vehicle for a so called pre-crash application is an important development target of such a network. The main idea is to react very fast with a pre-crash sensor network and activate all necessary active components (brakes, or even steering) in the car to avoid an accident or at least minimize consequences of an impact with reduction of the vehicle’s kinetic energy. Early activation of airbags is very important. When talking about a sensor network it is not yet clear how many sensors are really required to cover the complete surrounding of a passenger car and manage all the mentioned applications.

2.4 Global deployment of 24GHz UWB SRRs:

US: Regulation in force-since February 2002

EU: European Commission decided-February 2005

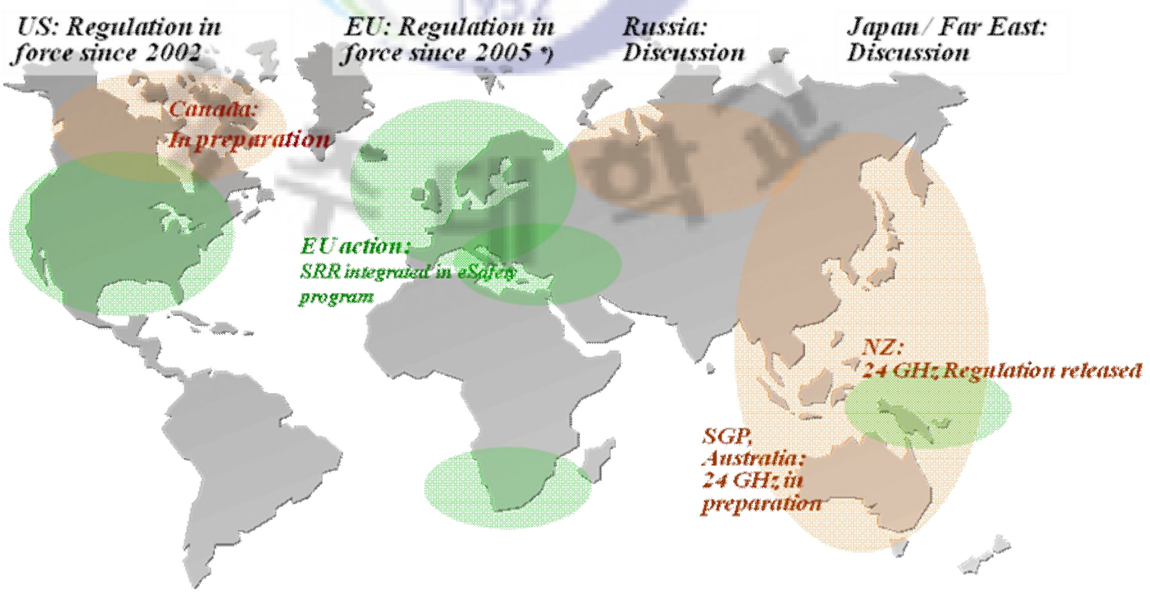
Russia: verbally confirmed-7 May 2007

Australia: regulated in July 2006

Canada: Frequency allocation from first half of 2007.Interim allowance was given to start using vehicles equipped with UWB SRR.

Japan: Compatibility Study group since December 2006.

Since cars are offered worldwide, a globally harmonized frequency regulation is very important. More than 50 countries in the world have approved 24GHz UWB SRR for contribution to their road safety.



*) the 24 GHz regulation is limited to 2013

Figure.3. Global Deployment of 24 GHz UWB Short Rang Automotive Radars

2.5 FCC Part 15 Ruling:

The specification is written in terms of an emitted power spectral density, or effective isotropic radiated power (EIRP), which allows for either a reduction in the peak transmitted power or, as is more likely, a reduction in the elevation side lobes of the Tx antenna.

Similar proposals in Europe are at the time of writing still under consideration by the ETSI. One mitigating solution that is the subject of much research notably by the Radar net consortium is the proposal by SARA in conjunction with the European Radio or ten years after their introduction, whichever is later. In conjunction, SRR sensors would slowly migrate in frequency to be based at 79 GHz. This would set an upper limit on the maximum number of sensors produced at 24 GHz and, thus, limit the increase in background noise that the EESS sensors would be exposed to. It should be noted that the corresponding spectrum at 79 GHz has also yet to be allocated.

FCC UWB Ruling, FCC 02-48,Section 15.515
Sensor operating only when engine running, or upon specific activation
Minimum Signal bandwidth 20% or 500 MHz(whichever is smaller) (Bandwidth defined as -10dB below peak emission points)
Peak Radiated Emission 0dBm EIRP in 50MHz around highest emission frequency
Emission 23.6GHz-24GHz 30°above horizon -25dB below spec limit by 2005 -30dB below spec limit by 2010 -35dB below spec limit by 2014

Table.II. Key Elements of FCC Ruling

Table II summarizes the key elements of the Part 153 ruling governing UWB radars for vehicular applications. The associated spectral mask is illustrated in Figure.4. To be considered an UWB device, the fractional bandwidth of the spectrum measured at the 10-dB point from the peak must be at least 20% or 500 MHz, regardless of the fractional bandwidth. The vehicular radars must operate between 22–29 GHz in such a way that the center frequency and the frequency at which the highest level emission occurs must be greater than 24.075 GHz. Thus, to be considered UWB, the vehicular radar must have at least 500-MHz bandwidth to satisfy the regulations. Normally, the spectral density of the average mission in this band should not exceed 41.3 dBm/MHz To reduce potential interference with radio astronomy observations and passive earth sensing satellites, the FCC further limits the radiated emissions by requiring that, in the 23.6–24.0-GHz band, the EIRP of the antenna side lobes beyond 30 above the horizontal plane not exceed 66.3 dBm/MHz until 2010, and dropping to 76.3 dBm/MHz beyond 2014.

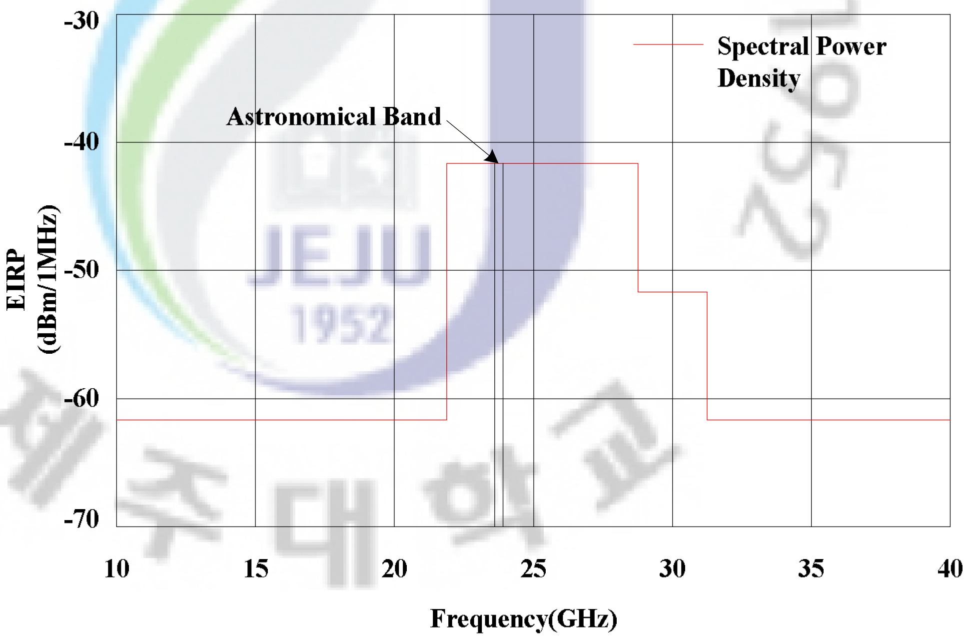


Figure.4. Spectral mask of the UWB ruling for vehicular radar

In addition to the average limit of 41.3dBm/MHz, the FCC also effectively limits the peak EIRP density emission to 17dBm/MHz in a 50-MHz band around the frequency of the highest power emission. These two constraints effectively dictate a maximum duty cycle for a sensor in pulsed operation to around 0.4% to take full advantage of the average power specifications.

2.6 Parameter Specifications:

In UWB automotive short range radar the K band frequency of 24.125 GHz is used as centre frequency with the System Bandwidth of 500 MHz, Pulse Repetition Interval of 500 ns and Pulse Duration of 2ns.

2.7 Information Available from the Radar Echo:

UWB Automotive Radar technology is a key enabling technology for innovative driver assistance systems and safety systems. High resolution UWB SRR systems are capable of reliable object tracking, to predict the path of encountering obstacles .This is vital to predict potential car crashes. Although the name radar is derived from radio detection and ranging, radar is capable of providing more information about the target than is implied by its name. Detection of a target signifies the discovery of its presence. It is possible to consider detection independently of the process of information extraction, but it is not often that one is interested in knowing only that a target is present without knowing something about its location and its nature. The extraction of useful target information is therefore an important part of radar operation.

The ability to consider detection independent of information extraction does not mean that there is no relation between the two. The extraction of information generally requires a matched filter, or its equivalent, for optimum processing. The more information that is known about the target a priori, the more efficient will be the detection. For example, if the target location were known, the antenna could be pointed in the proper direction and energy or time need not be wasted searching empty space. Or, if the relative velocity were known, the receiver could be pre tuned to the correct received frequency, negating the need to search the frequency band over which the doppler shift might occur.

The usual radar provides the location of a target in range and angle. The rate of change of target location can also be measured from the change in range and angle with time, from which the track can be established. In many radar applications detection is not said to occur until its track has been established. Radar with sufficient resolution in one or more coordinates can determine a target's size and shape. Polarization allows a measure of the symmetry of a target. In principle, radar can also measure the surface roughness of a target and determine something about its dielectric properties.

2.7.1 Range:

The ability to determine range by measuring the time for the radar signal to propagate to the target and back is probably the distinguishing and most important characteristic of conventional radar. No other sensor can measure range to the accuracy possible with radar, at such long ranges, and under adverse weather conditions. Radar has demonstrated its ability to measure interplanetary distances to an accuracy limited only by the accuracy to which the velocity of propagation is known. At more modest distances, the measurement of range can be made with a precision of a few centimeters. The usual radar waveform for determining range is the short pulse. The shorter the pulse, the more precise can be the range measurement.

2.7.2 Radial Velocity:

From successive measurements of range the rate of change of range, or radial velocity, can be obtained. The doppler frequency shift of the echo signal from a moving target also provides a measure of radial velocity. However, the doppler frequency measurement in many pulse radars is highly ambiguous, thus reducing its utility as a direct measurement of radial velocity. When it can be used, it is often preferred to successive range measurements since it can achieve a more accurate measurement in a shorter time. Any measurement of velocity, whether by the rate of change of range or by the doppler frequency shift, requires time. The longer the time of observation, the more accurate can be the measurement of velocity. (A longer observation time also can increase the signal-to-noise ratio, another factor that results in increased accuracy.) Although the doppler frequency shift is used in some applications to measure radial velocity (as, for example, in such diverse applications as the police speed meter and satellite surveillance radars), it is more widely employed as the basis for sorting moving targets from unwanted stationary clutter echoes, as in MTI, AMTI (airborne MTI), pulse doppler, and CW radars.

2.7.3 Size:

If the radar has sufficient resolution, it can provide a measurement of the target's extent, or size. Since many targets of interest have dimensions in meters, resolution must be several meters or less. Resolutions of this order can be readily obtained in the range coordinate. With conventional antennas and the usual radar ranges, the angular resolution is considerably poorer than what can be achieved in range. However, target resolution in the cross-range (angle) dimension can be obtained comparable with that obtained in range by the use of resolution in the doppler frequency domain. This requires that there be relative motion between the various parts of the target and the radar.

2.7.4 Shape:

The size of a target is seldom of interest in itself, but its shape and its size are important for recognizing one type of target from another. High resolution radar that obtains the profile of a target in both range and cross range provides the size and shape of the target. The shape of an object can also be obtained by tomography, in which a two dimensional image of a three-dimensional object is reconstructed from the measurement of phase and amplitude, at different angles of observation. (The radar might rotate around the fixed object, or the radar can be fixed and the object rotated about its own axis.) Range resolution is not necessary with the coherent tomographic radar method. As mentioned earlier, comparison of the scattered fields for different polarizations provides a measure of target asymmetry. It should be possible to distinguish targets with different aspect ratios (shapes). The complete exploitation of polarization requires the measurement of phase, as well as amplitude of the echo signal at two orthogonal polarizations and a cross-polarization component. Such measurements (which define the polarization matrix) should allow in principle the recognition of one class of target from another, but in practice it is not easy to do.

One characteristic of target shape is its surface roughness. This measurement can be of particular interest for echoes from the ground and the sea. Rough targets scatter the incident electromagnetic energy diffusely, smooth targets scatter specularly. By observing the nature of the backscatter as a function of the incident angle it should be possible to determine whether a surface is smooth or rough. Surface roughness is a relative measure and depends on the wavelength of the illuminating signal. A surface that appears rough at one wavelength might appear smooth when illuminated with longer-wavelength radiation. Thus another method for determining surface roughness is by varying the frequency of the illuminating radiation and observing the transition from specular to diffuse scatter. A direct method for determining roughness is to observe the scatter from the object with a resolution that can resolve the roughness scale.

3. System Description

The block diagram of a UWB radar system as shown in the figure 5 is split into two parts: the transmitter and the receiver. First, in the transmitter, the gaussian pulse is generated at each time that the Pulse Repetition Frequency (PRF) generator triggers the pulse generator. The gaussian pulse (T_P) has a sub-nano second duration of 2ns.

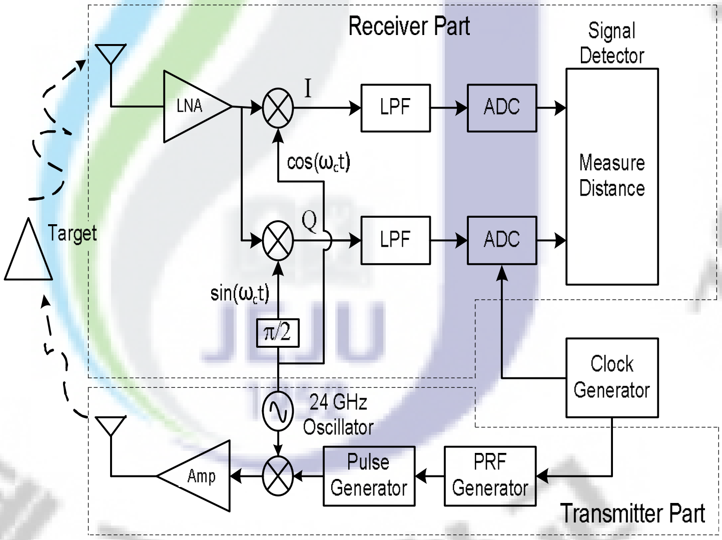


Figure.5. Block diagram of a UWB Radar system

Therefore we can write the transmitted signal as follows,

$$s(t) = A_T.\cos(2\pi f_c t + \varphi_0).P_n(t) \tag{1}$$

$$p_n(t) = \sum_{n=-\infty}^{+\infty} p(t\text{-}n\cdot T_{PRI}) \tag{2}$$

where $p_n(t)$ is gaussian pulse train The parameters employed in this UWB radar system are described as follows; A_T is the amplitude of single transmit pulse, φ_0 is the phase of the transmit signal, f_c is the carrier frequency, and T_{PRI} is the pulse repetition time.

Since the range resolution of the UWB radar system is much less than the extent of the target, the echo signal is the summation of the time-spaced echoes from the individual scattering centers that constitute the target [3]. Therefore, in this paper, we can assume that the target has L independent reflecting cells. The target model is written as,

$$h(t)=\sum_{l=0}^{L-1}\alpha_l\cdot\delta(t-\tau_l) \tag{3}$$

where the number of scatters L, the amplitude of the scatters α_l, and the time delays of the scatters τ_l are all unknown. The baseband complex received signal reflected from the target with clutter signal is given by,

$$\bar{r}(t)=A_T\sum_{n=-\infty}^{+\infty}\sum_{l=0}^{L-1}\alpha_l\cdot e^{j\theta_l}\,p(t-nT_{PRI}-\tau_l)\;+c(t) \tag{4}$$

where c(t) is the clutter signal.

4. Clutter Characteristic

4.1 Log-Normal Distribution:

A log-normal distribution is a probability distribution of a random variable whose logarithm is normally distributed. If X is a random variable with a normal distribution, then Y=exp(X) has a log-normal distribution. The log-normal distribution resembles the road clutter environment when the system bandwidth of 500MHz is used. The log-normal distribution is used to analyze the system performance in clutter environment.

The probability density function of the log-normal distribution is,

$$f_X(x;\mu,\sigma) = \frac{1}{x\sigma\sqrt{2\pi}} e^{-\frac{(\ln x-\mu)^2}{2\sigma^2}}, x > 0 \tag{5}$$

where μ and σ are the mean and standard deviation of the variables of natural logarithm [9].

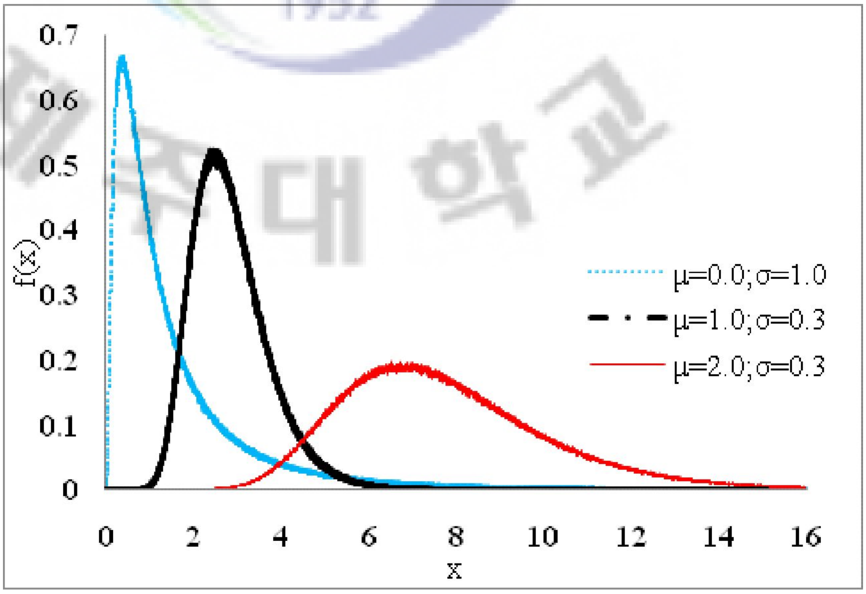


Figure.6. Log-Normal Probability Density Function

In the figure 6, the probability density funtion of the log-normal distribution at different mean μ and standard deviation σ is shown.

4.2 Weibull Distribution:

The weibull distribution is a continuous probability distribution. The weibull distribution resembles the road clutter environment when the system bandwidth of 100MHz is used. The weibull distribution is used to analyze the system performance in clutter environment. The probability density function of a weibull random variable X is,

$$f(x;\lambda,k)=\frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1}e^{-(x/\lambda)^{k}},x\geq 0 \tag{6}$$

where λ>0 is scale parameter and k >0 is shape parameter of the distribution.

The Probability density function of the weibull distribution is shown below,

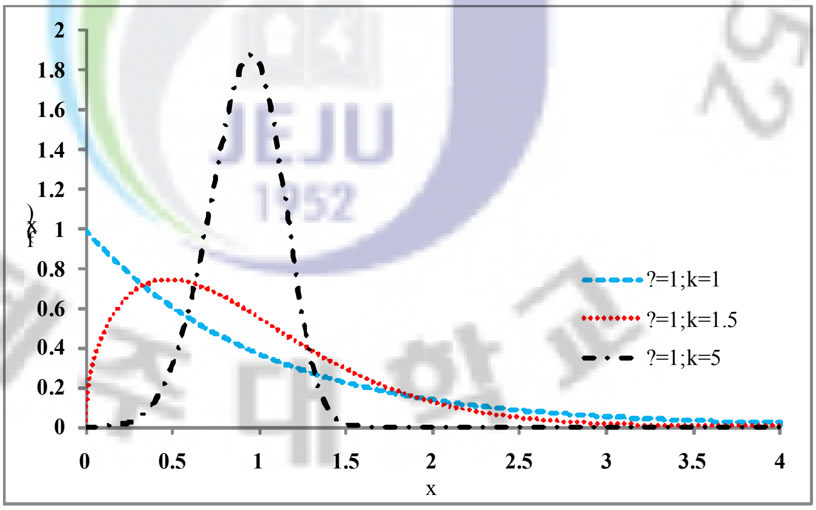


Figure.7. Weibull Probability Density Function

In the figure 7, the probability density function of the weibull distribution at different λ scale parameter and k shape parameter is shown.

5. Measuring the Range of a Target

First, in the receiver, the signal detector of the UWB radar must determine that a signal of interest is present or absent and then processes it for range determination. In this thesis, we use the non-coherent detectors like square law, linear and logarithmic for the range determination of the target. The detector consists of coherent range gate's memory, non-coherent range gate's memory, coherent integrator, and non-coherent integrator. The coherent and non-coherent range gate's memory size (M) is less than maximum range and indicates the total number of target range to be tested. These are used as buffer to coherently and non-coherently integrate. Therefore, at every T_{PRI}, we use the samples as much as the range gate's memory size (M).

At every $T_{p,}$ the in-phase component (I) and quadrature component (Q) values are sampled and used as the input for the detector. In the pre detection or coherent integration the switch-I shifts to adjacent bin after sampling time T_p. It takes $N_c \cdot T_{PRI}$ time duration to coherently integrate and dump for all range gates; N_c indicates the coherent integration length. If the round trip delay (τ) from target is equal to the time position of i-th range gate ($i \cdot T_p$), then the target range can be expressed as $i \cdot T_p/2 = i \cdot \Delta R$ where the range resolution ΔR is given by $\Delta R = c \cdot T_p/2$. The output of the coherent integrator (Signal present H_1 or absent H_0) can be given by two hypotheses,

$$H_1:\ \bar{X}_m(i)=\frac{A_T\alpha}{N_c}\sum_{n=mN_c}^{(m+1)N_c-1} e^{j\theta_l}\, p(t-nT_{PRI}-\tau_l)+\bar{n}_e(i) \tag{7}$$

$$H_0:\ \bar{X}_m(i)=\frac{1}{N_c}\sum_{n=mN_c}^{(m+1)N_c-1} \bar{n}_e(i) \tag{8}$$

where m indicates the m-th coherent integration and H_1 is for $\tau = i \cdot T_p$ and H_0 for $\tau \neq i \cdot T_p$. Also we assume that the sampling rate of the ADC is equal to the pulse width and the baseband received signal is sampled at peak point of $p_n(t)$. Then the values of the coherent integration for each range gate ($\bar{X}(i)$, i=1, 2,…., M) are stored in the coherent range gate's memory.

The sample value received from the coherent integration is squared and operated at every $N_c \cdot T_{PRI}$. In square law detector the squared range gate samples are combined and then both I and Q branch values are summed as shown in the figure 9a. The output after squaring Y(i) can be represented as,

$$Y(i)=(X^I(i))^2+(X^Q(i))^2 \tag{9}$$

In the case of linear detector as shown in the figure 9b, the sample value received from the coherent integration is squared and operated at every $N_c \cdot T_{PRI}$. The squared range gate samples are combined and then both I and Q branch values are summed and square root is taken to the summed value. The output of the linear detector Y(i) can be represented as,

$$Y(i) = \sqrt{(X^I(i))^2 + (X^Q(i))^2} \tag{10}$$

In the case of logarithmic detector as shown in the figure 9c, the sample value received from the coherent integration is squared and operated at every $N_c \cdot T_{PRI}$.

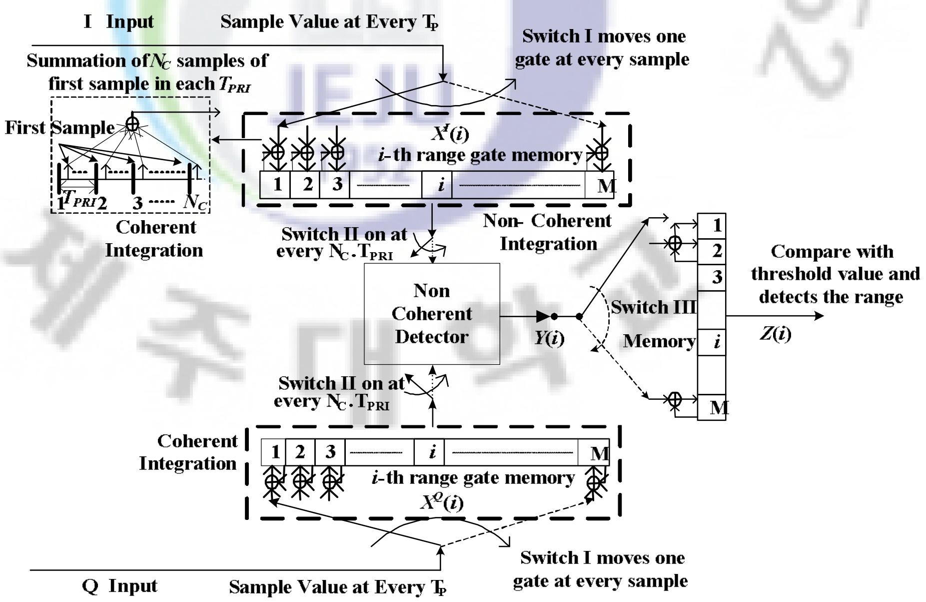
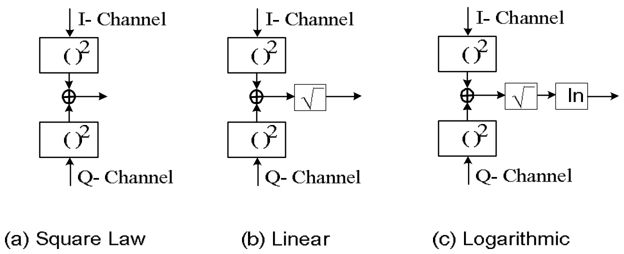


Figure.8. Block diagram of the receiver with detector



(a) Square Law (b) Linear (c) Logarithmic

Figure.9. Non-coherent Detectors

The squared range gate samples are combined and then both I and Q branch values are summed and square root is taken to the summed value before natural logarithm is applied. The output of the logarithmic detector Y(i) can be represented as,

$$Y(i) = \ln \sqrt{(X^{I}(i))^{2} + (X^{Q}(i))^{2}} \tag{11}$$

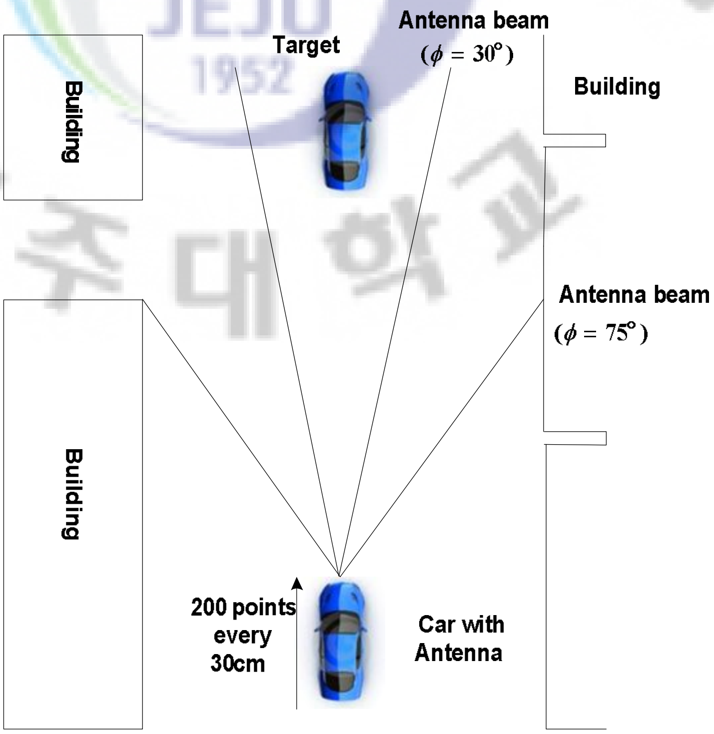
All of the reflected signals from the target can be added non-coherently. The value Y(i) is stored in the i-th register of the non-coherent integration at every $N_c \cdot T_{PRI}$ for $N_c \cdot M.T_{PRI}$. The output of the non-coherent integration Z(i) can be written as,

$$Z(i) = \frac{1}{M}\sum_{m=1}^{M} Y_m(i) \tag{12}$$

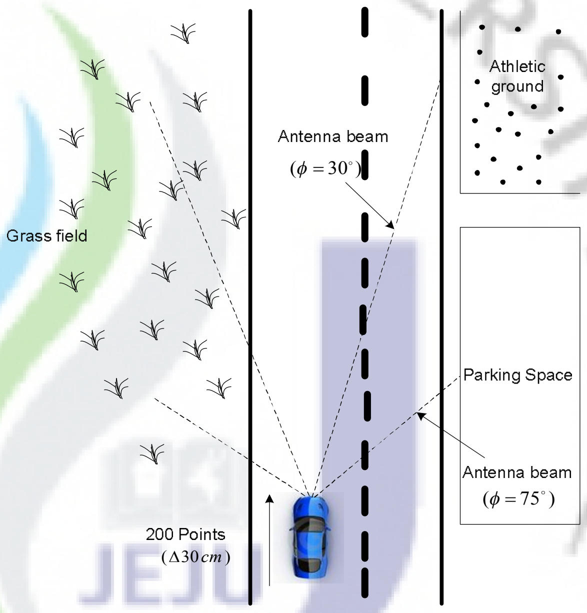
where $Y_m(i)$ is the power at $m \cdot N_c \cdot T_{PRI}$.

6. Computer Simulation Results

In this thesis, we assume that each clutter is independent and un-correlated. The parameters we used in the simulation are, coherent integration number N_C is 200 and the non-coherent integration number N_n is 100. The tabulated μ and σ values are taken from the reference paper where the empirical data's for the 24 GHz UWB automotive short range radar clutters is obtained using the experimental setup in the University of Kitakyushu at different clutter environment as shown in the figure. These values are used in the simulation for the checking the performance of the detectors in automotive radar clutter environment.



a) Environment (1)



b) Environment (2)

Figure.10. Measurement environment

	Environment (1)	Environment (2)
Both sides	Building	Right side Parking and Athletic ground ,Left side grass field
Road width	15m	8m
Road material	Asphalt	Asphalt

Table.III. Environmental Specifications

System	Vector Network Analyzer	
Bandwidth	Band width 10MHz,100MHz,500MHz,1GHz,3GHz, 5GHz(Center frequency 24GHz)	
Antenna	Polarization	H-H
	Type	Double-ridged Horn
	Beam Width	φ=75◦, 30◦
	Height	60cm

Table.IV. Environmental Parameters

The simulation is carried out in two ways as follows;

i) The performance of non-coherent (Linear, Logarithmic and Square law) detectors is analyzed in log-normal clutter environment.

ii) The performance of non-coherent Logarithmic detector is analyzed in log-normal and weibull clutter environment.

6.1 Non-coherent detectors in Log-Normal Clutter Environment:

The mean, variance and clutter power of the log-normal distribution is calculated using the following equations.

6.1.1 Log-Normal Clutter Power Calculation:

$$\text{Mean} = e^{\mu+\sigma^2/2} \tag{13}$$

$$\text{Variance} = (e^{\sigma^2} - 1)(e^{2\mu+\sigma^2}) \tag{14}$$

$$\text{Clutter Power} = e^{2(\mu+\sigma^2)} \tag{15}$$

μ	σ	Clutter Power
5.2	0.8	118KW
4.7	0.7	32KW
5.1	0.6	55KW
3.8	0.8	7KW

Table.V. Log-Normal Clutter Characteristics

The clutter power is the function of mean and variance value of the distribution. As the mean and variance value decreases the clutter power decreases, so the performance of the detector increases.

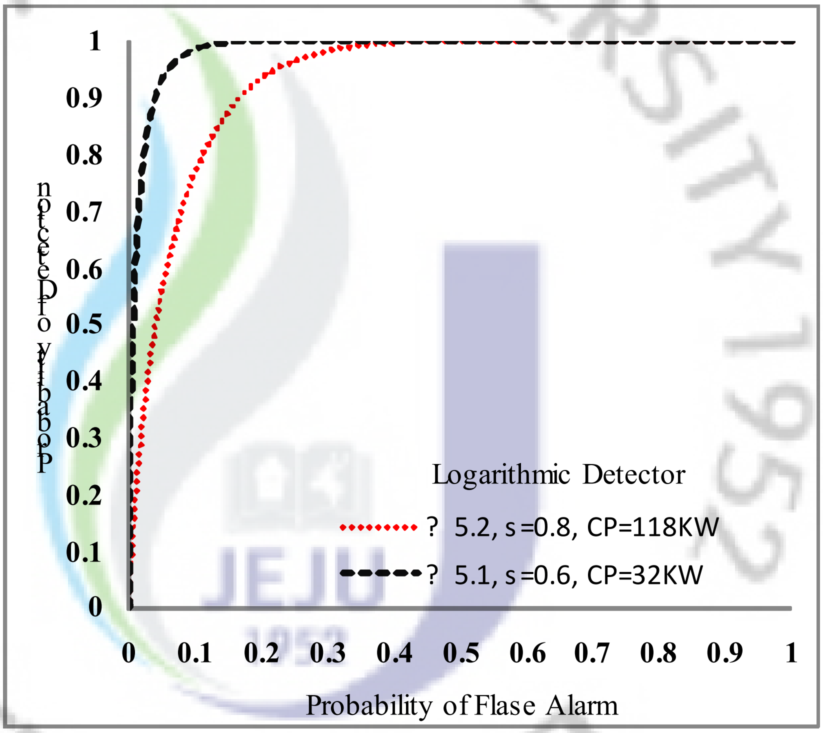


Figure.11. Performance of Logarithmic detector at different clutter power values

In the figure 11, the performance of the logarithmic detector is analyzed for different clutter power values in log-normal clutter environment with coherent integration number of 200 and non-coherent integration number of 100. The logarithmic detector gives better performance when the clutter power is small. The clutter power is 118KW when the mean and variance value is 5.2 and 0.8 the clutter power decreases as the mean and variance value decreases, so the performance of the logarithmic detector is increased when the clutter power reduces to 32KW.

In the figure 12, the performance of the non-coherent signal detectors (logarithmic detector, linear detector and square law detector) is analyzed for log-normal clutter environment with the coherent integration number of 200 and non-coherent integration number of 100. The logarithmic detector gives better performance than linear detector and square law detector because after coherent integration the values in the range gates of the in-phase and quadrature channel are added and square rooted before taking natural logarithm in the logarithmic detector, so the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore signal to clutter ratio increases, thus the detection probability of the logarithmic detector is more optimum compared to other two detectors.

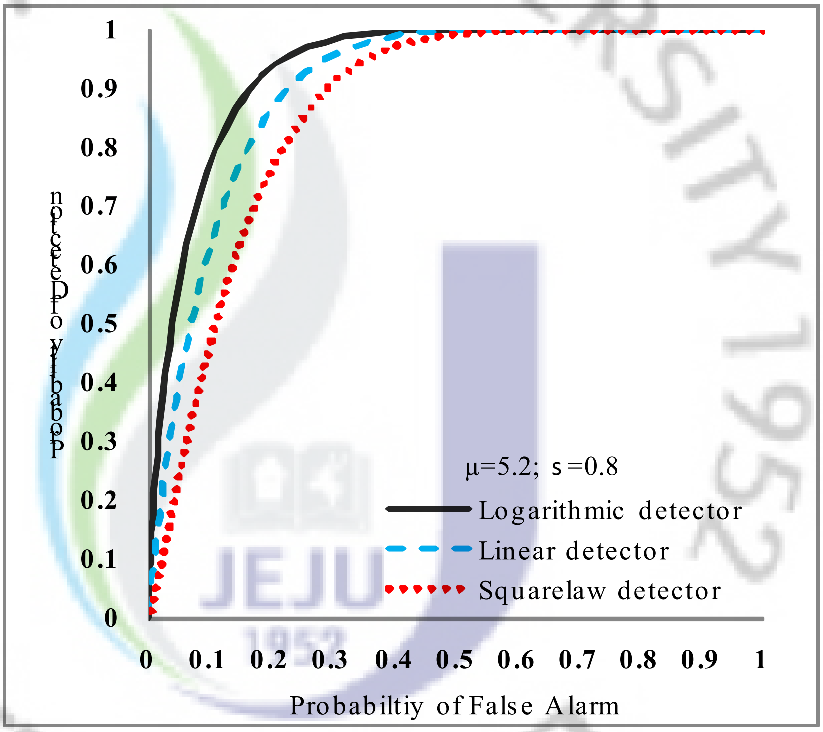


Figure.12. Performance of non-coherent detectors for μ = 5.2 and σ = 0.8

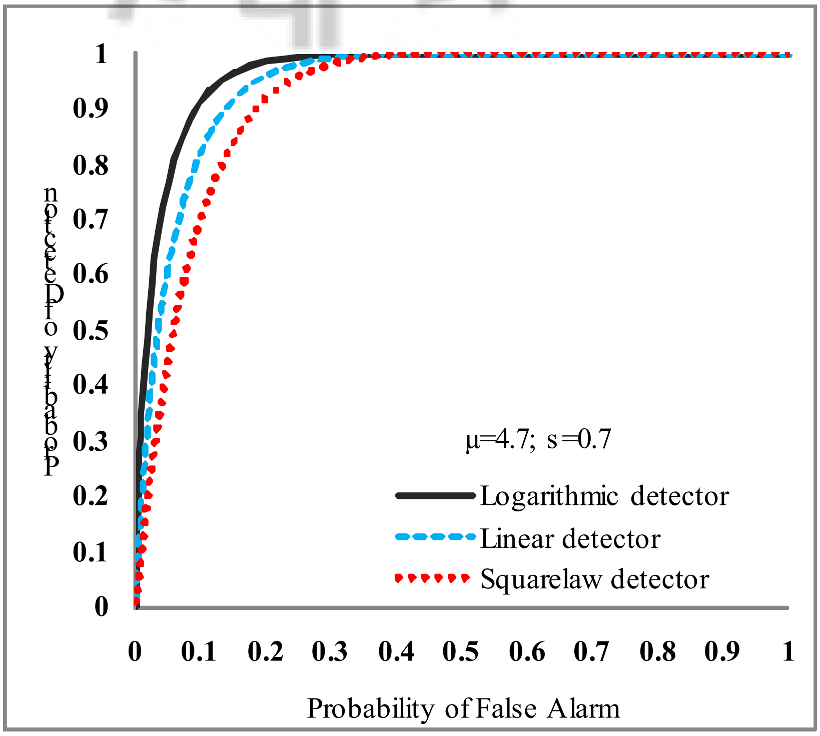


Figure.13. Performance of non-coherent detectors for μ = 4.7 and σ = 0.7

In the figure 13, the performance of the non-coherent signal detectors (logarithmic detector, linear detector and square law detector) is analyzed for log-normal clutter environment with the coherent integration number of 200 and non-coherent integration number of 100. The logarithmic detector gives better performance than linear detector and square law detector because after coherent integration the values in the range gates of the in-phase and quadrature channel are added and square rooted before taking natural logarithm in the logarithmic detector, so the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore signal to clutter ratio increases, thus the detection probability of the logarithmic detector is more optimum compared to other two detectors.

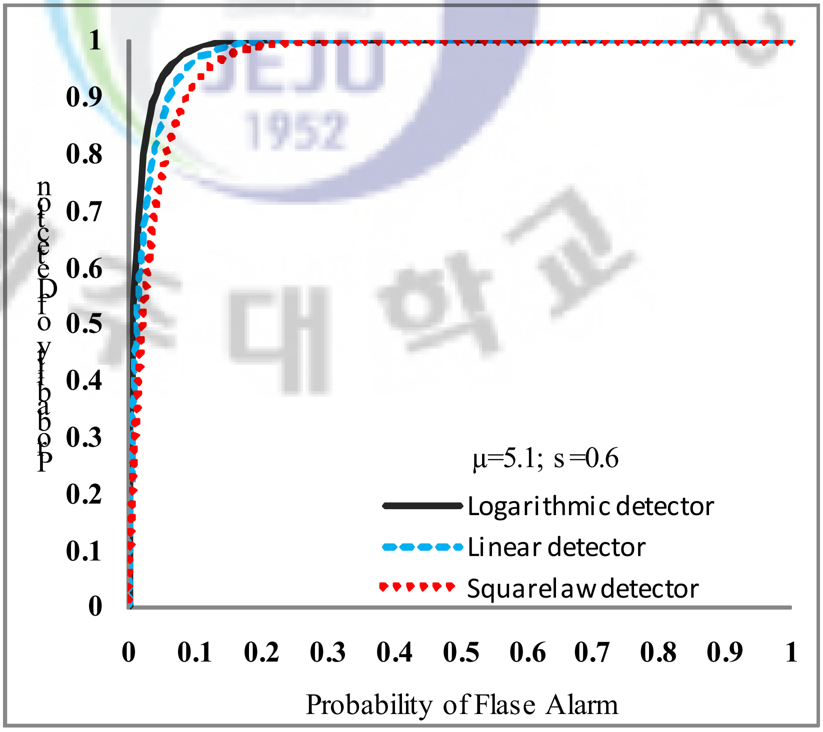


Figure.14. Performance of non-coherent detectors for μ = 5.1 and σ = 0.6

In the figure 14, the performance of the non-coherent signal detectors (logarithmic detector, linear detector and square law detector) is analyzed for log-normal clutter environment with the coherent integration number of 200 and non-coherent integration number of 100. The logarithmic detector gives better performance than linear detector and square law detector because after coherent integration the values in the range gates of the in-phase and quadrature channel are added and square rooted before taking natural logarithm in the logarithmic detector, so the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore signal to clutter ratio increases, thus the detection probability of the logarithmic detector is more optimum compared to other two detectors.

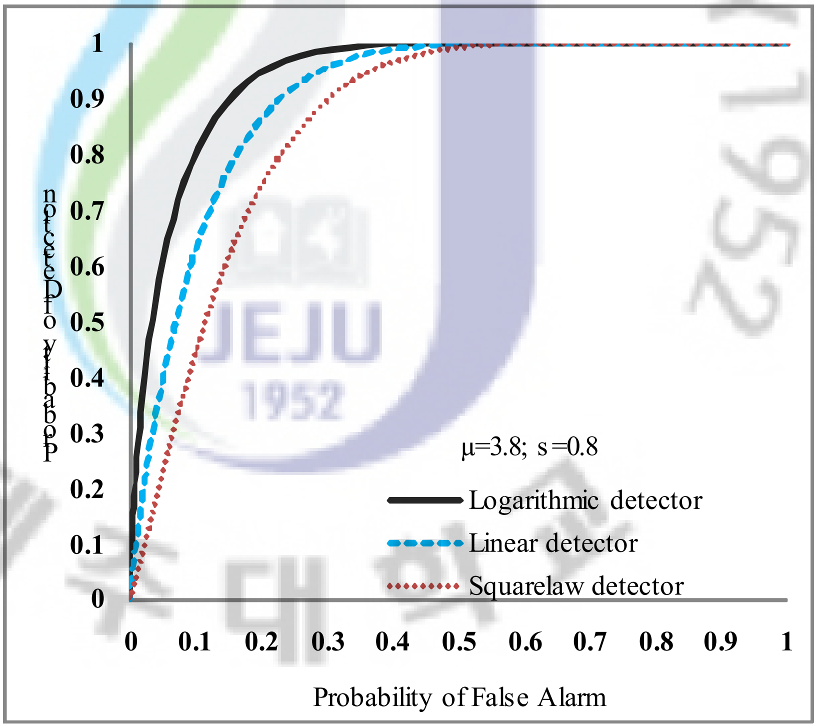


Figure.15. Performance of non-coherent detectors for μ = 3.8 and σ = 0.8

In the figure 15, the performance of the non-coherent signal detectors (logarithmic detector, linear detector and square law detector) is analyzed for log-normal clutter environment with the coherent integration number of 200 and non-coherent integration number of 100. The logarithmic detector gives better performance than linear detector and square law detector because after coherent integration the values in the range gates of the in-phase and quadrature channel are added and square rooted before taking natural logarithm in the logarithmic detector, so the clutter power values of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore signal to clutter ratio increases, thus the detection probability of the logarithmic detector is more optimum compared to other two detectors.

6.2 Logarithmic Detector in Log-Normal and Weibull Clutter Environment:

The performance of non-coherent logarithmic detector is analyzed in log-normal and weibull clutter environment at different bandwidth parameters.

BW (Band Width)	Log normal		Weibull	
	μ	σ	λ	k
1GHz	5.0	0.8	1.4	6.7
500MHz	5.2	0.8	1.6	6.9
100MHz	5.7	0.7	2.5	8.7

Table.VI. Clutter Characteristics at different Band Width

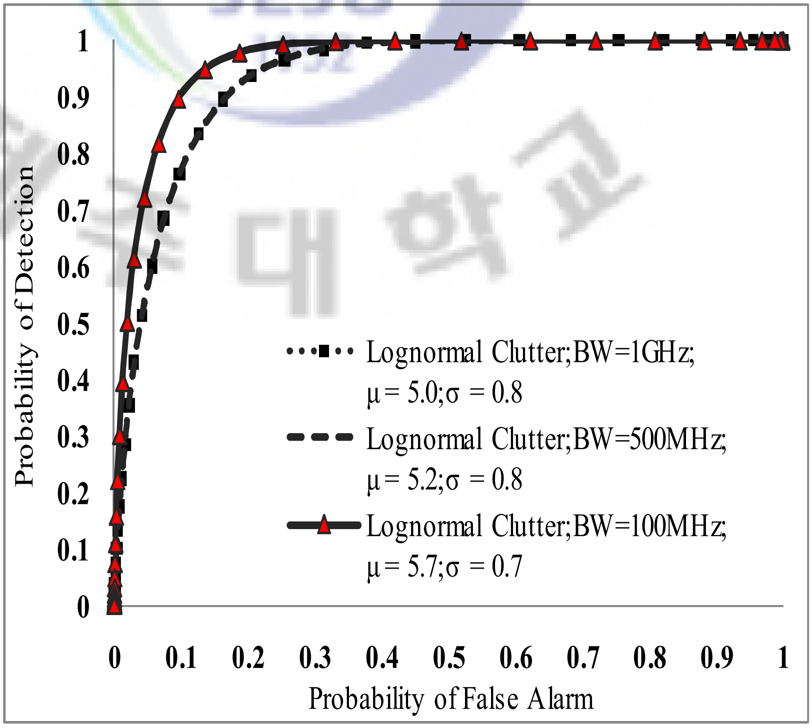


Figure.16. Performance of non-coherent Logarithmic detector in log-normal clutter at 1 GHz 500MHz and 100MHz bandwidth(BW)

In the figure 16, the performance of the non-coherent logarithmic signal detectors is analyzed for log-normal clutter with coherent integration number of 200 and non-coherent integration number of 100. The detection probability of logarithmic detector is optimum at the system bandwidth of 100MHz than 1GHz and 500MHz, because of the small variance value.

The clutter power decreases as the variance value decreases. So the performance of the detector increases if the clutter power decreases.

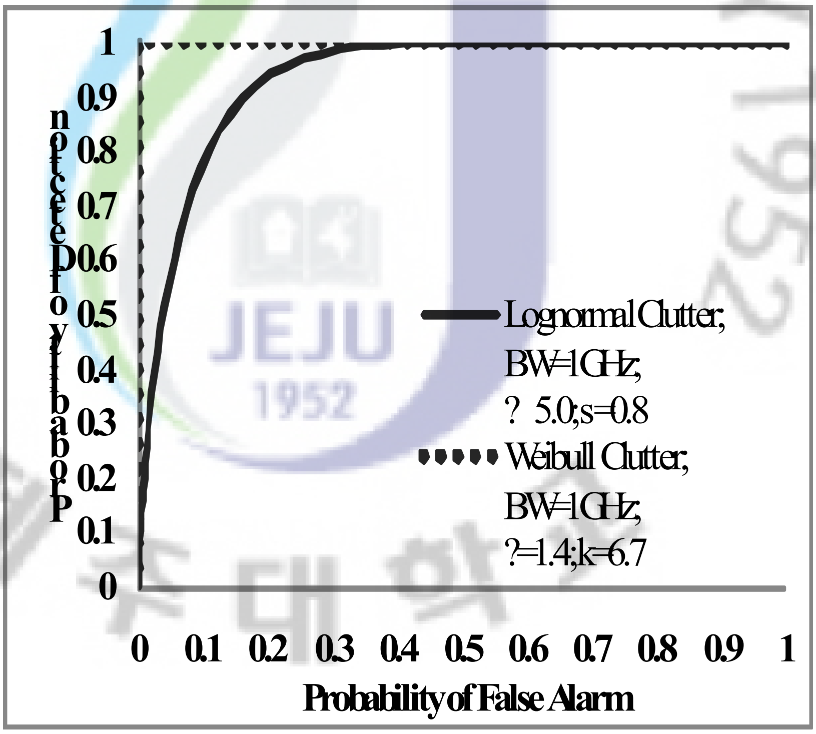


Figure.17. Performance of non-coherent Logarithmic detector in log-normal and weibull clutter at 1 GHz bandwidth(BW)

In the figure 17, the performance of the non-coherent logarithmic signal detectors is analyzed for log-normal clutter and weibull clutter environment. At 1GHz bandwidth the logarithmic detector with coherent integration number of 200 and non-coherent integration number of 100, gives better performance in log-normal clutter environment with mean μ=5.0 and standard deviation σ=0.8 and also in weibull clutter environment with scale parameter λ=1.4 and shape parameter k =6.7. In weibull clutter environment the logarithmic detector gives maximum detection probability because the clutter power is very low compared with the log-normal clutter power.

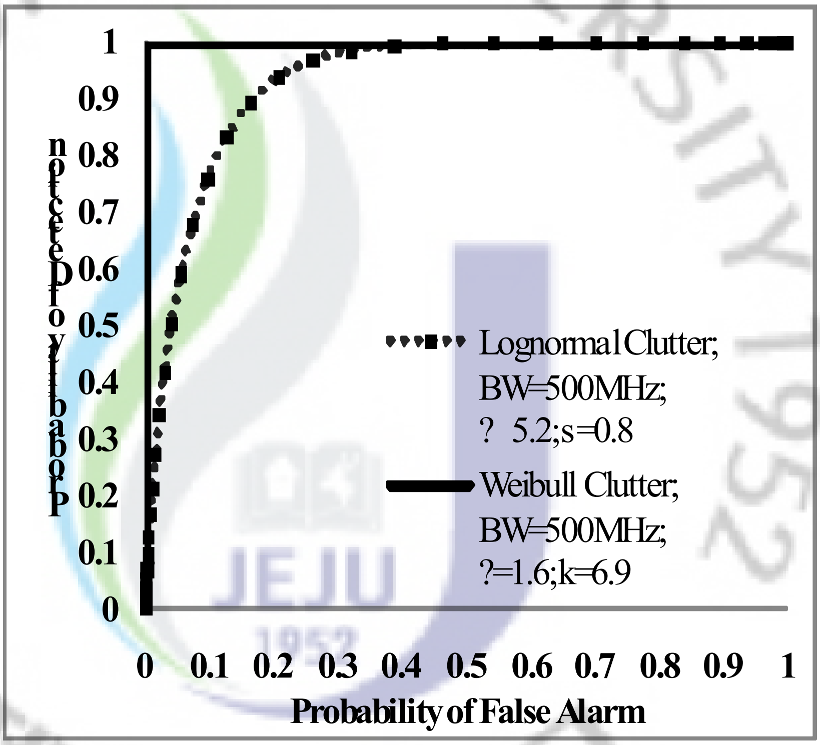


Figure.18. Performance of non-coherent Logarithmic detector in log-normal and weibull clutter at 500MHz bandwidth(BW)

In the figure 18, the performance of the non-coherent logarithmic signal detectors is analyzed for log-normal clutter and weibull clutter environment. At 500MHz bandwidth the logarithmic detector with coherent integration number of 200 and non-coherent integration number of 100, gives better performance in log-normal clutter environment with mean μ=5.2 and standard deviation σ=0.8 and also in weibull clutter environment with scale parameter λ=1.6 and shape parameter k =6.9. In weibull clutter environment the logarithmic detector gives maximum detection probability because the clutter power is very low compared with the log-normal clutter power.

In the figure 19, the performance of the non-coherent logarithmic signal detectors is analyzed for log-normal clutter and weibull clutter environment. At 1GHz bandwidth the logarithmic detector with coherent integration number of 200 and non-coherent integration number of 100, gives better performance in log-normal clutter environment with mean μ=5.7 and standard deviation σ=0.7 and also in weibull clutter environment with scale parameter λ=2.5 and shape parameter k=8.7

In weibull clutter environment the logarithmic detector gives maximum detection probability because the clutter power is very low compared with the log-normal clutter power.

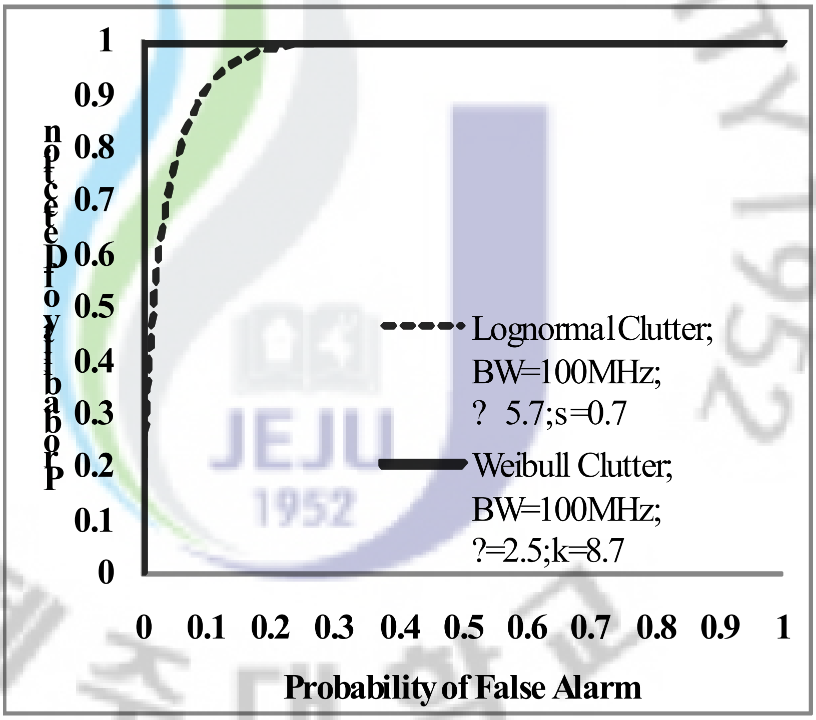


Figure.19. Performance of non-coherent Logarithmic detector in log-normal and weibull clutter at 100MHz bandwidth(BW)

7. Conclusion

In the UWB automotive short range radar, the clutter echoes are the reflected signals from the unwanted objects in the road environment. The non-coherent detectors performance is analyzed in the log-normal clutter environment and the optimal detector is determined. Then the performance of the optimal detector is compared in two different clutter (log-normal and weibull) environments.

We have analyzed the performance of non-coherent (Linear, Logarithmic and Square law) detectors in log-normal clutter environment. For 500MHz bandwidth, the road clutter resembles log-normal clutter distribution. Considering log-normal clutter environment, the performance of the non-coherent detectors is analyzed for different sets of μ and σ value. In all the cases, the performance of the logarithmic detector is superior to the linear detector and square law detector because the coherent integration values are square rooted and taking natural logarithm. Resultantly, the clutter power value of the logarithmic detector reduces to 5% of the linear detector clutter power value and 50% of the square law detector value. Therefore, the signal to clutter ratio of the logarithmic detector is increased. We can conclude that if the clutter power value decreases, then the signal to clutter ratio is increased. So, the detection probability is increased. Therefore, the logarithmic detector can be considered as the optimal detector for the automotive short range radars in log-normal clutter environment.

The optimum performance of the non-coherent logarithmic detector is analyzed at different system bandwidth (1GHz, 500MHz, and 100 MHz) using different sets of mean and variance value in log-normal clutter environment and in weibull clutter environment. In all the cases the performance of the logarithmic detector in log-normal clutter and weibull clutter varies as the function of their distributional parameters. The mean and variance values of the distribution decreases, the clutter power decreases. If the clutter power decreases, the performance of the detector increases. So, logarithmic detector gives better performance in weibull clutter environment at the system bandwidth of 1GHz, 500MHz and 100MHz because of the very less clutter power value compared with log-normal clutter power.

Finally, we can say that the non-coherent logarithmic detectors will give maximum performance in the UWB short range automotive radar receivers in the clutter environment.

8. Programming Layout

8.1 Parameters used in the Program:

Non-coherent Integration number = 100

Coherent integration number = 200

Array size = 2

8.2 Algorithm:

Step 1: Initialize the variables i, j, k, l, m, n to zero.

Step 2: Initialize the array values to zero (cohInt_I1[2],cohInt_Q1[2],I2[2],Q2[2],IQ3[2],IQ4[2],NCIQ4[2]).

Step 3: Open an Excel file for storing the detector output values to generate pdf.

Step 4: Generate Clutter values using clutter generating function.

Step 5: Add the clutter value with the received signal of the detector in both I& Q channel and store it in an array cohInt_I1 [2], cohInt_Q1 [2].

Step 6: Square the values of array cohInt_I1 [2], cohInt_Q1 [2] and store it in a new array I2 [2], Q2 [2].

Step 7: Add the array I2 [2], Q2 [2] and store it in a new array IQ3 [2].

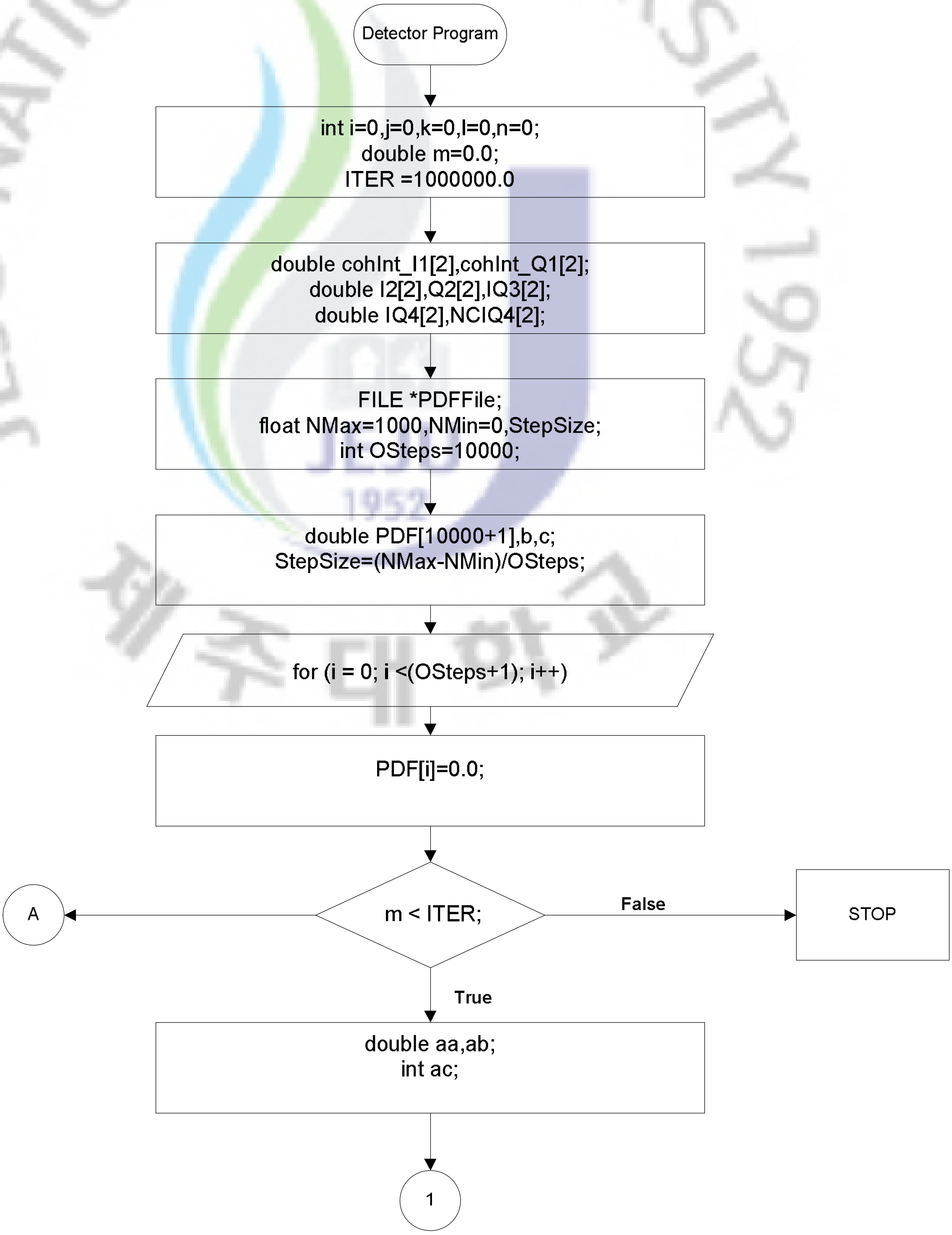
Step 8: Repeat step4 to step 7 for a non-coherent integration value of 100.

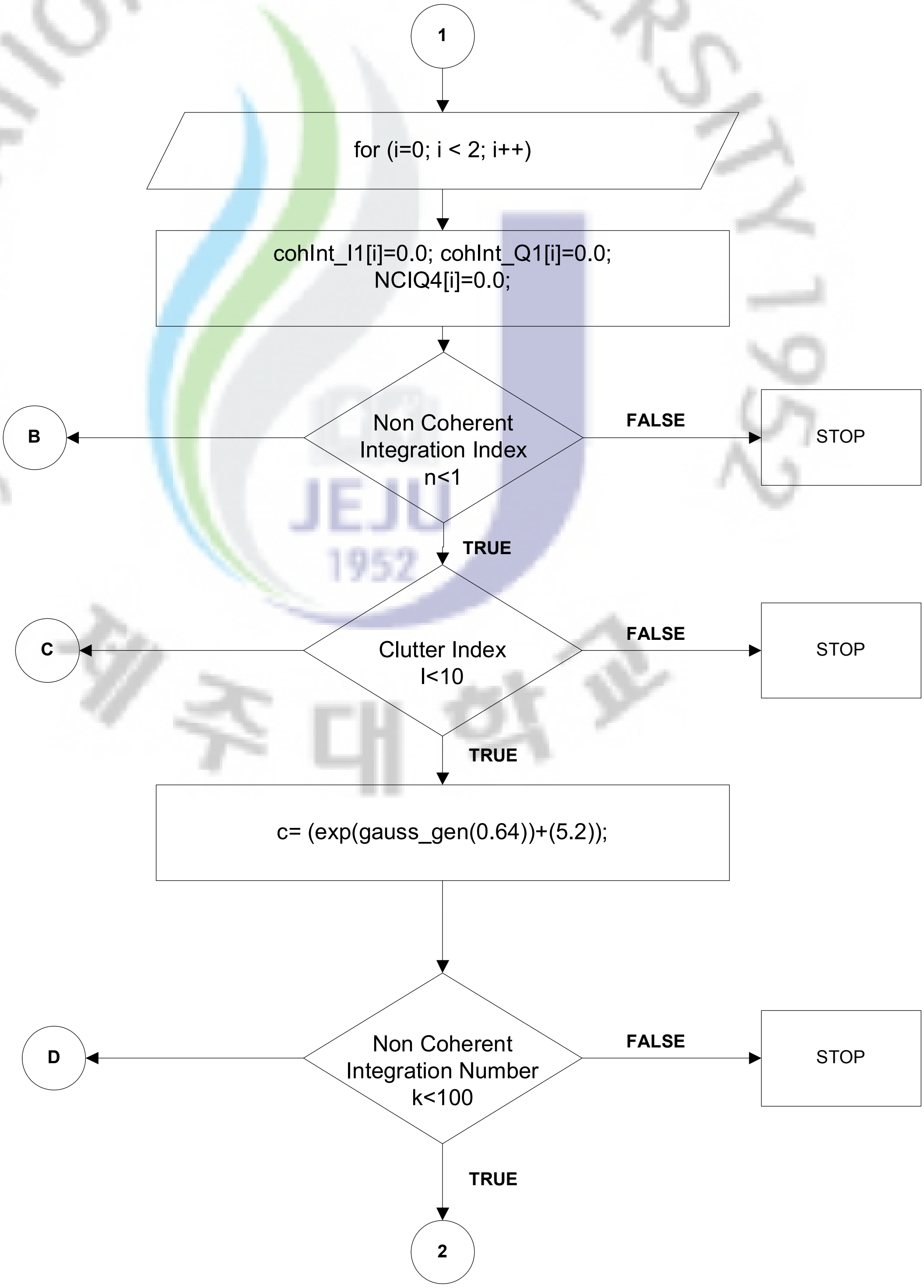
Step 9: Store the values of IQ3 [2] in a new array NCIQ4 [2] after step 10.

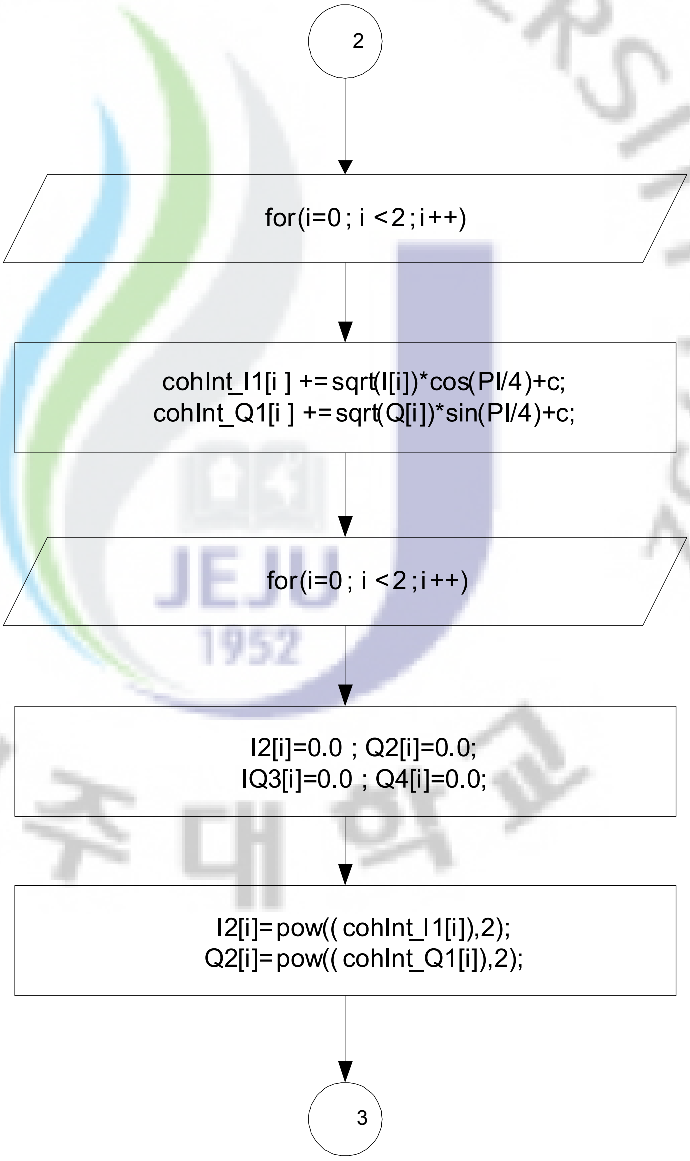
Step 10: Store the values of NCIQ4 [2] in an excel sheet for generating pdf.

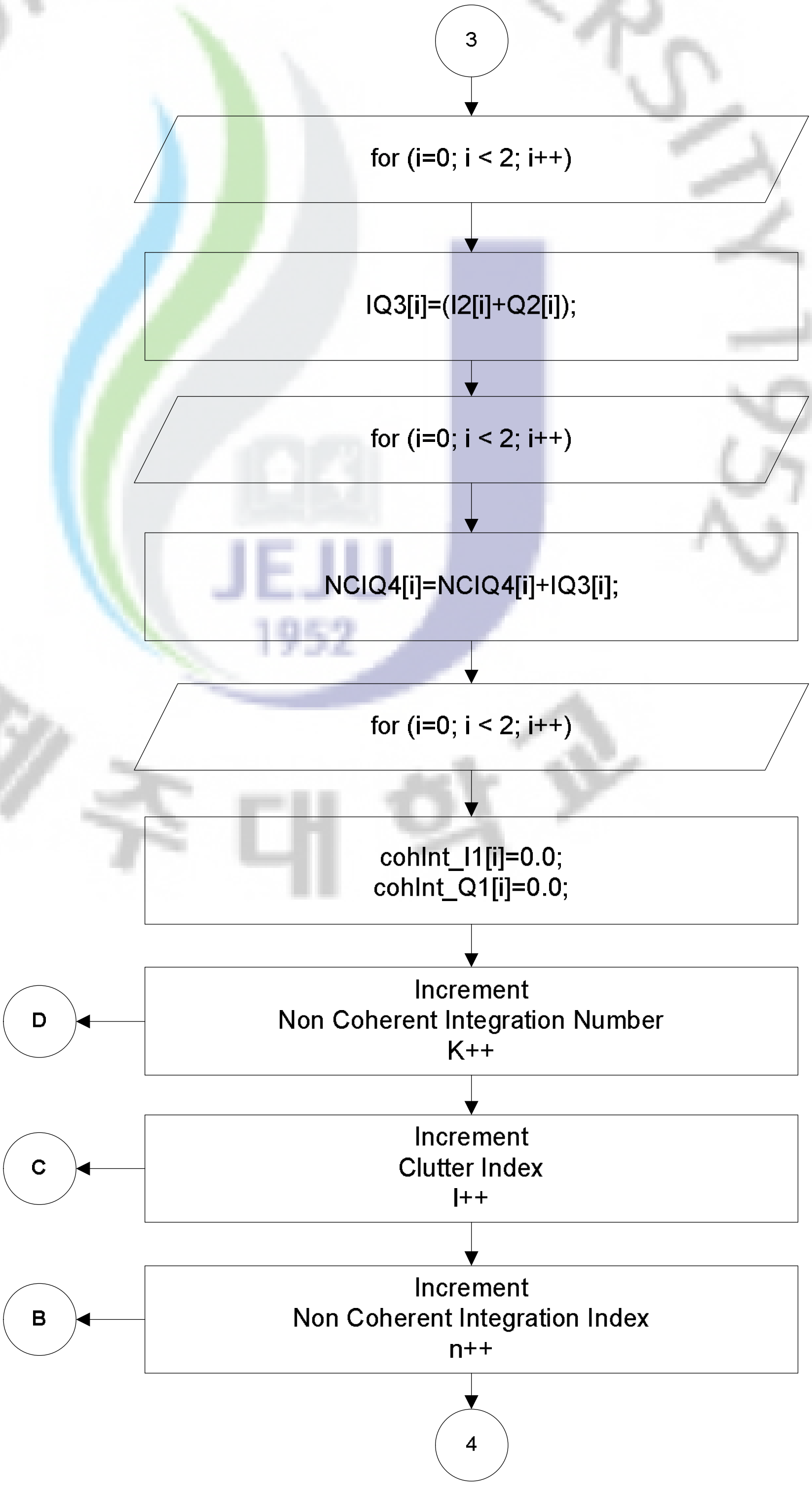
Step 11: end

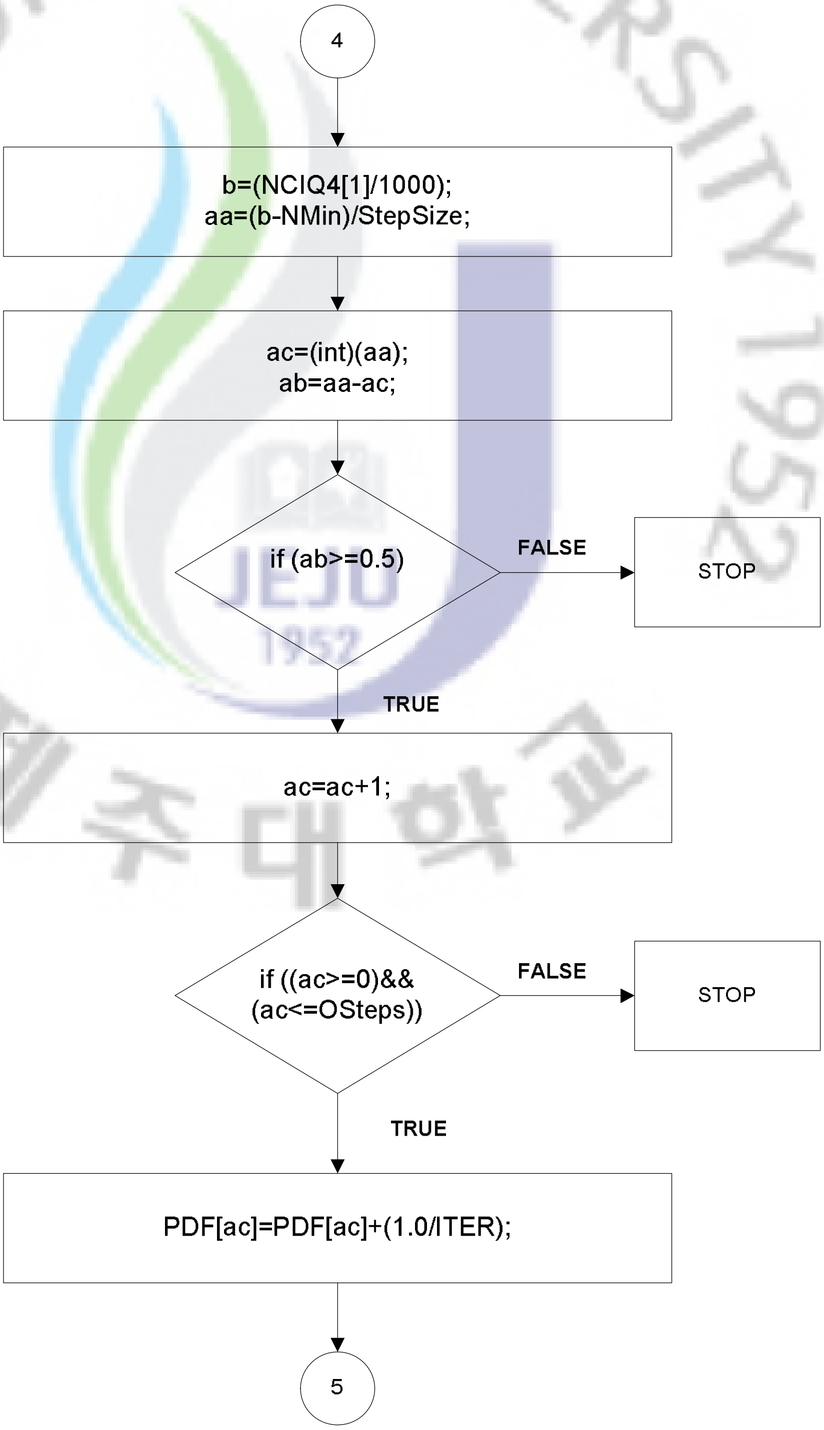
8.3 Flow Chart:

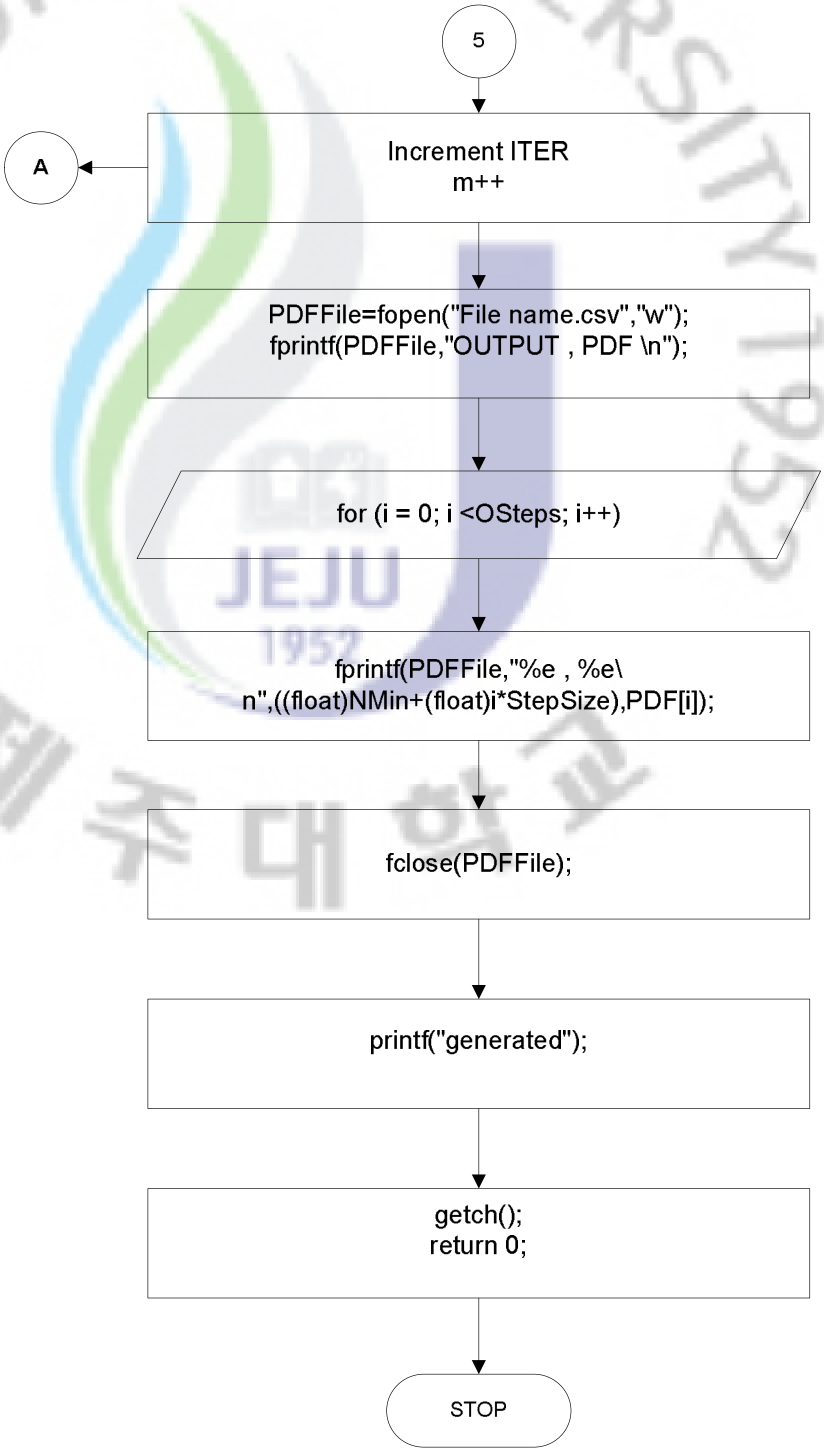



1
for (i=0; i < 2; i++)
cohInt_I1[i]=0.0; cohInt_Q1[i]=0.0;
NCIQ4[i]=0.0;
B
Non Coherent
Integration Index
n<1
FALSE
STOP
TRUE
C
Clutter Index
l<10
FALSE
STOP
TRUE
c= (exp(gauss_gen(0.64))+(5.2));
D
Non Coherent
Integration Number
k<100
FALSE
STOP
TRUE
2


2
for(i=0 ; i <2 ;i++)
cohInt_I1[i] +=sqrt(I[i])*cos(PI/4)+c;
cohInt_Q1[i] +=sqrt(Q[i])*sin(PI/4)+c;
for(i=0 ; i <2 ;i++)
I2[i]=0.0 ; Q2[i]=0.0;
IQ3[i]=0.0 ; Q4[i]=0.0;
I2[i]=pow((cohInt_I1[i]),2);
Q2[i]=pow((cohInt_Q1[i]),2);
3


3
for (i=0; i < 2; i++)
IQ3[i]=(I2[i]+Q2[i]);
for (i=0; i < 2; i++)
NCIQ4[i]=NCIQ4[i]+IQ3[i];
for (i=0; i < 2; i++)
cohInt_I1[i]=0.0;
cohInt_Q1[i]=0.0;
Increment
Non Coherent Integration Number
K++
D
Increment
Clutter Index
l++
C
Increment
Non Coherent Integration Index
n++
B
4


4
b=(NCIQ4[1]/1000);
aa=(b-NMin)/StepSize;
ac=(int)(aa);
ab=aa-ac;
if (ab>=0.5)
FALSE
STOP
TRUE
ac=ac+1;
if ((ac>=0)&&
(ac<=OSteps))
FALSE
STOP
TRUE
PDF[ac]=PDF[ac]+(1.0/ITER);
5


5
Increment ITER
m++
A
PDFFile=fopen("File name.csv","w");
fprintf(PDFFile,"OUTPUT , PDF \n");
for (i = 0; i <OSteps; i++)
fprintf(PDFFile,"%e , %e\
n",((float)NMin+(float)i*StepSize),PDF[i]);
fclose(PDFFile);
printf("generated");
getch();
return 0;
STOP

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