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M'HAMED BOUGARA-BOUMERDES UNIVERSITY

Faculty of Technology

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Master memory

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Sector: Telecommunications

Specialty: Networks and Telecommunications

Performance Analysis of Combined SLB/CFAR Lobe Blanking (SLB) with CFAR Systems in 4G Network

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Defended on 20 / 09 / 2020 in front of the jury composed of:

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Dedication

I dedicate this work to my father and mother, who have given me a lot so that I can reach what I am.

I also dedicate this work to my brothers and Sister And their children. Without forgetting all my family. My friends BOUGUERA, BELGACEM ,ZIADAT and especially my friend LAMRI Faycel.

Not forgetting KHODJA Baya who supported and helped me many times.

Last but not least, without forgetting my partner in this work, KASDI Oubeida and his family, and I thank them for their generosity and hospitality.

And finally, all my colleagues who I met at the university

LAMRI Nour Islam

Dedication

I dedicate this work to my father and mother, who have given me a lot so that I can reach what I am.

I also dedicate this work to my brothers and Sister. Without forgetting all my family. My friends

LAMECHE Salah Eddine, DJIR Akram, AMARI Anis and BIRECHE Nacereddine,

Without forgetting my partner in this work, LAMRI Nour Islam and his family

And finally, all my colleagues who I met at the university

KASDI Oubeida

ABSTRACT

One of the most important problems facing 4G systems and the antennas of cellular systems is the interference that penetrates the antenna through the side lobes and maintaining the false alarm probability constant.

In this thesis we examine the performance of the SLB / CA-CFAR where we analyze its performance and analyze the results.

Résumé

L'un des problèmes les plus importants auxquels sont confrontés les systèmes 4G et les antennes des systèmes cellulaires est l'interférence qui pénètre dans l'antenne à travers les lobes latéraux et le maintien de la probabilité de fausse alarme constante.

Dans cette thèse, nous examinons les performances du SLB / CA-CFAR où nous analysons ses performances et analysons les résultats.

ملخص

من أهم المشاكل التي تواجه أنظمة **G4** وهوائيات الأنظمة الخلوية هو التداخل الذي يخترق الهوائي عبر الفصوص الجانبية ويحافظ على ثبات احتمال الإنذار الخاطئ.

في هذه الأطروحة نقوم بفحص أداء **SLB / CA-CFAR** حيث نقوم بتحليل أدائها وتحليل النتائج.

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CUT: Cell Under Test

CA-CFAR: Cell-Averaging-CFAR

CFAR: Constant False Alarm Rate

Ve: the voltage at the input

δ^2: is the power of the clutter noise

P_D: probability of detection

SNR: the signal to noise ratio

INR: the interference to noise ratio

JNR: Jammer to noise ratio

P_{FA}: The probability of false alarm

G: the maximum gain of the main antenna

α_0: The detection threshold,

F: The blanking threshold,

β^2: The profit margin,

v: The random variable

G_A: the voltage gain of the auxiliary antenna

G_{SL}: the gain of the side lobes

P_B: The probability of blanking

$\boldsymbol{\mu}_c$: is the constant amplitude of the target signal

$\boldsymbol{\mu}_b$: is the amplitude of the noise signal

$\boldsymbol{f_i}$: is the intermediate frequency

η: is the random amplitude of the noise signal

λ: is the non-centrality parameter

ω_A: is the amplitude of the target received by the auxiliary receiver

$\Gamma(N)$: is the gamma function

N : Numbers of Cell Under Test

General Introduction:

The 4G communication system relies on antennas for coverage and is used for this as a cellular principle.

However, despite the coverage and the use of the cellular system, the antennas face problems due to the interference that makes their way to them through the side lobes of the antennas, and this is what generates fluctuation and a decrease in performance, and this is what prompted the use of the SLB system on the antennas in order to reduce the interference. But since this system works on a fixed threshold cannot be used because the probability of false alarm (Pfa) is affected by the power of this one. However, a new detection procedure known as CFAR (Constant False Alarm Rate) detection adopted in the sixties was considered to be an adaptive technique of digital processing of radar echoes for automatic detection of targets. In addition, real-time monitoring of the false alarm rate is provided by the CFAR algorithm, despite random variations in clutter parameters and / or in the presence of interfering targets. In CFAR detectors, the threshold of detection algorithm uses the values of the outputs of the adjacent range / Doppler cells of the cell under test (CUT: Cell Under Test) to determine the estimate of the clutter power that allows the Pfa to be maintained at a desired approximately constant value.and this is what we will address in our thesis.which in turn is divided into three chapters.

The first chapter: Generalities on communication systems

in which we talked about the TDMA, FDMA, CDMA communication systems and all Regarding its definitions and function,

The second chapter: Generalities on SLB systems and Study of SLB system performance according to Maisel

included everything related to the SLB system and antennas from the definition side and a study on the performance of the SLB system according to Maisel .

The third chapter: Performance Analysis of Adaptive SLB/CA-CFAR System

it is a study of the performance of the SLB / CA-CFAR system integrated on 4G communication systems And that with the help of MATLAB program

CHAPTER I

Generalities on Communication Systems

I.1.Introduction:

The communication systems describe a communication exchanges between two stations, transmitter and receiver. Signals or information's passes from transmitter to receiver through what is called channel, which represents a medium that signal use it to move from source toward destination. the development of communication systems requires better performance and increasing of number of users which means the augmentation of data transfer request and in the number of simultaneous accesses to the transmission channel. To solve this problem different multiple.

I.2.Time Division Multiple Access (TDMA):

Each user is allowed to transmit only within specified time intervals (Time Slots). Different users transmit in different Time Slots. When users transmit, they occupy the whole frequency bandwidth (separation among users is performed in the time domain).

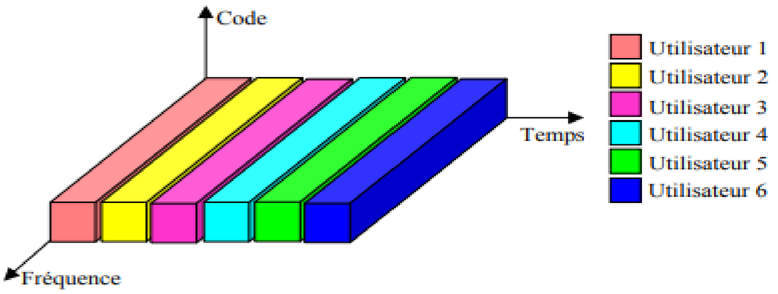


Figure1.1: Time Division Multiple Access Technique

I.2.1. TDMA Frame Structure:

TDMA requires a centralized control node, whose primary function is to transmit a periodic reference burst that defines a frame and forces a measure of synchronization of all the users. The frame so-defined is divided into time slots, and each user is assigned a Time Slot in which to transmit its information.

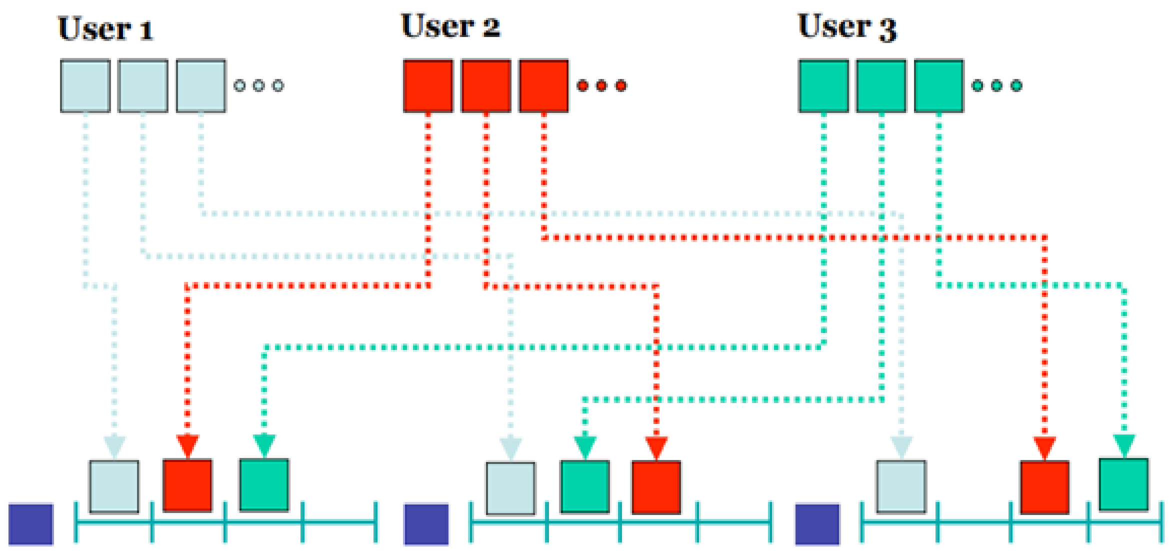


Figure1.2: Frame Structure

I.2.2. TDMA Guard times:

Since there are significant delays between users, each user receives the reference burst with a different phase, and its traffic burst is transmitted with a correspondingly different phase within the time slot. There is therefore a need for guard times to take account of this uncertainty. Each Time Slot is therefore longer than the period needed for the actual traffic burst, thereby avoiding the overlap of traffic burst even in the presence of these propagation delays

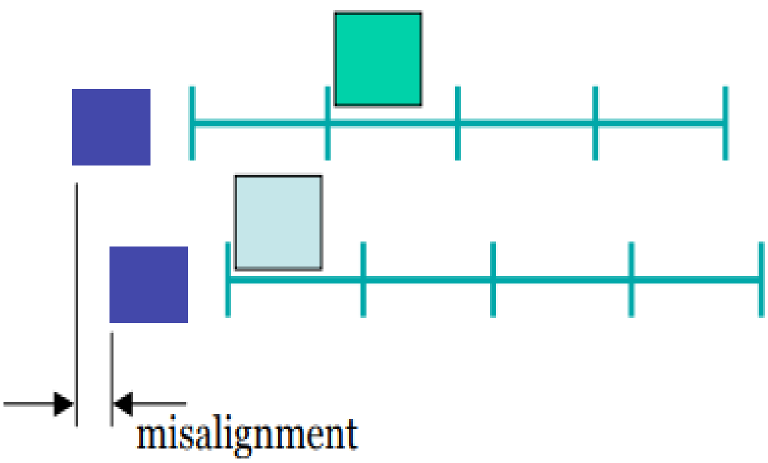


Figure1.3: TDMA with Guard times

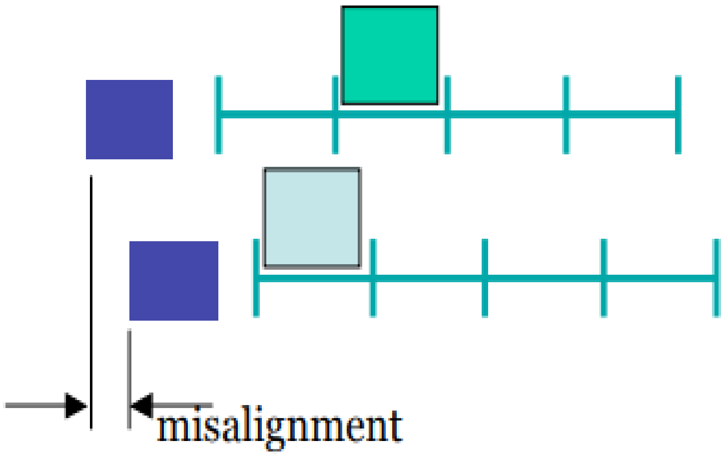


Figure1.4: TDMA without Guard times

I.2.3. TDMA Preamble:

Since each traffic burst is transmitted independently with an uncertain phase relaive to the reference burst, there is the need for a preamble at the beginning of each traffic burst. The preamble allows the receiver to acquire on top of the coarse synchronization provided by the reference burst a fine estimate of timing and carrier phase.

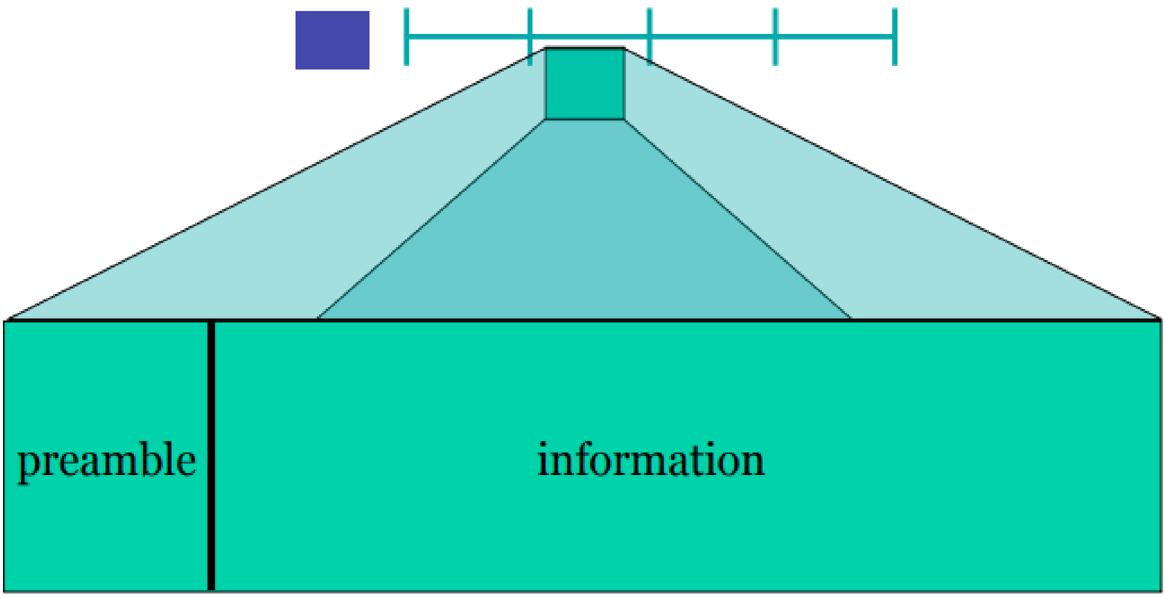


Figure1.5: TDMA preamble

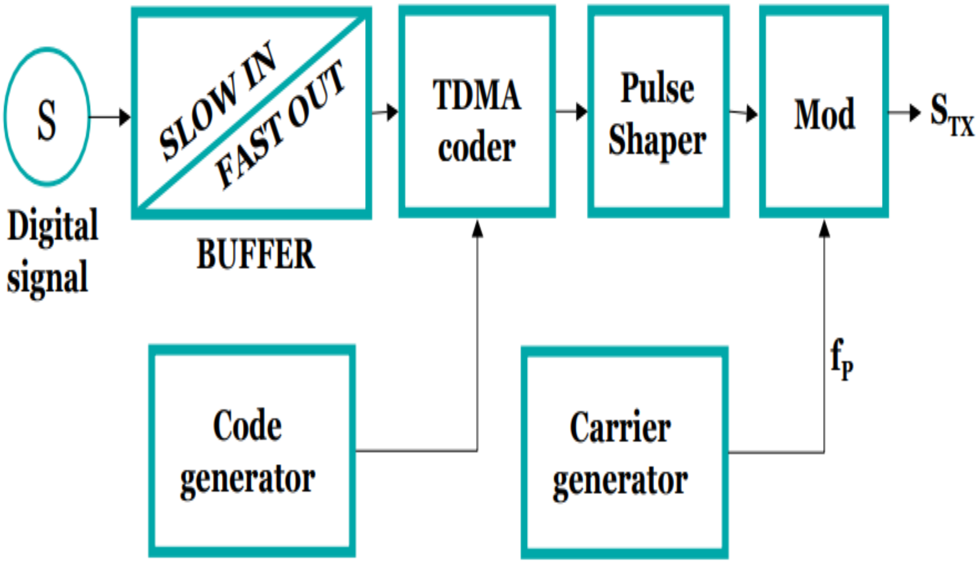


Figure1.6: TDMA reference transmitter scheme

I.3. Frequency Division Multiple Access (FDMA):

Each user transmits with no limitations in time, but using only a portion of the whole available frequency band width. Different users are separated in the frequency domain.

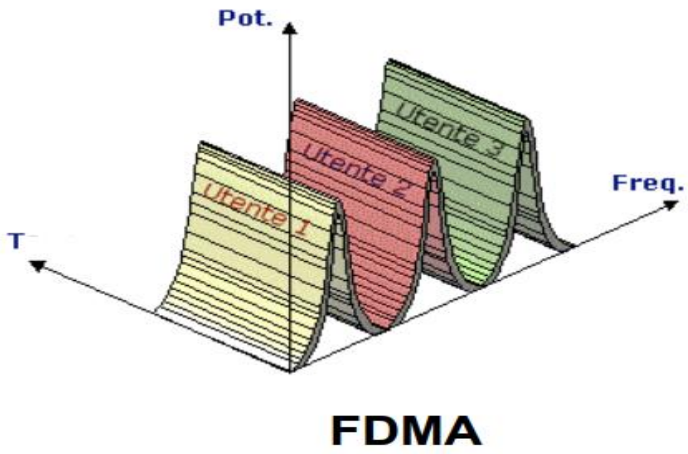


Figure1.7: Frequency Division Multiple Access Technique

I.3.1. FDMA vs TDMA:

Frequency division is very simple: all transmitters sharing the medium have output power spectra in non-overlapping bands. Many of the problems experienced in TDMA due to different propagation delays are eliminated in FDMA. The major disadvantage of FDMA is the relatively expensive and complicated bandpass filters required. TDMA is realized primarily with much cheaper logic functions. Another disadvantage of FDMA is the rather strict linearity requirement of the medium.

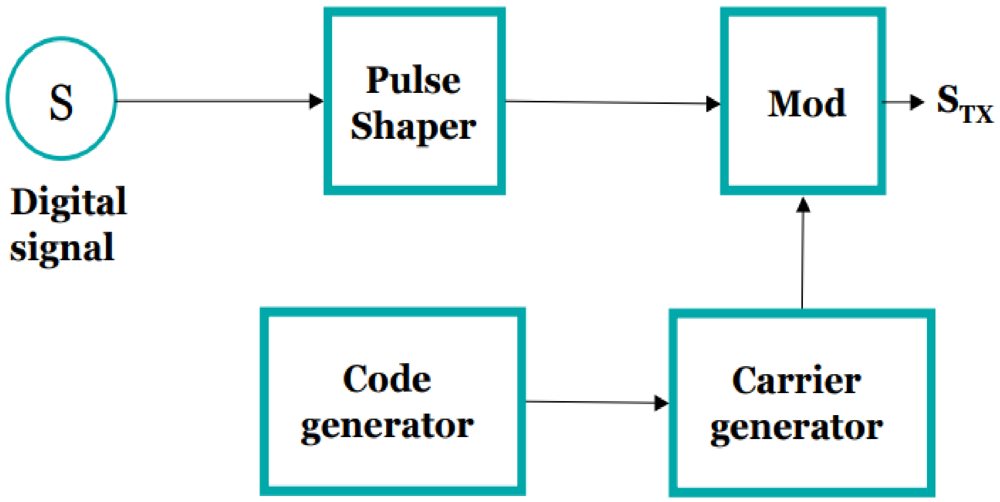


Figure1.8: TDMA reference scheme

I.4. Code Division Multiple Access (CDMA):

In CDMA each user is assigned a unique code sequence (spreading code), which it uses to encode its data signal. The receiver, knowing the code sequence of the user, decodes the received signal and recovers the original data. The bandwidth of the coded data signal is chosen to be much larger than the bandwidth of the original data signal, that is, the encoding process enlarges (spreads) the spectrum of the data signal. CDMA is based on spread-spectrum modulation. If multiple users transmit a spread-spectrum signal at the same time, the receiver will still be able to distinguish between users, provided that each user has a unique code that has a sufficiently low cross correlation with the other codes.

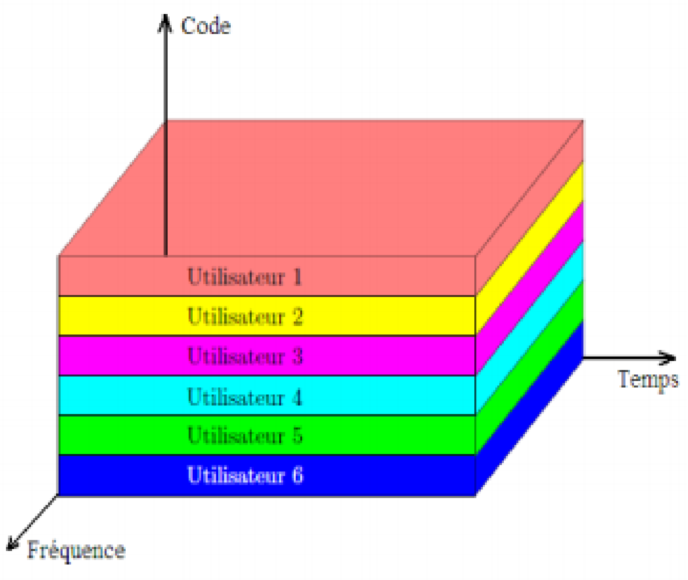


Figure1.9: Code Division Multiple Access Technic

I.4.1Spread Spectrum principal:

Thanks to the use of an independent code (PN) of the data sequence, the spread spectrum is carried out before the emission. At the reception, in order to recover the initial data, the same cade is used to dispreads the received signal.

Spread Spectrum Technique:

The performance of communications systems can be improved by Spread Spectrum Technique. This technique can be divided to three standards

. Direct Sequence CDMA (DS-CDMA): The original data signal is multiplied directly by the high chip rate spreading code.

. Frequency Hopping CDMA (FH-CDMA): The carrier frequency at which the original data signal is transmitted is rapidly changed according to the spreading code.

. Time Hopping CDMA (TH-CDMA): The original data signal is not transmitted continuously. Instead, the signal is transmitted in short bursts where the times of the bursts are decided by the spreading code.

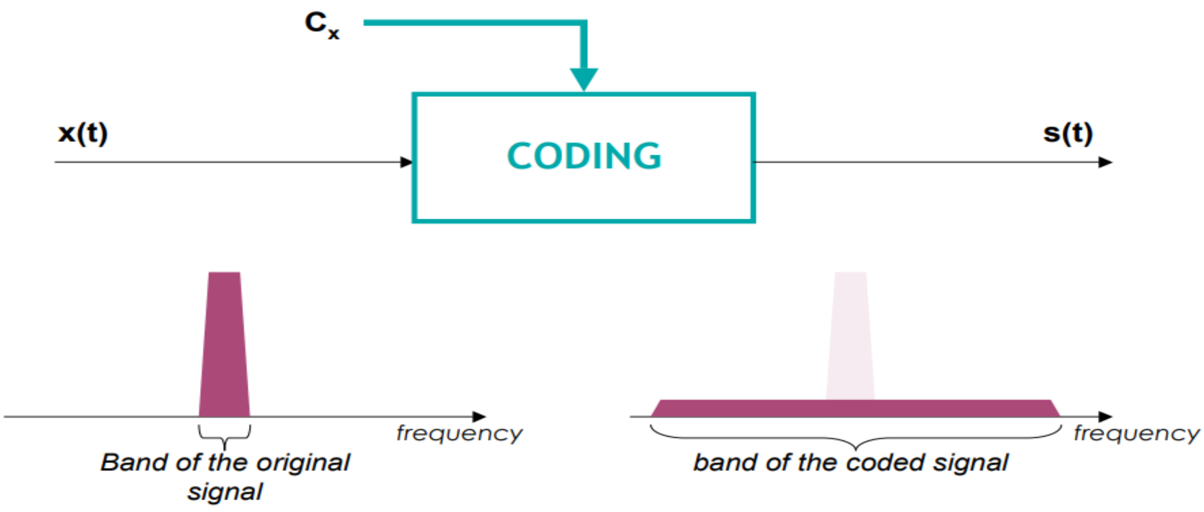


Figure1.10: Direct Sequence Spread Spectrum

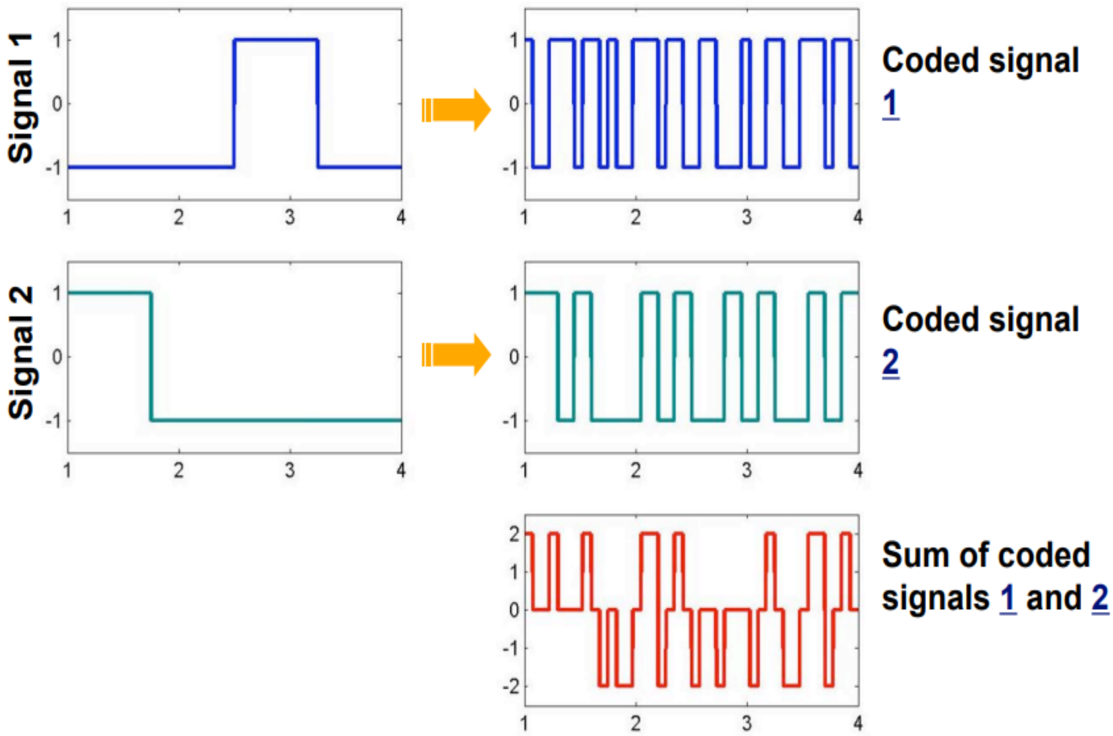


Figure1.11: the spreading process

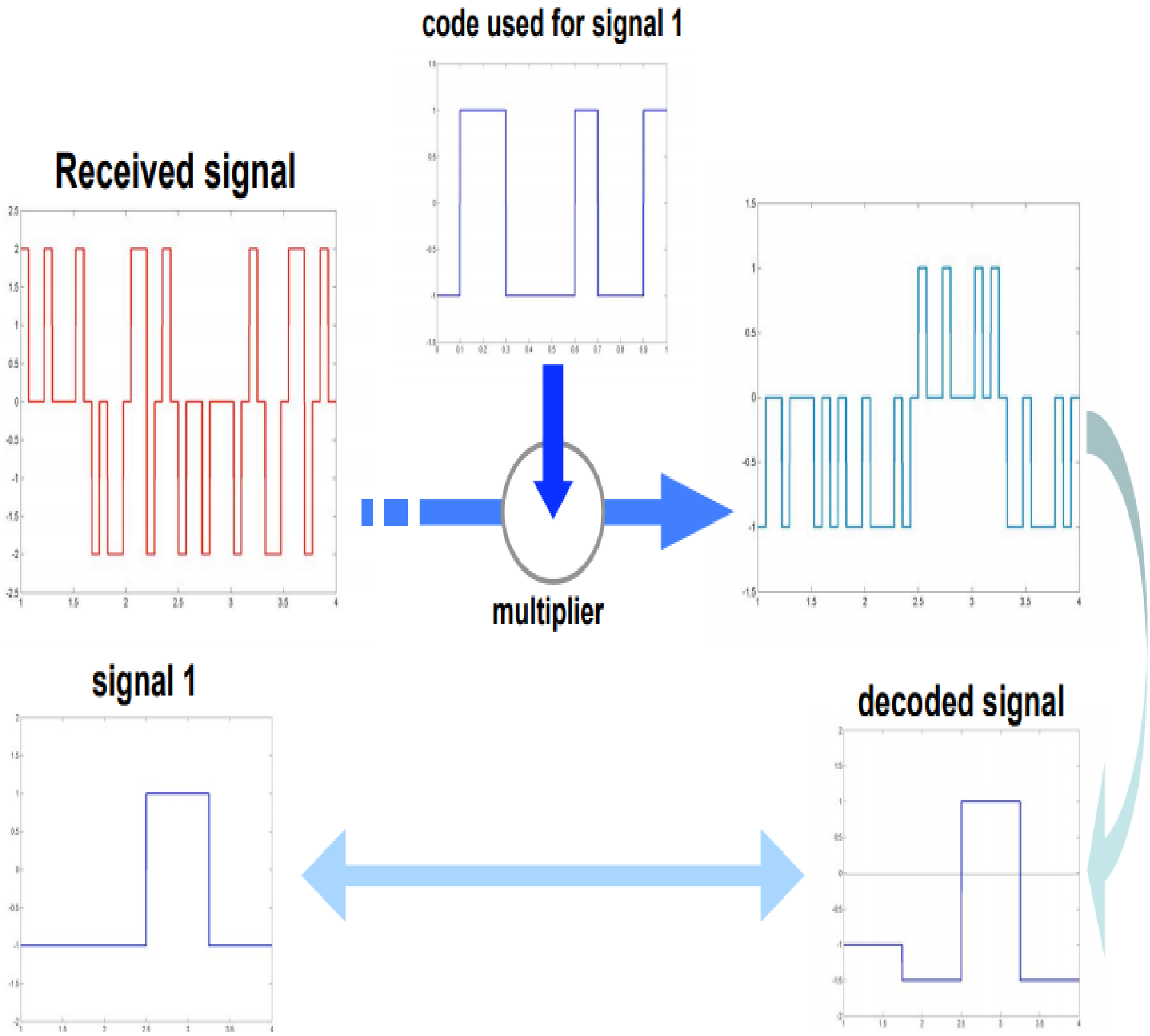


Figure1.12: the spreading and de-spreading process

I.4.2. Frequency Hopping Spread Spectrum:

In FH-SS, the transmitter spreads the spectrum by continuously jumping from one frequency channel to another. A larger number of intervals leads to a better spreading, Each user selectees the next frequency hop according to a code (FH code)

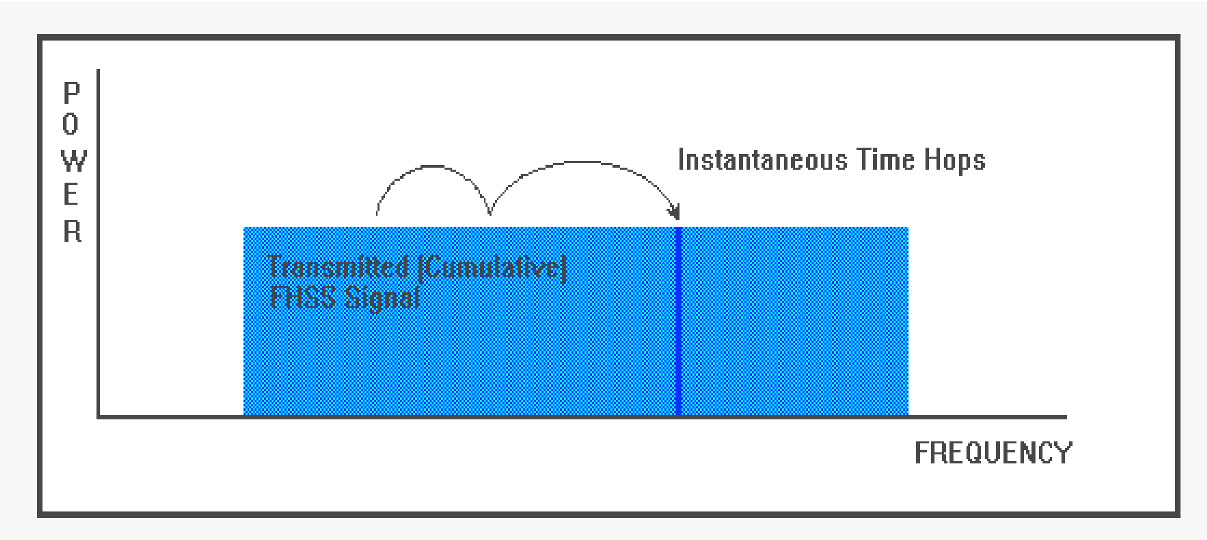


Figure1.13: Frequency Hopping Spread Spectrum

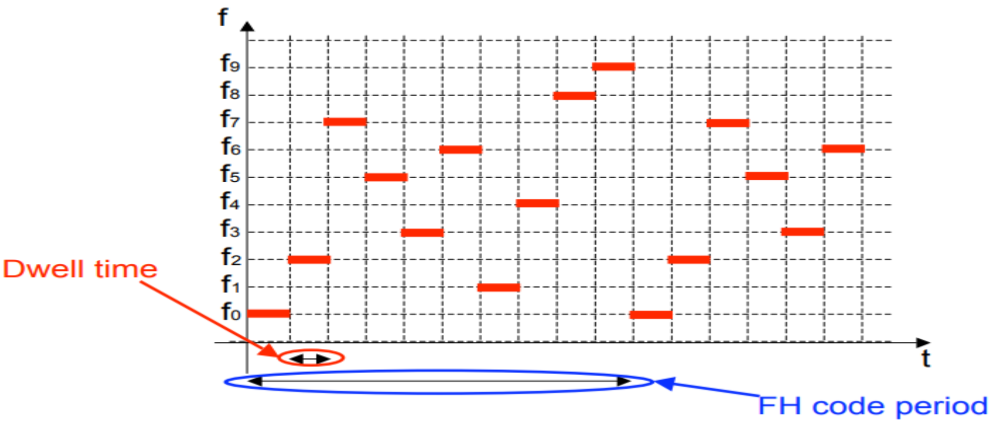


Figure1.14: Time-frequency occupation for a FH-SS signal

I.4.3. CDMA the partial correlation problem atrial correlation problem:

Partial correlations among encoded signals arise when no attempt is made to synchronize the transmitters sharing the channel, or when propagation delays cause misalignment even when transmitters are synchronized. Partial correlations impede the receiver to totally cancel the contributions of other users even in the presence of spreading codes having low cross-correlation. In presence of partial correlations, the received signal is therefore affected by Multi User Interference. The partial correlations can be reduced by proper choice of the spreading codes, but cannot be totally eliminated. CDMA system capacity is thus tipically limited by the interference from other users, rather than by thermal noise.

I.4.4. CDMA the near-far problem:

If all the users transmit at the same power level, then the received power is higher for transmitters closer to the receiving antenna. Thus, transmitters that are far from the receiving antenna are at a disadvantage with respect to interference from other users. This inequity can be compensated by using power control. Each transmitter can accept central control of its transmitted power, such that the power arriving at the common receiving antenna is the same for all transmitters. In other words, the nearby transmitters are assigned a lower transmit power level than the far away transmitters. Power control can be easily achieved in centralized access schemes (e.g. third generation cellular networks), but is a challenging issue in distributed systems.

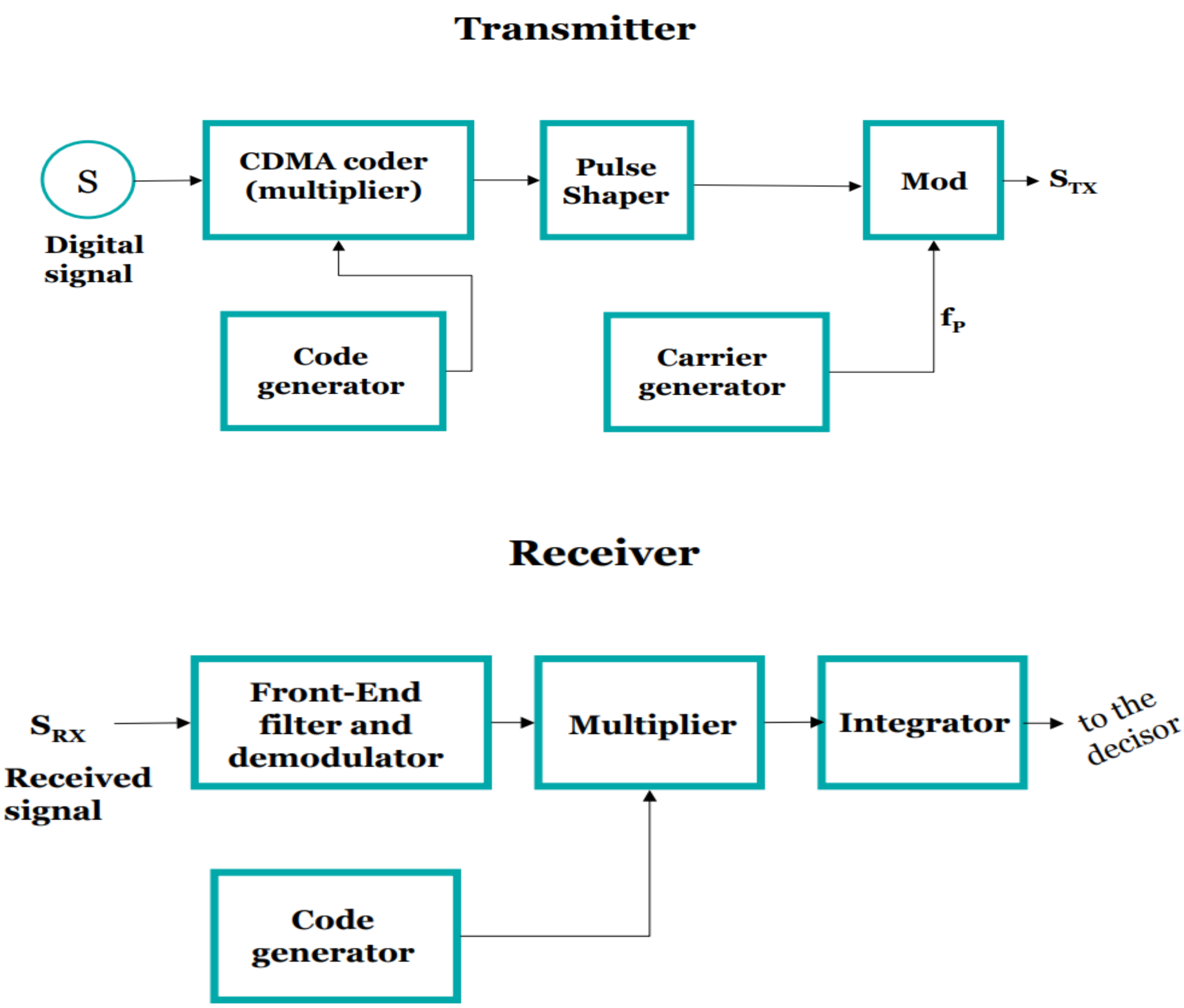


Figure1.15: DS-CDMA reference scheme

I.4.5. Synchronization in CDMA Systems:

In ds-cdma system, the synchronization of PN (pseudo-noise) at the reception is the main operation to gain a successful transmission. This operation consists on generate a local code at the level of the receiver which is the same received code.

The code synchronization is realized by two phases:

- Acquisition code PN phase: which is used to synchronize the received code and the locally generated code.
- Tracking phase: which is used to maintain fine synchronization between the two code.

I.4.5.1. Acquisition code PN phase :

The objective of the acquisition is to obtain a first synchronization between the code received and the locally generated code in the receiver. The local generator generates the spreading code with a delay chosen according to a hypothesis.

The signal will dispreads correctly if the offset corresponds to the received code then we use a band pass filter in order to recover the dispreads signal. When the two codes are aligned it means that the receiver goes through the first synchronization phase, it then the tracking loop will be activated to further refine the synchronization. In the other case, if they are not aligned and the delay of the code received does not correspond, the signal obtained after dispreading always remains broadband and there is no power significant at the output of the band pass filter. The decision circuit then decides that this hypothesis is not valid and other phases must be tried.

I.5. Detection in Communication Systems:

In communication systems, the difficulty of make a decision about the presence or absence of the desired signal provides a defective detection. This decision can be described in terms of statistical hypothesis which consists in comparing the detector output with a fixed or an adaptive threshold, all this will be more explained in the next chapters.

I.6. Conclusion:

In this chapter, we have presented the different multiplexing techniques used in communication systems (TDMA, FDMA and CDMA) and we based on the spread spectrum in DS-CDMA.

We mentioned that to obtain a successful transmission of data in communication systems it has to be there a synchronization between the code used in transmission and the code generated locally in the reception this operation which is accomplished with two phases code acquisition (faces difficulty of detection because of the threshold type) and tracking phase.

CHAPTER II

Generalities on SLB systems and Study of SLB system performance according to Maisel

II.1. Introduction:

The performance of antenna systems can be improved by giving importance to the useful signal which is accompanied by unwanted signals. These signals are generated by several sources such as jamming systems in electronic countermeasures, interference, clutters, natural brunt sources and thoughts on the various obstacles. These signals can access the system through the secondary lobes of the receiving antenna and be interpreted as signals from the main lobe and this results in: false detections and direction errors. It is for these reasons that Ia Removing unwanted signals becomes an essential operation for any application and especially radar systems. Sidelobe blanking (SLB), a system for suppressing the effects of secondary lobes, makes it possible to suppress such signals when they are impulsive (detection threshold low). due to jammers, residual echoes from Targets or clutter echoes In 1968, Maisel [7] presented the architecture, currently called classic of the SLB system. he studied the simplest case where detection is based on a single target echo with a constant radar equivalent area, he obtained compact mathematical expressions of the probabilities of false alarm and detection, have refined this work to include other expressions for the case of a Swerling I type target.

We will study in this chapter the general principle of SLB and these design parameters and define other expressions of probabilities than those we are used to seeing them: the probability of detection and the probability of false alarm.

II.2. The Antennas:

A transmitter provides a modulated high frequency current at its output. To transmit information remotely, the modulated current must be transformed into electromagnetic waves capable of moving in the atmosphere. This is the role of the broadcast antenna.

The electromagnetic wave in the atmosphere is reflected by several obstacles and arrives at the receiver. It is the receiving antenna that is responsible for converting the electromagnetic wave into current that can be processed by the receiver.

In aerial surveillance, centimeter and decametric wave radars are generally used. For these types of waves, the antenna of conventional radar consists of a parabolic reflector and a focal power supply, generally a horn. Whatever the shape of the antenna, its radiation is always more or less concentrated around an axis: it is the main lobe, and around this lobe there are other less important but not negligible directions of radiation: this are the secondary lobes.

The antenna radiation pattern, DDR, shows how the antenna distributes its radiation in the surrounding space.

The radiation diagram is therefore three-dimensional. It is represented by a spherical or rectangular coordinate system. The choice of one or the other system depends on the location of the radiated field in space. If the radiated field is distributed throughout the space (not very directive antenna), the spherical system is advantageous. The rectangular system is best suited when the Field is concentrated around a particular direction (directional antenna). The two-dimensional representation of the radiation diagram is deduced by making cuts and projections.

The cuts are made in planes of symmetry if there are any, or, more conventionally in orthogonal planes corresponding to the planes of polarization of the field in a preferred direction, for example: the plane of the electric field or that of the field magnetic. The polar representation is very suggestive. The Cartesian representation is convenient for comparing diagrams: with logarithmic scales since in this case any readjustment of a diagram due to a multiplicative factor only requires vertical translation.

The projections are justified for highly directional antennas. They are carried out on a plane normal to the preferred direction of radiation. The radiation diagram is then presented in the form of contour lines whose interpretation is immediate.

The performance of an antenna is defined by the following parameters:

- the gain
- opening of the main lobe,
- polarization,
- the rate of secondary lobes,
- the bandwidth,
- the yield.

Antenna gain

An antenna cannot emit a power larger than that which it receives, and consequently, a priori, it is surprising to speak of antenna gam the antenna in a radar can concentrate this power in a given direction. Two types of gain are to be defined: directional gain and power gain

To define the directional gain and the power gain. The antenna considered is compared to a reference antenna. An isotropic antenna is used as the reference antenna, that is to say an antenna radiating the same power in all directions.

We call directional gain: the ratio between the power emitted in the direction of the main lobe and the power that an isotropic antenna (considered reference) would emit, if the two antennas radiated the same power.

Power gain is called: the ratio between the power emitted in the direction of the main lobe and the power that the isotropic reference antenna would emit, if the two antennas consumed the same power. The gain in power therefore takes account of losses in the antenna. The power gain is equal to the product of the directional gain by the efficiency of the antenna.

Main lobe opening:

The opening of the main lobe is an essential feature of a radar system. In the horizontal plane, it defines the position and the power of angular resolution; in the vertical plane, it expresses the possibilities of vertical coverage.

Polarization:

The polarization of the wave expresses the position of the electric field in space. Depending on whether it is vertical or horizontal, the polarization is said to be vertical or horizontal. It is also possible to rotate the electric field of the radiated wave in a continuous manner, by keeping it the same amplitude: the polarization is said to be circular; either by varying the amplitude, generally following an ellipse the polarization is said to be elliptical

Secondary lobe rate:

The rate of secondary lobes [41] is called the ratio between the maximum field of the secondary lobes Es and the maximum field of the main lobe Em. Expressed in decibels, this rate is k = 20log (Es / Em).

In the theoretical case of a radiation pattern of an antenna illuminated uniformly over its entire surface, the rate of secondary lobes is 13 dB. By ensuring that the illumination is stronger in the center of the antenna than at the edges, what a cornet achieves quite naturally, the rate of the lobes secondary is reduced to 20 or 22 dB. This advantage of the reduction of the side lobes is important in certain radar applications, in order to avoid the ambiguity of the determination of the direction at close distances; it is paid for by a widening of the main lobe and a slight decrease in gain, therefore in range maximum.

Yield:

Yield is measured by the ratio of the effective area of radiation on the geometric surface, it is generally between 0.5 and 0.7.

II.3. Parasites and Noises:

Any signal other than the useful signal is a parasite which interferes with the detection of the target.

In addition, what is in our case an unwanted signal may be the useful signal for another application; this is the case with atmospheric echoes, which represent noises for airborne target detection radars, but which are useful signals from meteorological radars. Spurious signals in antenna consist of:

1. . internal noise and in particular thermal noise.
2. . Natural externat noise (clutter).

3. . artificial external noise such as interference signals (called electronic countermeasures) and interference from another antenna.
4. . parasitic echoes (clutter) resulting from the reflection of the pulses emitted by the antenna itself on the surrounding natural reflectors targets (soil, rain, sea, forests, etc…).

Depending on whether they come from the receiver itself, from the ground, from the atmosphere or from the sea, the characteristics of these echoes (probability density, mean, variance, etc.) are diffe0rent, and consequently, the means used to minimize their effects are also different.

Noises, since they are of a random nature, follow probability laws for ease of use in mathematical modeling, radar specialists have always considered that these clutters (ground clutter, sea clutters, etc.) Gaussian law; but in reality, this is not always true.

A lot of research has shown that these clutters follow non-Gaussian laws such as the Weibull distribution, the log-normal distribution or the K distribution.

To determine the performance of an antenna system with a certain probability of false alarm desired, it is absolutely essential to know which law obeys the clutter in question. The meteorological clutter. which is harmful for radar detection, generally follows a Rayleigh law; its form is:

$$P(x) = \begin{cases} \frac{1}{\delta^2} \exp\left[-\left(\frac{x^2}{2\delta^2}\right) \right] \text{pour } x \geq 0 \\ 0 \qquad \qquad \qquad \qquad ailleurs \end{cases} \qquad (2.1)$$

With representative standard deviation. This type of distribution can be applied to the envelope of the echoes of homogeneous grounds such as the desert. Some urban and rural areas with buildings and mountains can be approximated by a Weibull distribution law.

But in reality, neither Rayleigh's law nor that of Weibull describes in a precise way the distribution of the envelope of atmospheric or sea clutter. On the other hand, the log-normal distribution models this type of clutter well, its form is:

$$P(x) = \begin{cases} \frac{1}{\delta\sqrt{2\pi x}} \exp\left[-\left(\frac{ln(x)-m^2}{\delta\sqrt{2}}\right)^2\right] \text{pour } x \geq 0 \\ 0 \qquad \qquad \qquad \qquad ailleurs \end{cases} \qquad (2.2)$$

The parameters of the log-normal distribution are respectively calculated by doing:

$$m = \ln[mx] - \frac{1}{2}\ln\left[1 + \frac{\delta x^2}{mx^2}\right]$$

$$\delta = \ln\left[1 + \frac{\delta x^2}{mx^2}\right]$$

where m_x is the mean and δ_x is the standard deviation of the random variable x.

II.4. Principle of Logarithmic Detection [3]:

To improve the contrast between useful weak echoes and strong parasitic echoes, as in the case of a log-normal clutter, a logarithmic amplification chain can be used which gives the receiver a relatively lower gain when the signal input level is high. These essential properties can be explained from the following remark: if we designate by Ve the voltage at the input of an amplifier and by Vs the voltage at its output, and if we arrange to get:

$$\mathbf{V_s = a.\ln (b.V_e)}$$

Where a and b are constants, we see, by differentiating, that a variation Ave of the input voltage will cause a variation at the output:

$$\mathbf{\Delta V_s = a.\Delta V_e / V_e}$$

If **ΔVe** is proportional to IL. which is appreciably exact for clutter signals, the fluctuation of the output voltage becomes independent of the amplitude at the input. this remark is very interesting since it allows us to design a device that will give variations in output level independent of the average level at the input.

However, a truly logarithmic receiver cannot practically exist; this receiver would give an output voltage of minus infinity when the input signal was zero. The amplifiers produced in practice comply with the law:

$$\mathbf{Y = a.\ln (1 + bx)}$$

When x becomes weak, the output voltage y tends to zero. The receiver is therefore linear for weak signals, then logarithmic: this device is sometimes called an " Iin-log " amplifier. In an analog receiver this function is performed in accordance with block diagram (Figure1.1). Amplifier outputs (Vmax represents the voltage which saturates the amplifier). After detection, these signals are sums, which provides the output signal represented on the logarithmic abscissa.

II.5. Equivalent Surface and Target Fluctuation [4][5]:

If a target receives from the radar a power density p (p expressed in watts per square meter). everything happens as if it radiates, in a directional way, the diffracted power. A small part of the latter is received by the radar receiver with a power pδ (δ by definition being its Radar Equivalent Area (SER)). Therefore, the signal from the target is related to the reflectivity of the latter. Knowing the value of the RES of the target is very difficult to know a priori with exactitude, given the extreme sensitivity of this value to the various parameters (shape, frequency emitted, polarization of the transmitted wave and movements of the target and radar, ...).

The SER is thus considered as a random variable associated with a density of probability that we must establish from a given observation. The RES must therefore be considered as a random process defined by its probability density function and its auto-correlation function. Two probability densities and two autocorrelation functions were assumed to result in four combinations of target fluctuation patterns.

<u>Swerling type target I</u>

In this case, we assume that the pulses received from the target have a constant amplitude throughout the duration of illumination and statistically independent of a switch from the antenna to another "Scan-to-Scan fluctuation". This assumption ignores the effect of the antenna on the amplitude of the echo. The envelope of the signal reflected at the output of the quadratic detector follows an exponential law of the form

$$P(s) = \begin{cases} \dfrac{\exp\left[\frac{-s}{\delta^2}\right]}{\delta^2} & \text{for} \quad S \geq 0 \\ 0 & \text{elsewhere} \end{cases} \tag{2.3}$$

where δ^2 represents the average power of the received Signal.

<u>Swerlinq II type target</u>

In this case, the envelope of the signal follows the same law as that of the Swerling I type given by equation (2.3). But the fluctuations are faster than in the first case so that the amplitudes are independent from pulse to pulse "Pulse-to-Pulse fluctuation" for each sweep.

<u>Swerling III type target</u>

For this model, the fluctuations are considered slow as in the case of the Swerling type 1, that is to say "Scan-to-Scan fluctuation", but the probability density of the signal envelope at the output of the quadratic detector is given by the equation:

$$P(s) = \begin{cases} \dfrac{4s\ \exp\left[\frac{-2s}{\delta^2}\right]}{\delta^2} & \text{for} \quad S \geq 0 \\ 0 & \text{elsewhere} \end{cases} \tag{2.4}$$

Swerling IV type target

For this type of model, the targets have rapid fluctuations and the amplitudes are independent from one pulse to another "Pulse-to-Pulse fluctuation", the probability density of the signal envelope at the output of the quadratic detector is the same as that given by equation (2.4).The probability density used for the cases of the Swerling I and II type relates to the complex targets made up of several independent elementary reflectors (scatters) and no reflector is dominant.

This model is used to represent fluctuations in aircraft echoes and reflection over most terrain. In contrast, the probability density of Swerling III and IV cases is used to model targets composed of a predominantly constant reflector and a set of small independent reflectors. This model can be applied for missiles and satellites. In the case where only one pulse is transmitted during the illumination duration, the Swerling I model is equivalent to the Swerling II model, and the Swerling III model is equivalent to the Swerling IV model.

II.6. Principle of suppression of the effect of secondary Lobes:

The antennas generally have secondary lobes due to their construction. Because of these lobes, whose gains are significant, the antenna does not fully fulfill its role: a target can be detected by the secondary lobes as well as by the main lobe. So, it is very difficult, and sometimes impossible, to determine the direction of the target. Ground echoes appear especially since there are large side lobes.

To eliminate the effects of the side lobes, a system should be implemented which will validate the signals received by the main lobe and which will block the signals received by the side lobes. In order for this system to take into account or ignore the information, it is necessary for it to make a comparison with respect to a reference, then it decides whether the signal should be transmitted or not. This system, well known by radar operators as SLB (Side Lobe Blanking), makes it possible to give the antenna its ideal radiation pattern (without side lobes).

II.7. Stat of Art on systems with suppression of secondary lobes effects (SLB):

Maisel introduced a classic architecture of the SLB system by considering the case where detection is based on the use of a single pulse, with a target model of Swerling0 or Marcum type. It obtained compact expressions of probabilities of detection and false alarm. The performance of the system was analyzed by numerical simulation. Pedro continued work on the basic theory and the principle of the SLB system as well as the design and the implementation of the circuit were presented with examples of visualized signals and these results. Harvey and Wood designed and implemented, on a real system, the SLB device assuming that the clutter follows a Rayleigh law.

Farina and Gini studied the SLB system, for a target embedded in a correlated clutter, by introducing a suitable whitening matched filter. Farina and Gini calculated the final expressions of the probability of false alarm, blanking and false blanking, for a fluctuating target according to the Swerlingl model drowned in a Gaussian clutter. Shnidman and Toumodge generalized the work of Maisel using a non-coherent integration and a fluctuation of the model target based on the gamma distribution. More general mathematical expressions have been determined. The performance of the SLB system was obtained and graphically illustrated

II.8. Principle of SLB systems [7]:

The architecture of the SLB system according to Maisel is very simple. The noise can reach the receiver through the side lobes of the radar antenna. We will install a so-called omnidirectional reference antenna (auxiliary) capable of receiving signals from all directions, and we use these signals to block the receiver whenever the ratio of the signal level (v) of the auxiliary antenna and that from the main antenna (u) exceeds a certain threshold (figure 2.1); this one is called thresholds of blanking.

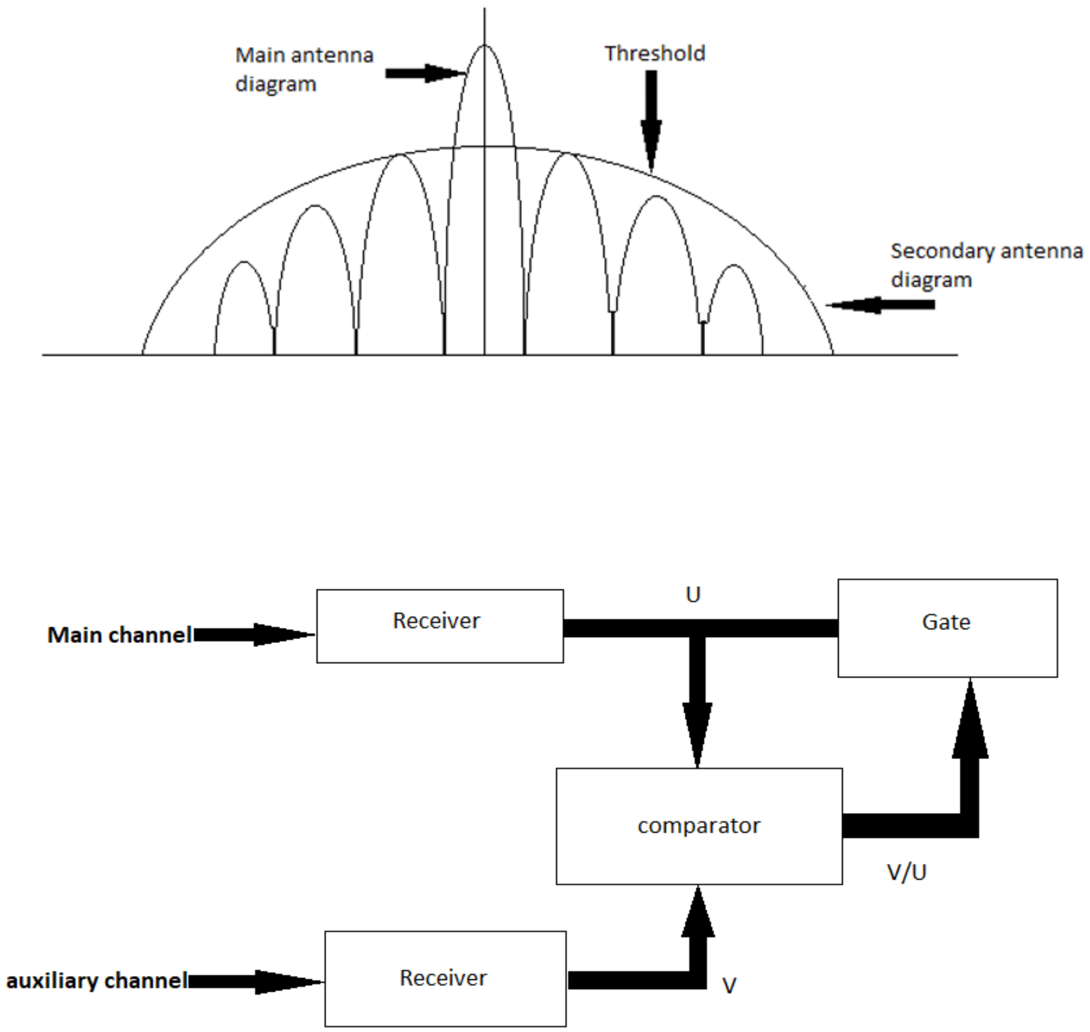


Figure2.1: Simplified block diagram of an SLB Radiation diagram

II.9. SLB Concept [7]:

Side lobe suppression systems are frequently used to prevent the acquisition of a relatively strong target in the side lobes of the antenna. The basic operation of these systems is illustrated in Figure2.2, where the detected outputs of two channels are illustrated in Figure2.3, When the target or pulsed interference is in the side lobes of the acquisition antenna, the output of the auxiliary channel will ideally be greater than that of the main channel so that the threshold difference can be used to mask the channel main before detection circuits and final displays, thus preventing target detection .

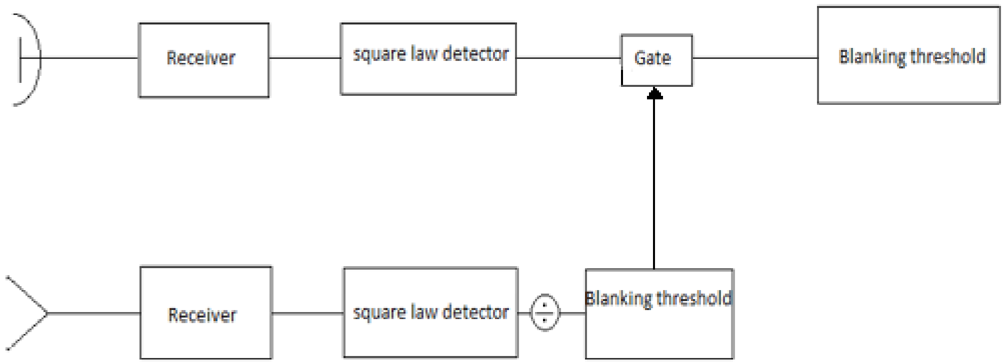


Figure2.2: outline of antenna and SLB device processing scheme

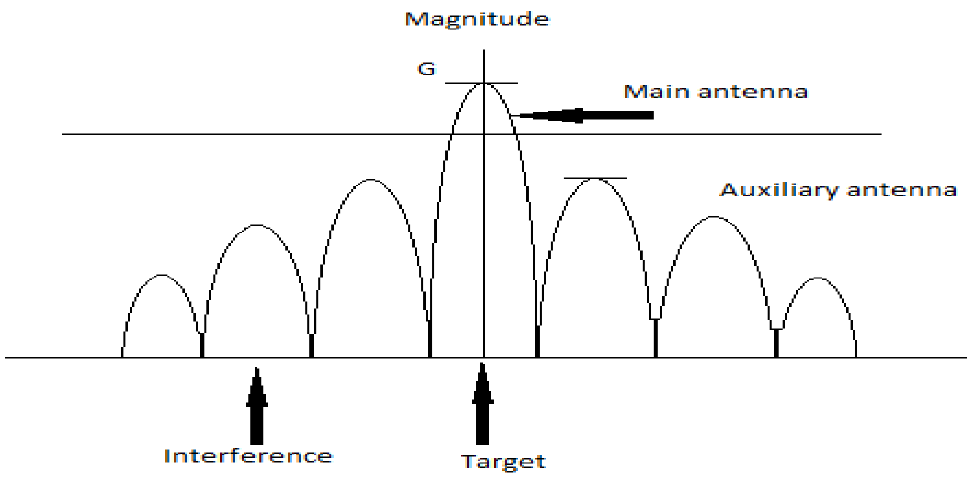


Figure2.3: Main and auxiliary patterns for SLB processing

SLB performance is evaluated based on the level of the side lobes of the main antenna, the gain of the auxiliary antenna, the signal to noise ratio (SNR) and the interference to noise ratio (INR). The performances are also influenced by the parameters $\beta = \sqrt{GA + Gsl}$, which is the ratio between the voltage gain G_A of the auxiliary antenna and the maximum value G_{SL} of the gain of the side lobes of the main antenna, and $\omega=\sqrt{GA + G}$ which is the voltage gain of the auxiliary antenna normalized to the maximum gain G of the main antenna. The performance of the system can be analyzed by examining the different results obtained following the pair (V, U) of processed signals. Three hypotheses are considered here in order to design the parameters of the SLB system: the null hypothesis H_0 corresponding to the presence on noise in the two channels; hypothesis H_1 relating to the target in the main lobe; and hypothesis H_2 corresponding to the target in the main lobe and/or the interference signal in the side lobe region in the same cell as the target

II.10. Antennas Characteristics [8]:

To facilitate the evaluation of the SLB system; the shape of the antenna radiation patterns is assumed to be ideal. The normalized power gain of the radar antenna in the main lobe is 1 (0 dB) and in the secondary lobes is δ^2. The auxiliary antenna has a normalized gain in power of ω^2. The parameter β^2 represents the ratio between the gain of the auxiliary antenna and that sidelobes; we call it margin of the gain. The main receiver antenna is characterized by a narrow main lobe and high gain. The choice of the reference antenna is dictated by the characteristics of the radar antenna. This antenna must be omnidirectional; its gain is between the gain of the main lobe and that of the secondary lobes.

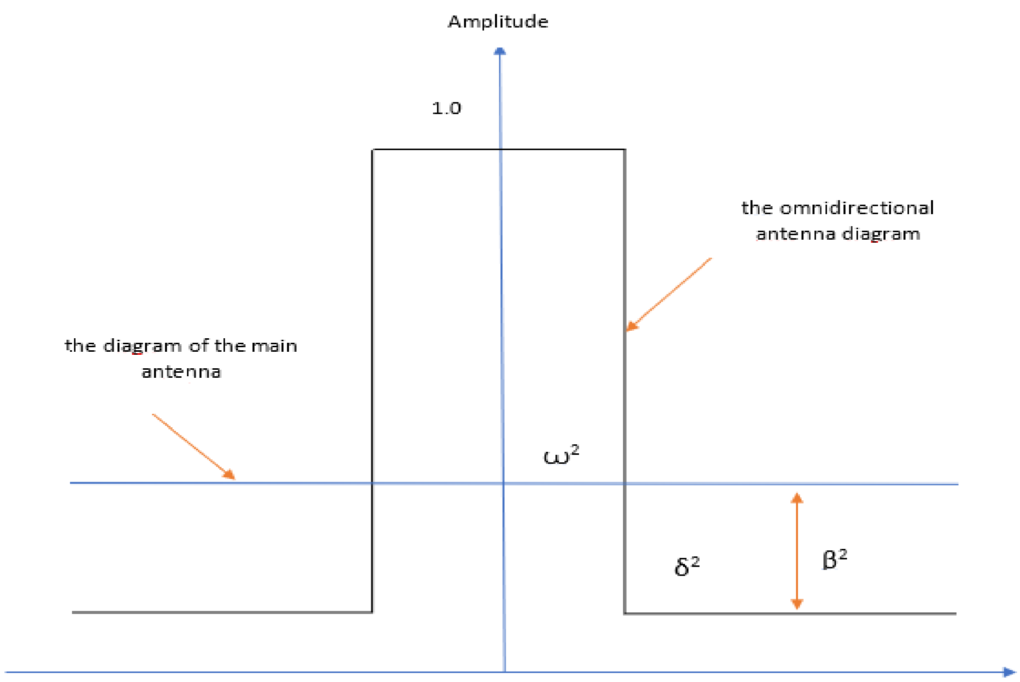


Figure2.4: idealized diagrams of the main antenna and the omnidirectional auxiliary antenna

II.11. The Study area:

To determine the random side of the SLB system, the signal at the main channel output is represented by the random variable u which is the secondary channel signal by the random variable v (square detection) [8]. α_0 and F are the detection and blanking threshold.

Maisel logic devise (u, v) into three areas of definition instead of two regions in the case of classic radar without SLB(Figure2.5). The definitions of these regions are:

Blanking area, B:

This region contains the set of pairs (u, v) that satisfies the following condition: the ratio of the variable v over the variable u is greater than the blanking threshold F. This region is not present in the case of conventional radar without SLB. His mathematical definition is:

$$B = (v/u \geq F \text{ and } u \geq \alpha_0)$$

Detection area, D:

This region includes all UV pairs that check the detection state: the ratio of the variable v to that of u is less than the blanking threshold and the variable u is greater than the detection threshold:

$$D = (0 < v/u < F \text{ and } u \geq \alpha_0)$$

Empty area, N:

This area does not matter to determine the possibilities. His mathematical definition is:

$$N = (0 < v/u < F \text{ and } u < \alpha_0)$$

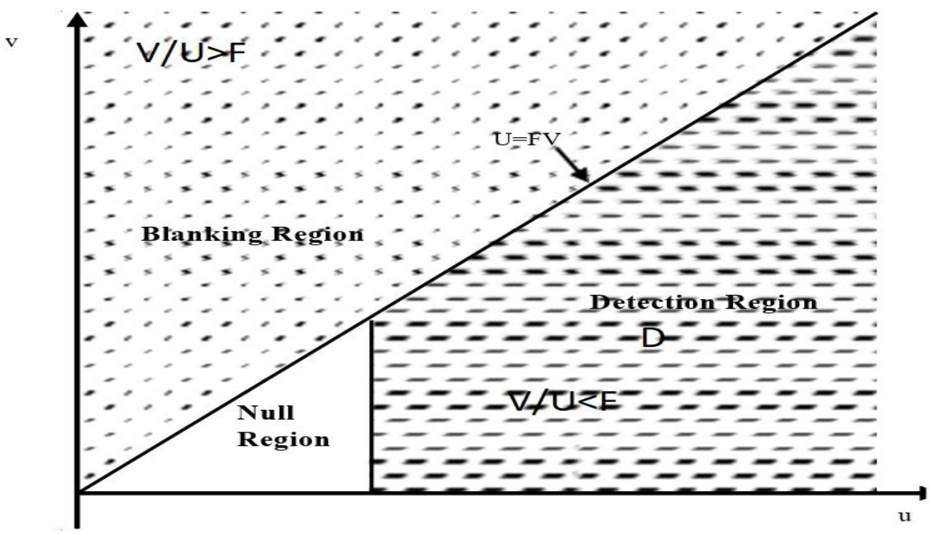


Figure2.5: The representation of the couple of random variables (u, v) the case of a radar with SLB [7]

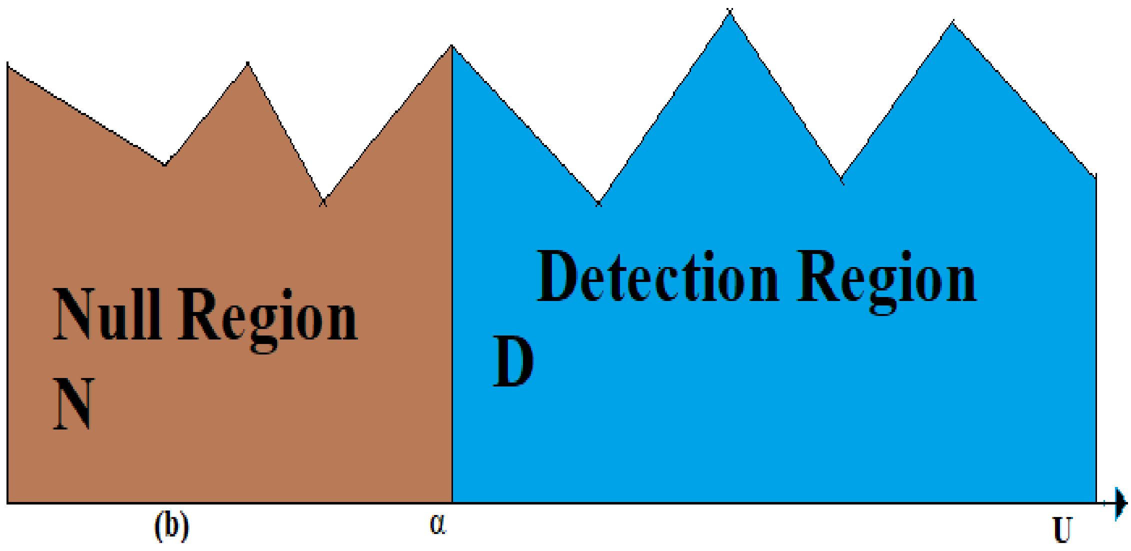


Figure2.6: The representation of the pair of random variables u in the case of a conventional radar without SLB

II.12. Definitions of the probability of the SLB systems [9]:

Before defining the different probabilities that tell us about the performance of the SLB system; we consider three hypotheses:

1) The hypothesis H_0 signifies the absence of target and jammer.

2) The hypothesis H_1 signifies the presence of the target in the main lobe.

3) The hypothesis H_2 signifies the presence of the jammer in the secondary lobes.

From these assumptions; the definitions of the probabilities allowing the evaluation of the SLB system are:

a. The probability of false alarm:

It is the probability that the couple (u, v) is in the D-region under the hypothesis H_0 therefore the detection is declared without there being target; his mathematical definition is:

$$P_{FA} = \text{Prob}\ \{(u, v) \in D / H_0\} \qquad (2.5)$$

b. The probability of detection:

It is the probability that the pair of random variables (u, v) is in region D under the hypothesis H_1 so detection is declared with the presence of target; its mathematical definition is:

$$P_D = \text{Prob}\ \{(u, v) \in D / H_1\} \qquad (2.6)$$

c. The probability of a false target caused by a jammer:

It is the probability that the pair of random variables (u, v) is in region D under hypothesis H_2; therefore, detection is declared by the presence of the jammer in the secondary lobes and without any target in the main lobe; its mathematical expression is:

$$P_{FT} = \text{Prob}\ \{(u, v) \in D / H_2\} \qquad (2.7)$$

d. The probability of false blanking:

It is the probability that the pair of random variables (u, v) is in region B under the hypothesis H_0; therefore, the blanking process is activated, without Ia presence of target and without the presence of jammer too; his mathematical definition is:

$$P_{FB} = \text{Prob}\ \{(u, v) \in B / H_0\} \qquad (2.8)$$

e. The probability of hiding the target:

It is the probability that the pair of random variables (u, v) is in region B under hypothesis H_1, hence the blanking process is activated with the presence of target in the main lobe; his mathematical definition is:

$$P_{TB} = \text{Prob}\ \{(u, v) \in D / H_1\} \qquad (2.9)$$

f. The probability of blanking:

It is the probability that the pair of random variables (u, v) is in region B under hypothesis H_2; that is to say; the blanking process is activated with the presence of a jammer in the secondary lobe and the absence of a target in the main lobe; it is defined mathematically by:

$$P_B = \text{Prob}\ \{(u, v) \in B / H_2\} \qquad (2.10)$$

II.13. Parameters Choices [8]:

The proper functioning of the SLB system is subject to conditions on the following parameters:

- The gain margin β^2.

-The blanking threshold F.

The first condition requires that the gain of the auxiliary antenna must be greater than or equal to the gain of the secondary lobes; that is to say:

$$\omega^2 \geq \delta^2$$

from where

$$\frac{\omega^2}{\delta^2} \geq 1$$

So

$$\beta^2 \geq 1$$

When a jammer enters the main channel through the secondary lobes with a power of J; it is received by the auxiliary channel with a power, $\beta^2 J$. So that the blanking condition is checked; the ratio between the two powers must be greater than the blanking threshold; it's hard:

$$\frac{\beta^2 J}{J} > F$$

hence, we deduce the second condition:

$$\beta^2 > F$$

II.14. SLB Design [8]:

The design of the SLB system consists in determining the values of the following parameters:

- The detection threshold, α_0

- The blanking threshold, F.

- The profit margin, β^2

The calculation of these parameters is essentially based on these two criteria:

1) A high probability of blanking since the main purpose of the SLB system is to eliminate the jammer from the antenna's secondary lobes.

2) A satisfactory probability of detection to maintain good target detection performance.

II.15. Problem Formulations:

The schematic diagram of the Maisel SLB system with quadratic detectors is shown in figure 3.1. In this section, we will do the general mathematical study which consists in determining the probability density of the random signal at the site of the main receptor. Then, we deduce that of the auxiliary receiver by taking into account the gain of the auxiliary antenna and the gain margin. At the end, we calculate the probabilities mentioned above

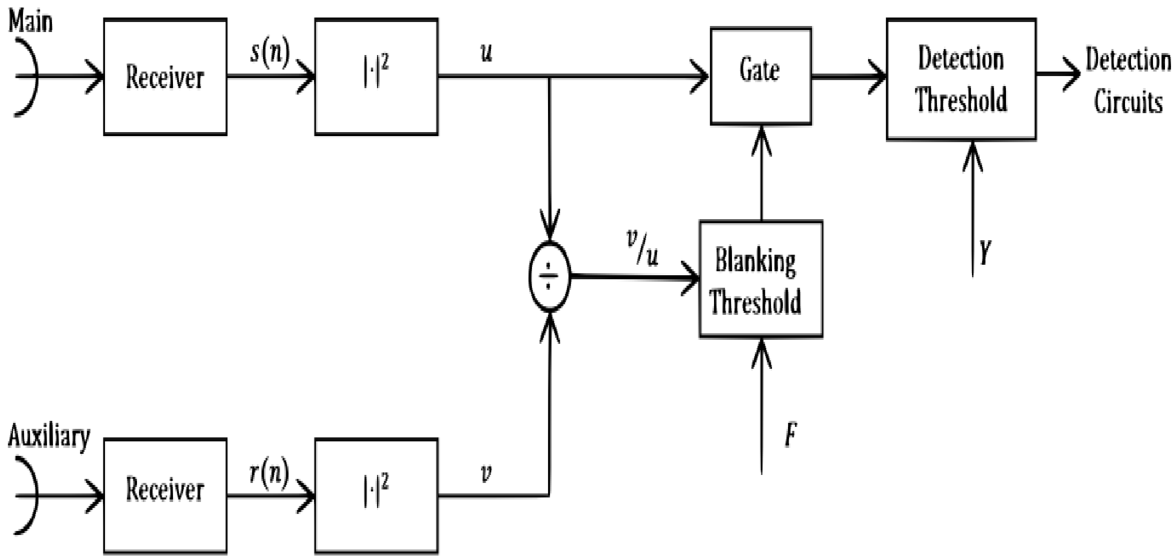


Figure2.7: Basic block diagram of classical SLB system

The general form of the signal at the input of the quadratic detector in a radar receiver operating in a Gaussian clutter environment:

$$S\ (t) = \boldsymbol{\mu} \cos (2\ \pi f_i\ t) + \eta \sin (2\pi f_i\ t) \qquad (2.11)$$

With:

f_i is the intermediate frequency

η is the random amplitude of the noise signal which is in quadrature phase with the target signal.

$\boldsymbol{\mu}$ is a random variable defined by:

$$\boldsymbol{\mu} = \boldsymbol{\mu}_c + \boldsymbol{\mu}_b$$

Or:

$\boldsymbol{\mu}_c$ is the constant amplitude of the target signal (non-fluctuating target).

$\boldsymbol{\mu}_b$ is the amplitude of the noise signal which is in phase with the signal target.

According to the theory of radar detection; the random variable η is centered Gaussian with variance δ and the random variable $\boldsymbol{\mu}$ is also Gaussian with the same variance but with mean $\boldsymbol{\mu_c}$.

In the SLB system, we have two receivers; according to the assumptions (already defined in paragraph 2.5 of chapter 2); the mean $\boldsymbol{\mu_c}$ takes the following values [9]:

In the main channel:

$$\boldsymbol{\mu c} = \begin{cases} \mathbf{0} & \text{under the hypothesis H0.} \\ \boldsymbol{A} & \text{under the hypothesis H1.} \\ \boldsymbol{C} & \text{under the hypothesis H2.} \end{cases} \qquad (2.12)$$

where: **A** is the amplitude of the target echo.

C This is the amplitude of the jammer.

In the auxiliary channel:

$$\boldsymbol{\mu c} = \begin{cases} \mathbf{0} & \text{under the hypothesis H0.} \\ \omega.\boldsymbol{A} & \text{under the hypothesis H1.} \\ \boldsymbol{\beta}.\boldsymbol{C} & \text{under the hypothesis H2.} \end{cases} \qquad (2.13)$$

with: $\boldsymbol{\omega}$ is the gain of the auxiliary antenna.

$\boldsymbol{\beta}$ is the amplitude gain margin.

At the output of the quadratic detector. we will have the following operation:

$$u = |\boldsymbol{\mu}|^2 + |\boldsymbol{\eta}|^2$$

According to probability theories, the sum of the squares of two independent Gaussian variables $\boldsymbol{\mu}$ and η with means $\boldsymbol{\mu}_m$ and $\boldsymbol{\eta}_m$ respectively and

of variance δ^2 is a random variable u; its probability density is defined by:

$$P_u(u)=\frac{1}{2\delta^2}\ \exp\left[-\left(\frac{u+\lambda}{2\delta^2}\right)\right]\ I_0\left(\frac{\sqrt{\lambda\, u}}{\delta^2}\right) \qquad (2.14)$$

where: I_0 (.) is the modified Bessel function of the first degree of order zero.

λ is the non-centrality parameter defined by :

$$\lambda = \boldsymbol{\mu}_m^2 + \eta_m^2 \qquad (2.15)$$

In our case, the average is zero. from where

$$\lambda = \mu_m^2$$

We use the general expression (2.14) to deduce the probability densities at the output of each receiver and under the three assumptions (H_0, H_1 and H_2).

H_0 hypothesis:

Main channel:

In this case, the clutter noise is the only one present in the reception channel; therefore, according to (2.12), we will have

$$\mu_m = 0$$

from where:

$$\lambda = 0$$

By replacing λ by its value in the expression non (2.14). we obtain the desired density:

$$P_u(u/H_0) = \frac{1}{2\delta^2} \exp\left[\frac{-u}{2\delta^2}\right] \qquad (2.16)$$

Auxiliary channel:

Same reasoning as before; by replacing the random variable u by v (v represents the signal at the output of the auxiliary channel) in expression (2.17); we obtain:

$$P_v(v/H_0) = \frac{1}{2\delta^2} \exp\left[\frac{-v}{2\delta^2}\right] \qquad (2.17)$$

Hypothesis H_1

Main channel:

In this case, the target is present in the main lobe; therefore, we will have:

$$\mu_m = A$$

from where

$$\lambda = A^2$$

By replacing the value λ in expression (3.4); we get the probability density of u:

$$P_u(u/H_1) = \frac{1}{2\delta^2} \exp\left[-\left(\frac{u+A^2}{2\delta^2}\right)\right] I_0\left(\frac{A\sqrt{u}}{\delta^2}\right) \qquad (2.18)$$

Auxiliary channel:

It suffices to substitute the amplitude A of the target by ω_A (ω_A is the amplitude of the target received by the auxiliary receiver) in expression (2.19); we obtain:

$$P_v(v/H_1) = \frac{1}{2\delta^2} \exp\left[-\left(\frac{v+(\omega A)^2}{2\delta^2}\right)\right] I_0\left(\frac{\omega A\sqrt{v}}{\delta^2}\right) \qquad (2.19)$$

Hypothesis H2:

Main channel:

In this case, the jammer is present in the side lobes so we will have:

$$\boldsymbol{\mu}_m = C$$

from where:

$$\lambda = C^2$$

From expression (2.14), we obtain the probability density of u at the exit of the main channel under the hypothesis H2:

$$P_u(u/H_2) = \frac{1}{2\delta^2} \exp\left[-\left(\frac{u+C^2}{2\delta^2}\right)\right] I_0\left(\frac{C\sqrt{u}}{\delta^2}\right) \qquad (2.20)$$

Auxiliary channel: By replacing the amplitude C of the jammer by, BC (, BC is the amplitude of the interfering signal received by the auxiliary receiver) in expression (3.10); we obtain:

$$P_v(v/H_1) = \frac{1}{2\delta^2} \exp\left[-\left(\frac{v+(\beta C)^2}{2\delta^2}\right)\right] I_0\left(\frac{\beta C\sqrt{v}}{\delta^2}\right) \qquad (2.21)$$

We can now determine the expressions of the probabilities of false alarm, detection and blanking. Details of the calculations are in Appendix A.

The probability of false alarm is written:

$$P_{FA} = \text{Prob}\ \{(u, v) \in D / H_0\}$$

$$= \text{Pr ob}\left(u \geq \alpha \quad \text{et} \quad 0 < \frac{v}{F} < u\right)$$

$$= \int_0^{+\infty} Pu(u/H0) \int_0^{Fu} Pv(v/H0)\, dv\, du \qquad (2.22)$$

where: F is the blanking threshold and δ^2 is the detection threshold standardized with respect to the power of the clutter noise; he writes:

$$\alpha_0 = \frac{\alpha}{2\delta^2}$$

where α is the detection threshold and δ^2 is the power of the clutter noise.

Note 1:

We notice that when the blanking threshold tends towards infinity; we will find from (2.22) the probability of false alarm for a conventional radar;

it is written:

$$P_{FA} = \exp[-\alpha_0]$$

au The probability of detection is written:

$$P_D = \text{Prob}\ \{(u, v) \in D / H_1\}$$

$$= \text{Prob}\left(u \geq \alpha \quad \text{et} \quad 0 < \frac{v}{u} < F\right)$$

$$= \int_0^{+\infty} Pu(u/H1) \int_0^{Fu} Pv(v/H1)\, dv\, du$$

$$P_D = \varrho\left(\sqrt{2SNR}, \sqrt{2\alpha}\right) - \frac{[-SNR * F/(F+1)]}{(F+1)} \varrho\left(\sqrt{\frac{2SNR}{(F+1)}}, \sqrt{2\alpha(F+1)}\right) \qquad (2.23)$$

with: $\varrho(.)$ is the function of Q-Marcum (Marcum's Q-function); it is an integral defined by the following expression:

$$\varrho[a, b] = \int_b^{+\infty} \exp\left[-(x + a^2)\right] I_0(a\sqrt{x})dx \qquad (2.24)$$

where: I_0 (.) is the modified Bessel function of the first order of degree zero.

SNR is the power ratio of the target signal to noise; it is written:

$$SNR = \frac{A^2}{2\delta^2}$$

Note 2:

The probability of detection of a radar without the SLB system is deduced from (2.23) by making the blanking threshold tend towards infinity; it is written:

$$P_D = \varrho\left(\sqrt{2SNR}, \sqrt{2\alpha}\right)$$

The expression of the blanking probability is given by:

$$P_B = \text{Prob}\ \{(u, v) \in B / H\}$$

$$= \text{Prob}\left(\frac{v}{F} \geq F \quad \text{et} \quad u \geq 0\right)$$

$$= \int_0^{+\infty} Pu(u/H2, A = 0) \int_{Fu}^{+\infty} Pv(v/H2, A = 0)\, dv\, du$$

$$P_D = 1 - \frac{1}{F+1}\left[1 - \varrho\left(\beta\sqrt{\frac{2JNR}{(F+1)}}, \beta\sqrt{\frac{2JNR*F}{F+1}}\right)\right] - \frac{F}{F+1}\varrho\left(\sqrt{\frac{2JNR*F}{(F+1)}}, \beta\sqrt{\frac{2JNR}{F+1}}\right) \quad (2.24)$$

with JNR is the power ratio of the interfering signal to noise, it is written

$$JNR = \frac{C^2}{2\delta^2}$$

The computation of the integral of the Q-Marcum function (2.24) is relatively complicated '. we can calculate it using numerical techniques. Parl [10] has developed an excellent algorithm to calculate this integral. we summarize it as follows:

II.16. PARL Algorithm [10]:

$$\alpha_0 = \begin{cases} 1 & \text{if} \quad a < b \\ 0 & \text{if} \quad a \geq b \end{cases} \quad (2.25)$$

$$d_1 = \begin{cases} a/b & \text{if} \quad a < b \\ b/a & \text{if} \quad a \geq b \end{cases} \quad (2.26)$$

$$\alpha_n = d_n + \frac{2n}{ab}\alpha_{n-1} + \alpha_{n-2} \quad (2.27)$$

$$\beta_n = 1 + \frac{2n}{ab}\beta_{n-1} + \beta_{n-2} \quad (2.28)$$

$$d_{n+1} = d_n\, d_1 \quad (2.29)$$

$$\varrho[a,b] = \begin{cases} \frac{\alpha n}{2\beta n}\exp\left[\frac{(a-b)^2}{2}\right] & \text{if} \quad a < b \\ 1 - \left[\frac{\alpha n}{2\beta n}\exp\left[\frac{(a-b)^2}{2}\right]\right] & \text{if} \quad a \geq b \end{cases} \quad (2.30)$$

We pose as initial data:

$$\alpha_{-1} = 0$$

$$\beta_0 = 0.5$$

$$\beta_{-1} = 0$$

The recursive equations (2.27), (2.28) and (2.29) are calculated as long as β_n is less than a fixed limit value; this value must be chosen greater than 10^p where p is greater than or equal to three. The flowchart of this algorithm is shown in figure 2.8

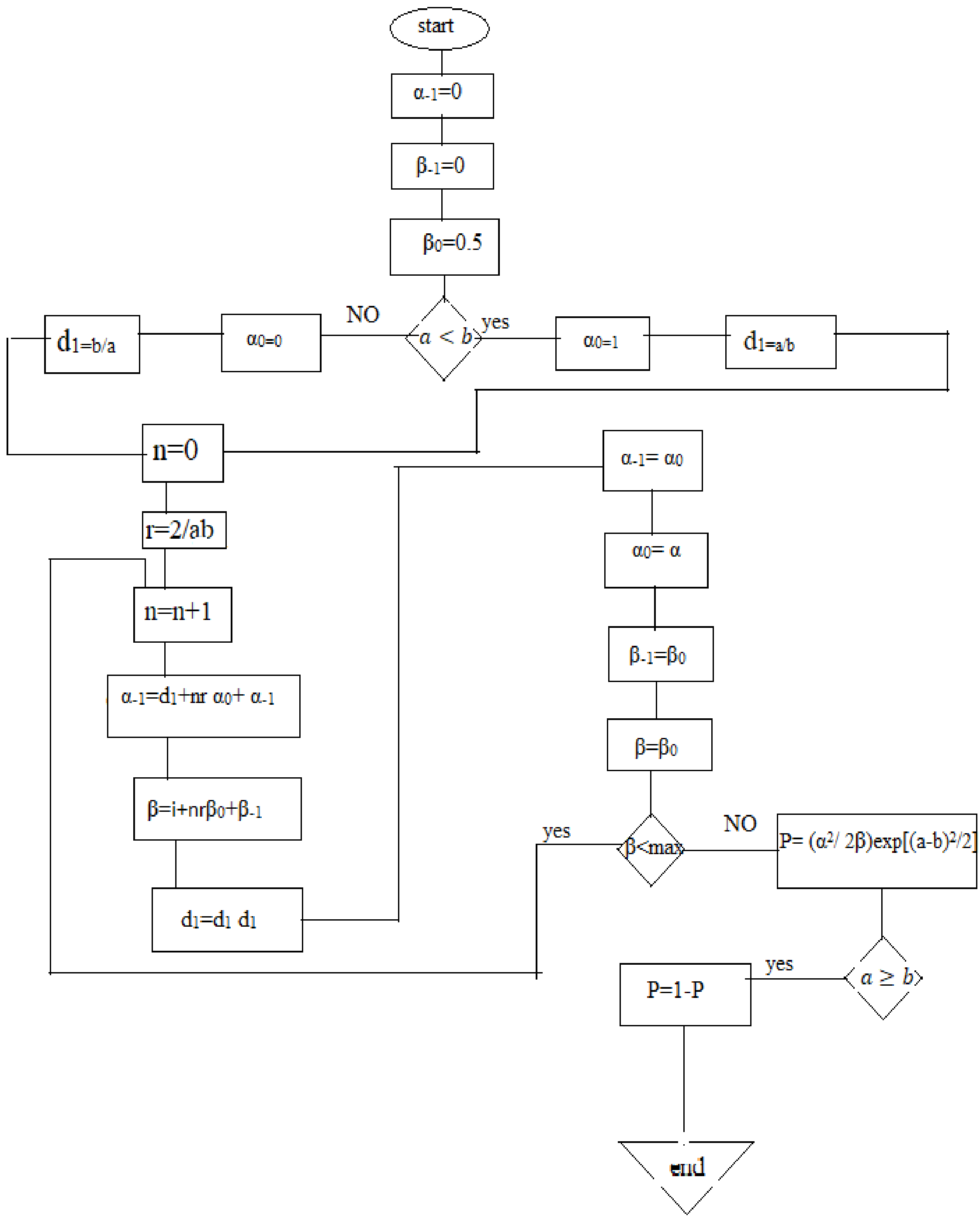


Figure2.8: PARL Algorithm flowchart [10].

II.17. Results and Discussions:

To study the performance of the proposed SLB system of a non-fluctuating pipe in a Gaussian clutter, we present the results of the calculations according to these parameters: the target signal to clutter noise ratio, the interfering signal to clutter noise ratio. The gain margin, the gain of the auxiliary antenna the detection threshold and the blanking threshold

Figures 2.9 show the probabilities of blanking as a function of the blanking threshold for different values of the interference-to-noise ratio when the gain margin is equal to -5dB. 0dB 5dB. 10dB .15dB. and 20dB respectively, we find that the probability of blanking increases when the interference-to-noise ratio increases when the blanking threshold is lower than the gain margin the opposite occurs in the opposite case. We also notice that the probability of blanking worsens suddenly when the value of the blanking threshold exceeds that of the gain margin

Figure 2.10 shows the variations of the probabilities of detection as a function of the Signal to noise ratio for different blanking thresholds and for a false alarm probability of 10 [6] We observe that the probability of detection improves when the Signal to noise increases for only one fixed blanking. At the end we also notice for a blanking threshold of -3dB the detection probability values are very close to those of the classic radar without SLB hence the efficiency of the SLB system.

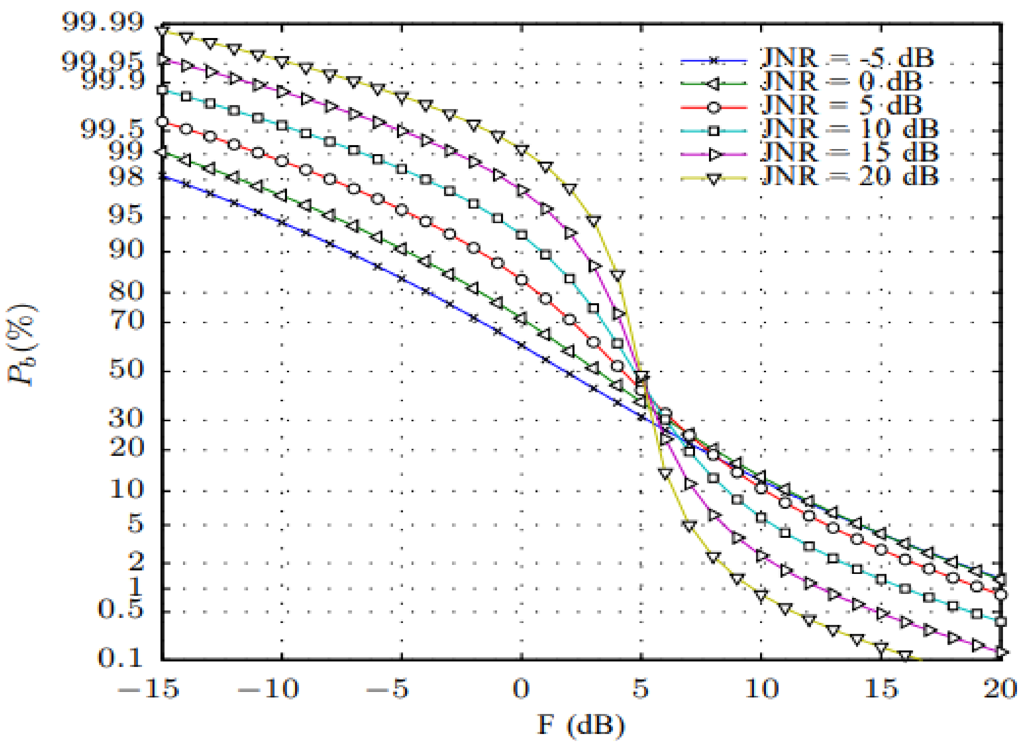


Figure2.9: The variation in the probability of blanking as a function of the blanking threshold for different values of JNR with β = 5 dB

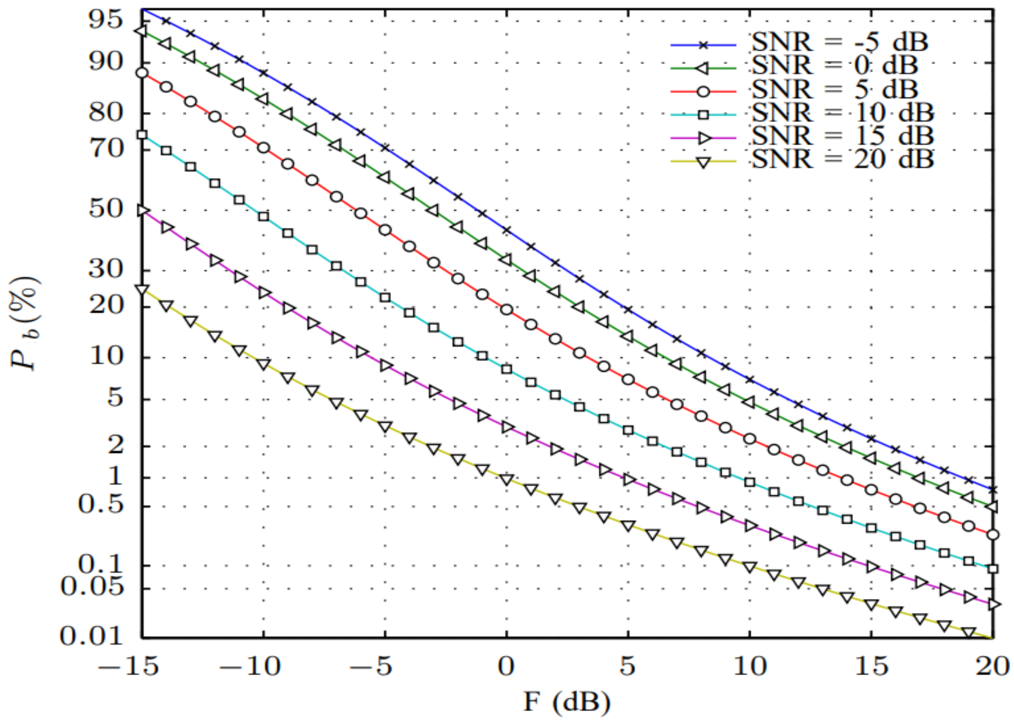


Figure2.10: probability of detection as a function of SNR for different blanking threshold P_{Fa} = 10 ^{6}, ω^2 = -30dB.

III.18. CONCLUSIONS:

In this chapter, we studied the performance of the SLB system in a Gaussian clutter of a non-fluctuating target; detection is based on a single target echo. The performance of the system was analyzed. The results obtained showed that the probability of blanking increases with the increase in the interference-to-noise ratio when the threshold of blanking is lower than the gain margin. An opposite effect is obtained in the opposite case. We find that the probability of detection increases as the target signal to noise ratio increases. The contribution of this chapter is the determination of the expression of the probability of blanking and the computation of the Q-Marcum function by the PARL Algorithm

CHAPTER III

Performance Analysis of Adaptive SLB/CA-CFAR System

III.1. Introduction:

Sidelobe blanking (SLB) can be used as an Electronic Counter Counter Measure (ECCM) technique that prevents pulsed ECM energy received through the radar antenna sidelobes from adversely affecting radar performance. The SLB architecture is based on two antennas where the first one is the radar antenna, with its main lobe and sidelobes. The second one is the sidelobe blanking antenna, whose gain is less than that of the main lobe of the radar antenna, but greater than the radar antenna's sidelobes. The SLB logic decides, for each range/Doppler bin, whether or not to blank the main radar channel on the basis of a single sweep of each bin. When the main channel output is larger than threshold level, that is based on the auxiliary channel output, the main channel signal as usual and is compared with a false alarm threshold to decide if a detection should be declared. When this is not the case, the main channel is inhibited or blanked. Maisel [7] introduced a classical SLB architecture based on a single radar pulse from a target with a constant radar cross section (RCS). He analyzed the performance of the system from the determination of closed form of the probabilities of detection and false alarm. Farina and Gini proposed a design of SLB system in the presence of correlated ground clutter with known Doppler spectrum plus white Gaussian thermal noise and impulsive interference. Shnidman extended the work of Maisel SLB [7] using integration and fluctuation of target. Probability expressions have been generalized to include both an arbitrary number of integrated pulses and target fluctuation models based on the gamma distribution, the problem of SLB system using fixed threshold detection was treated. Thus, the problem of adaptive threshold is not treated. A fixed threshold cannot be used because the false alarm probability increases intolerably. Therefore, adaptive threshold techniques are needed to maintain a constant false alarm rate (CFAR). Finn and Johnson developed a theory based on the arithmetic mean of the nearby resolution cells of the test cell. This is known as the CA-CFAR, Cell Averaging Constant False Alarm Rate. Many others techniques based on the cell averaging have been developed in the literature. As evident from the above discussion, an extensive amount of research has been performed on CFAR and SLB systems. To our knowledge, no work is reported on SLB combined with adaptive CFAR detection. The goal of this paper is to determine a closed form of probabilities of detection, false alarm, blanking and false blanking using a novel architecture of a combined SLB/CA-CFAR system.

The radio interface of 4G mobile networks is based on a cellular approach because frequencies must be reused due to the limited frequency resources and the large number of users sharing these resources. Cellular infrastructure in a suburban area Each cell contains base station equipment that sends and receives voice and / or data traffic using an antenna and a specific set of frequencies. All frequencies are reused after a sufficient distance to avoid very high interference levels. Planning for cellular radio is always a task for improvement as coverage and capacity must be maximized and interference minimized.

The capacity and coverage of the Communication Systems is directly related to the amount of interference that the BTS node and UEs generate in the system.

III.2. CFAR Detector:

The principle of classical detection using a matched filter and a fixed detection threshold, shown in Figure 3.1, cannot be applied. Indeed, a slight variation of 3db in the power density of the total parasitic noise (thermal noise plus clutter) causes an increase in the probability of false alarm setpoint by a factor of the order of 10^{-6} like is illustrated in Figure 3.2. This unwanted increase in the false alarm rate can cause saturation of the operator, whether human or computer. This remark is the basis of adaptive methods to analyze and improve radar detection. The idea, to get around the limitations of the fixed threshold, is to take an adaptive detection threshold, that is to say varying proportionally with the power of the noise. The devices using this solution are called CFAR detectors. In order to fully understand the contribution of CFAR detectors in terms of detection quality, we propose the following to give more details on the CFAR algorithm and the various detectors linked to this type of detection. Detection algorithms based on the CFAR technique are used to detect targets embedded in spurious signals, the powers of which are unknown. The CFAR detector as shown in Figure 3.3 is the process by which a target is declared present in the test cell while maintaining a constant and very low false alarm rate. Finally, the decision is made by comparing the output of each cell under test (CUT: Cell Under Test) to an adaptive threshold whose value is the product of the static test q, which represents the estimate of the clutter power obtained at from the samples: (q1, q2, q3… qN) in the reference window and a factor scale T which is chosen in such a way as to ensure a desired probability of false alarm PFA. The content of each cell is obtained by sampling the signal received from the output of the quadratic detector and passing it through a delay register formed by a set of reference cells. To simplify the presentation, we take the scope cells for a specific Doppler frequency.

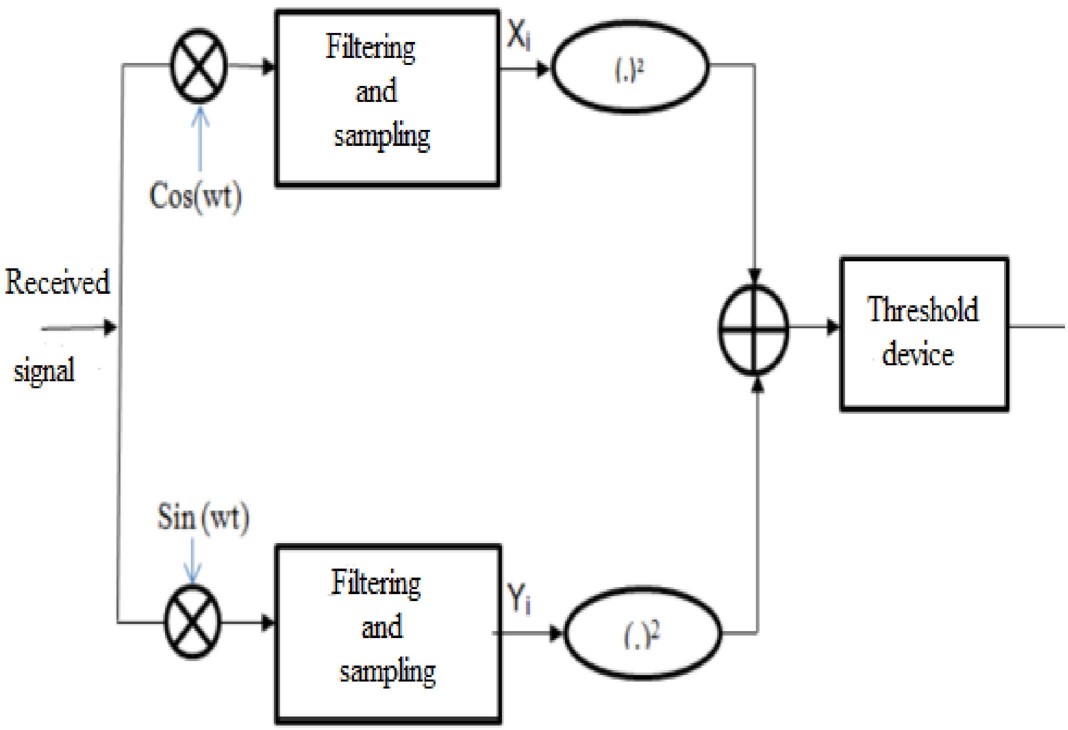


Figure 3.1: optimal quadratic detector

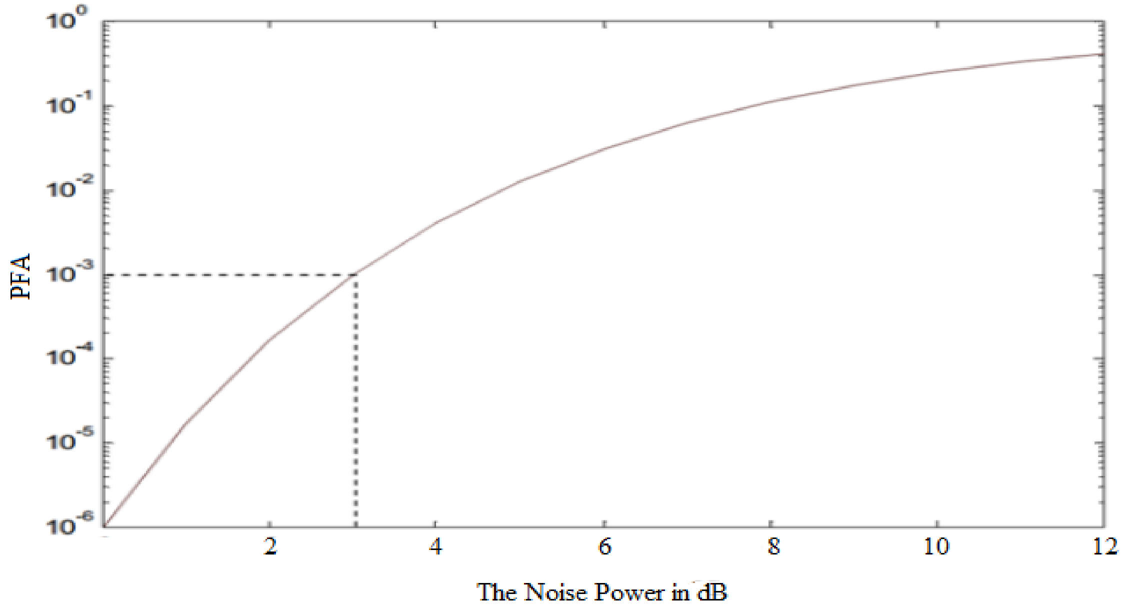


Figure 3.2: Effect of increasing noise power on P_{FA} for a fixed threshold.

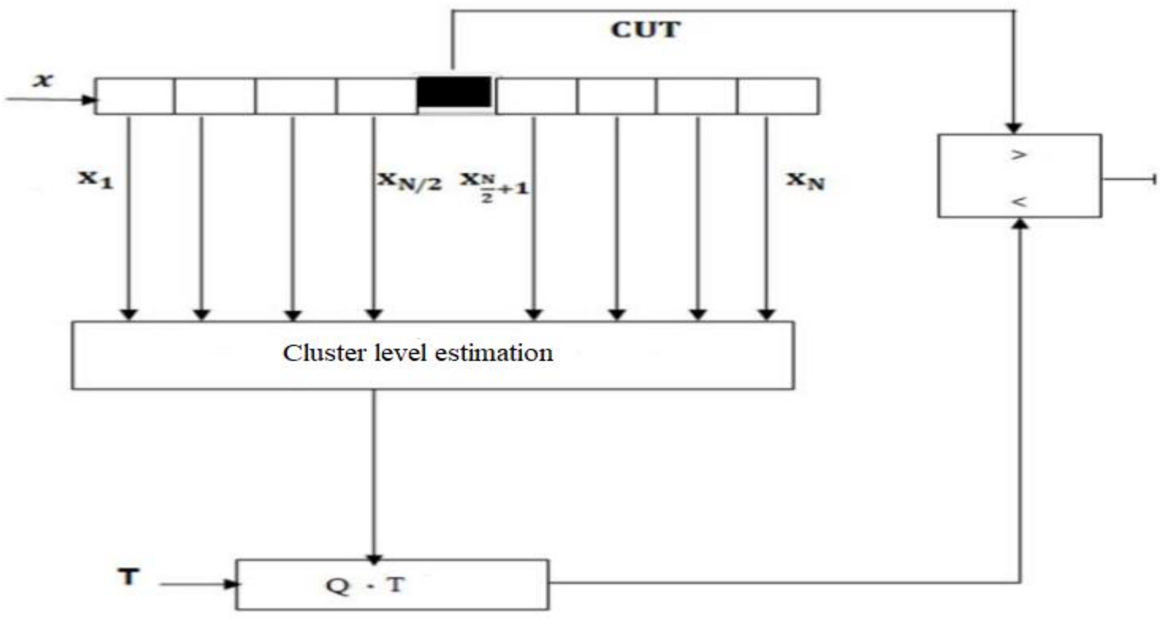


Figure (3.3): General architecture of adaptive CFAR detection

III.3. CA-CFAR Detector:

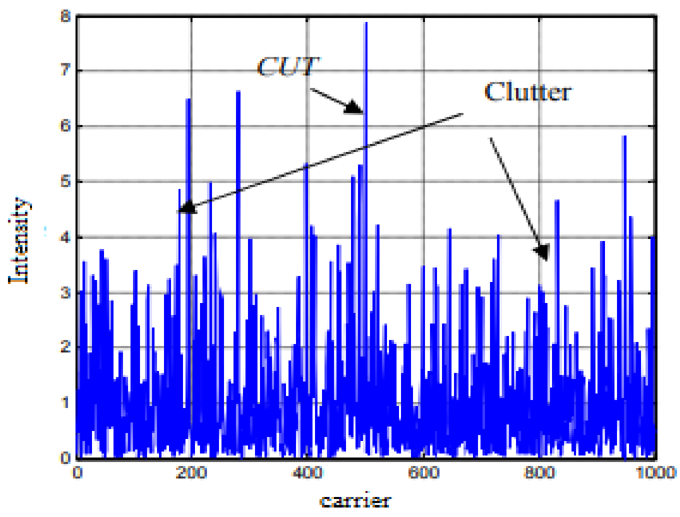
The paradigm of CFAR detectors is the mid-level CA-CFAR. This last was first proposed in 1968 by American researchers Finn and Johnson. This algorithm estimates in real time the power of the noise which is equal to the sum or the arithmetic mean of the samples in the reference window as shown in Figure.3.4. b

$$\varrho = \sum_{i=1}^{M} xi \qquad (3.1)$$

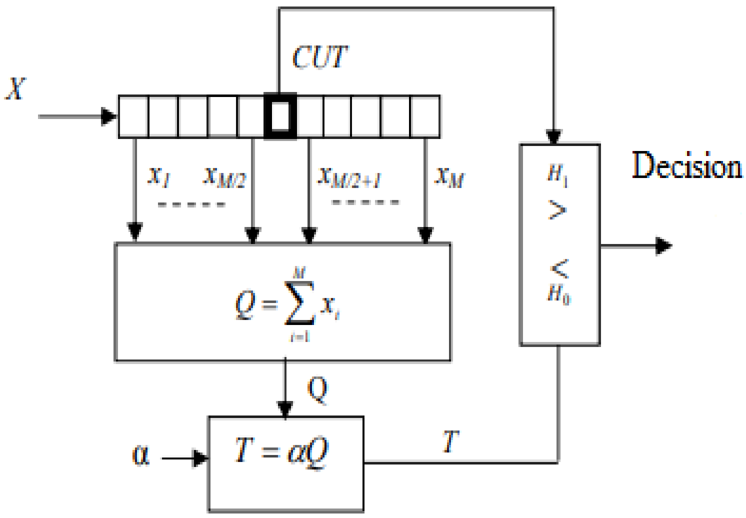
This detector is constructed for the detection of targets in homogeneous media (Figure.3.4.a) whose sample fdps are independent and identically distributed (iid). Taking a Swerling type 1 target drowned in Gaussian white noise, the pdfs of the signals received for each hypothesis are given by

$$\begin{cases} H0 : Px(x/H0) = \frac{1}{b}\exp(-\frac{x}{b}) \\ H1: Px(x/H1) = \frac{1}{b+a}\exp(-\frac{x}{b+a}) \end{cases} \qquad (3.2)$$

With $b=2\delta^2$ represent the power of the target signal and the noise power



(a)



(b)

Figure 3.4:CA-CFAR Detector

(a) Situation of clutter with $2\delta^2$ =1 and SNR= 5 dB

(b) Use the arithmetic averaging

The calculation of the probability of false alarm, P_{FA} and the probability of detection, P_D explain it with the solution of this integrations:

$$\begin{cases} PFA = \int_0^{\infty} Pr(CUT > \alpha/H0)\, P\varrho(q)dq \\ PD = \int_0^{\infty} Pr(CUT > \alpha/H1)\, P\varrho(q)dq \end{cases} \quad (3.3)$$

With

$$Pr(CUT > \alpha/H0) = \exp\left(-\frac{\alpha q}{b}\right) \quad (3.4)$$

And

$$Pr(CUT > \alpha/H1) = \exp\left(-\frac{\alpha q}{b(1+SNR)}\right) \quad (3.5)$$

where Pr (.) denotes the probability and SNR = a / b is the signal-to-noise ratio. To evaluate (3.3), the determination of the analytical pfd of (3.1) is necessary. In the theory of probabilities and statistics, the pfd of the sum of the random variables is equal to the product of convolution, $f(x)*g(x) = \int_{-\infty}^{+\infty} f(t)\, g(x-t)\, dt$ of the fdps of the samples received, x_i, i=1,…, N.

with

$$P\varrho(q) = p(x1) * p(x2) *, \ldots, * p(xn)$$

$$= \frac{1}{b}\exp\left(-\frac{x1}{b}\right) * \frac{1}{b}\exp\left(-\frac{x2}{b}\right) *, \ldots, * \frac{1}{b}\exp\left(-\frac{xN}{b}\right)$$

$$= \frac{q^{N-1}}{b^N \Gamma(N)} \exp - \frac{q}{b} \quad (3.5)$$

And $\Gamma(N)$ is the gamma function. By replacing (3.4), (3.3) and (3.5) in (3.4), (3.4) becomes

$$\begin{cases} PFA = \int_0^{\infty} \exp\left(-\frac{\alpha q}{b}\right) \frac{q^{N-1}}{b^N \Gamma(N)} \exp(-\frac{q}{b})dq \\ PD = \int_0^{\infty} \exp\left(-\frac{\alpha q}{b(1+SNR)}\right) \frac{q^{N-1}}{b^N \Gamma(N)} \exp(-\frac{q}{b})dq \end{cases} \quad (3.6)$$

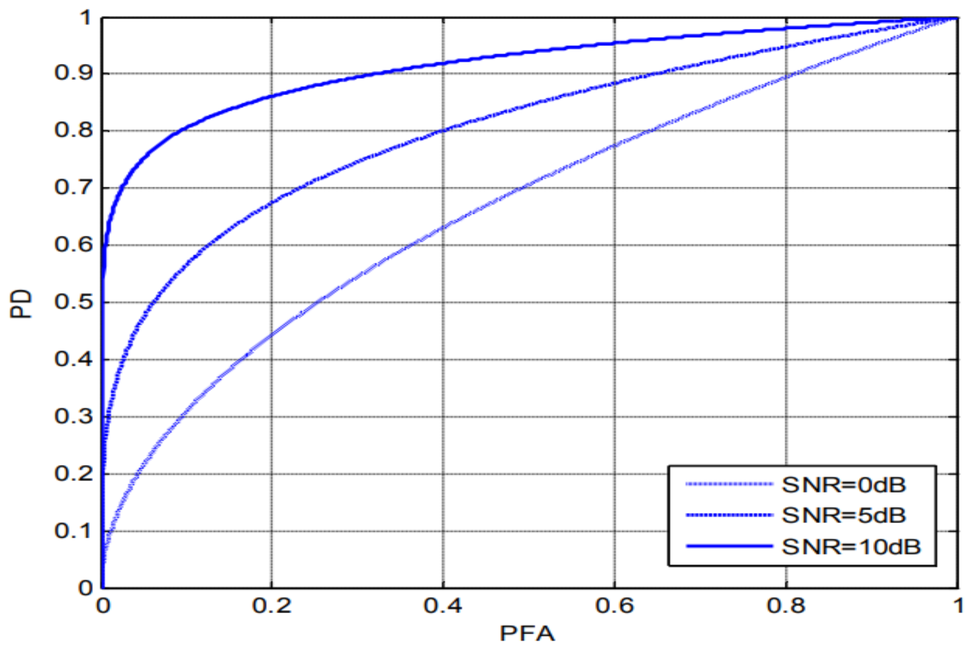
The integral, $\int_0^{\infty} x^{n-1} \exp(-\alpha x)\, dx - \frac{\Gamma(N)}{a^n}$ is used to determine (3.6) as

$$\begin{cases} PFA = (1+\alpha)^N \\ PD = \left(1 + \frac{\alpha}{1+SNR}\right)^N \end{cases} \quad (3.7)$$

Clearly, PFA expression does not depend on noise power, $2\delta^2$, which means that the CA-CFAR detector has the full CFAR property. Sometimes the ROC (Receiver Operating Characteristic) which links the PD and the PFA is often used to evaluate the performance of the given detector by

$$ROC = P_D = (1+PFA^{-1/N}-1/1+SNR) \quad (3.8)$$

In (3.8), the SNR and N are considered as parameters. Generally, P_D versus SNR is considered to illustrate radar detection performance. The figure.3.5 shows the ROC values as a function of the PFA with N= 16 and SNR = 0 dB, 5dB and 10 dB. For a given PFA, we notice that the PD increases with the increase in SNR. After setting the desired value of PFA as a function of N, Figure.3.6 gives the corresponding value of the threshold multiplier, α.



Figures 3.5: ROC curves for different SNR values with $\alpha=P_{FA}^{-1/N}-1$ and N=16

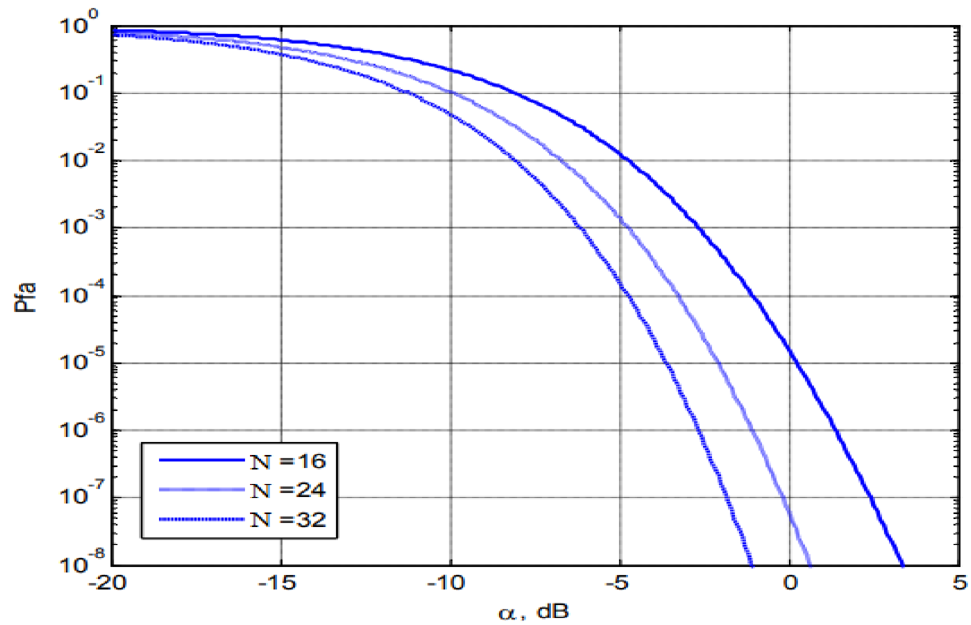


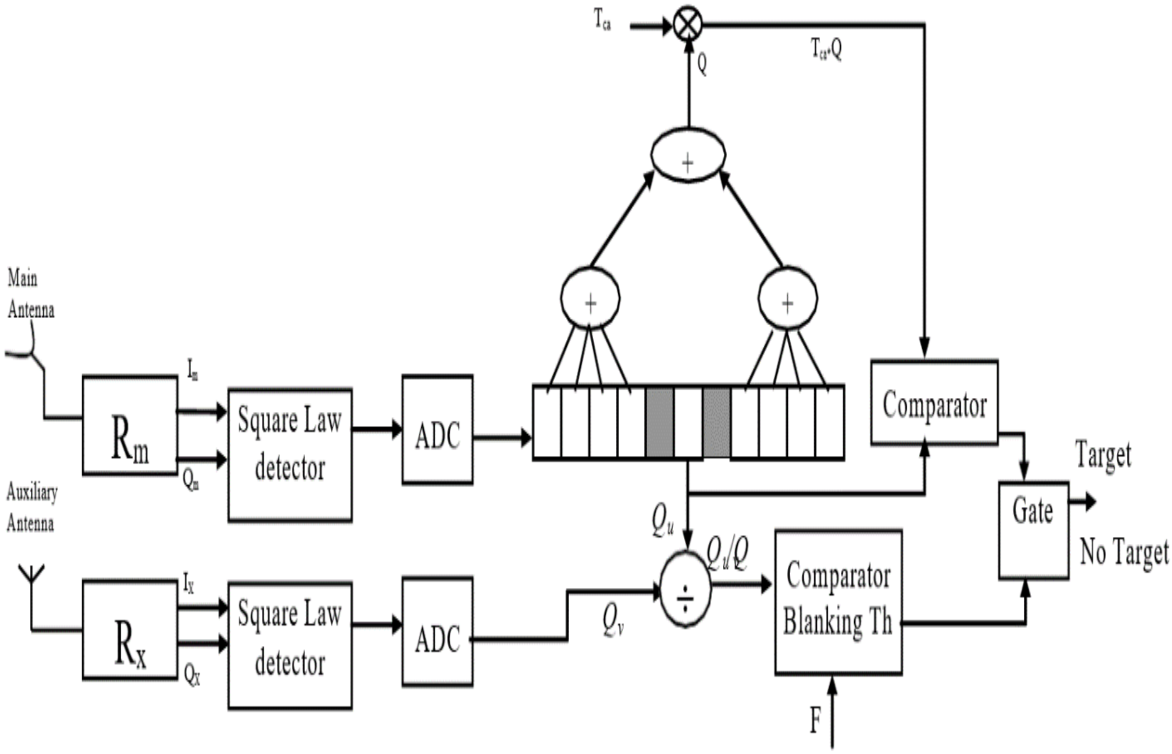
Figure.3.6: Plots of the P_{FA} as a function of the threshold coefficient α

III.4. Problem Formulation:

The processing scheme of the novel combined CA-CFAR/SLB is shown in Figures 3.7

In the CA-CFAR processor, to determine whether a target is present in the cell under test, corresponding value of the signal should be compared to a threshold. If this value is above the threshold, the target is declared present.

A blanking signal is generated when the ratio Qv/Qu between the signals at the output of the square-law detectors in the two channels is greater than a suitable blanking threshold F. This signal is used to control the decision output of the CA-CFAR processor via a gate.



Figures 3.7: The combined CA-CFAR/SLB configuration

To determine a closed form of probabilities of detection, false alarm, blanking and false blanking using a novel architecture of a combined SLB/CA- CFAR system, we assume that the square-law detected output for any range cell is exponentially distributed. With the probability density function (Pdf)

$$P_{Q_i}=\exp(-q_i) \quad (3.9)$$

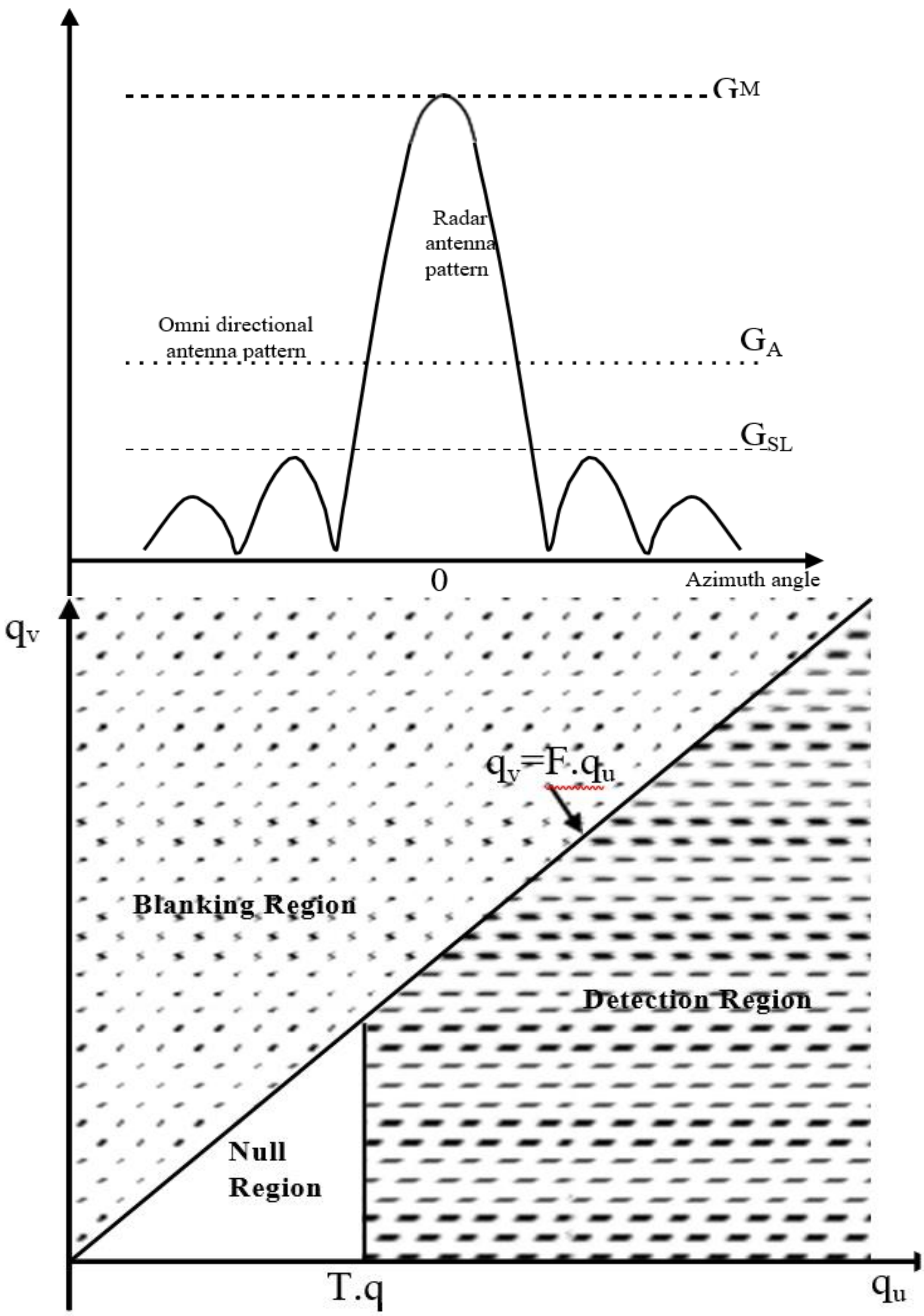


Figure 3.8: Maisel SLB patterns

The statistic distribution of the sum of the reference cells in the CA-CFAR processor is given by

$$P(q)=\frac{q^{N-1}}{(N-1)!}\exp(-q) \qquad (3.10)$$

The square-law receiver densities at the output of each channel, for hypothesis H_1, are given by

$$P(q_u)=\frac{1}{1+S}\exp(-q_u/1+S) \qquad (3.11)$$

for the main channel and

$$P(q_v)=1/\ (1+G_A\ S)\ \exp\ (-q_v/1+\ G_A\ S) \qquad (3.12)$$

for the auxiliary channel.

Hence, after mathematical manipulation, the closed form of probabilities of detection and false alarm are determined and are given by

$$P_D=\int_0^{\infty}\left(\int_{Tq}^{\infty}\int_0^{Fqu}\frac{1}{1+S}exp\left(-\frac{qu}{1+S}\right).\frac{1}{1+GA.S}exp\left(-\frac{qv}{1+GA.S}\right)\right)dq_u\, dq_v\, dq \qquad (3.13)$$

$$P_D=\left(1+\frac{T}{1+S}\right)^N-\frac{\left\{1+\frac{1}{1+S}\left(1+F\left(\frac{1+S}{1+GA.S}\right)\right)T\right\}^N}{\left(1+F\left(\frac{1+S}{1+GA.S}\right)\right)T} \qquad (3.14)$$

And

$$P_F=(1+F)^{-N}-\left(\frac{[1+(1+F)T]^N}{(1+F)T}\right) \qquad (3.15)$$

where F is the blanking factor and T, S, G_A and J are respectively the scale factor, the signal to noise ratio, the auxiliary antenna gain and jamming power. The probabilities of banking and false blanking are given by.

$$P_B=\int_0^{\infty}P(qu,\beta^2J)\ [\int_0^{\frac{qu}{F}}P(qu,T)dqu]dqv \qquad (3.16)$$

$$P_B=\frac{1+\beta^2J}{1+\beta^2J+F(1+J)} \qquad (3.17)$$

B^2 = G_A/G_{LS}, with GSL is the maximum level of the main antenna sidelobes. probability of false blanking happens when no signal (S=0) or Jammer (J=0) is present, hence the probability becomes

$$P_{FB}=\frac{1}{1+F} \qquad (3.18)$$

III.5. Results and discussion:

In this section, we present the performance of the combined SLB/CFAR detector. Closed form probabilities of detection, false alarm, blanking and false blanking are determined. We observe that expressions of probabilities of detection (3.9) and false alarm (3.10) for $F\rightarrow\infty$ (without SLB) tend to the expression of CA-CFAR probabilities of detection and false alarm. Figure 3.9 shows the simulated probability of detection versus the SNR with the blanking factor F as a parameter, for a probability of false alarm PFA $=10^{-6}$ and GA =1dB. We observe that when the blanking factor F increases, the probability of detection is improved Figure 3.10 illustrates the probability of blanking versus JNR with the blanking factor F as a parameter, for β^2 =10dB. We observe that the probability of blanking decrease when the blanking factor increase.

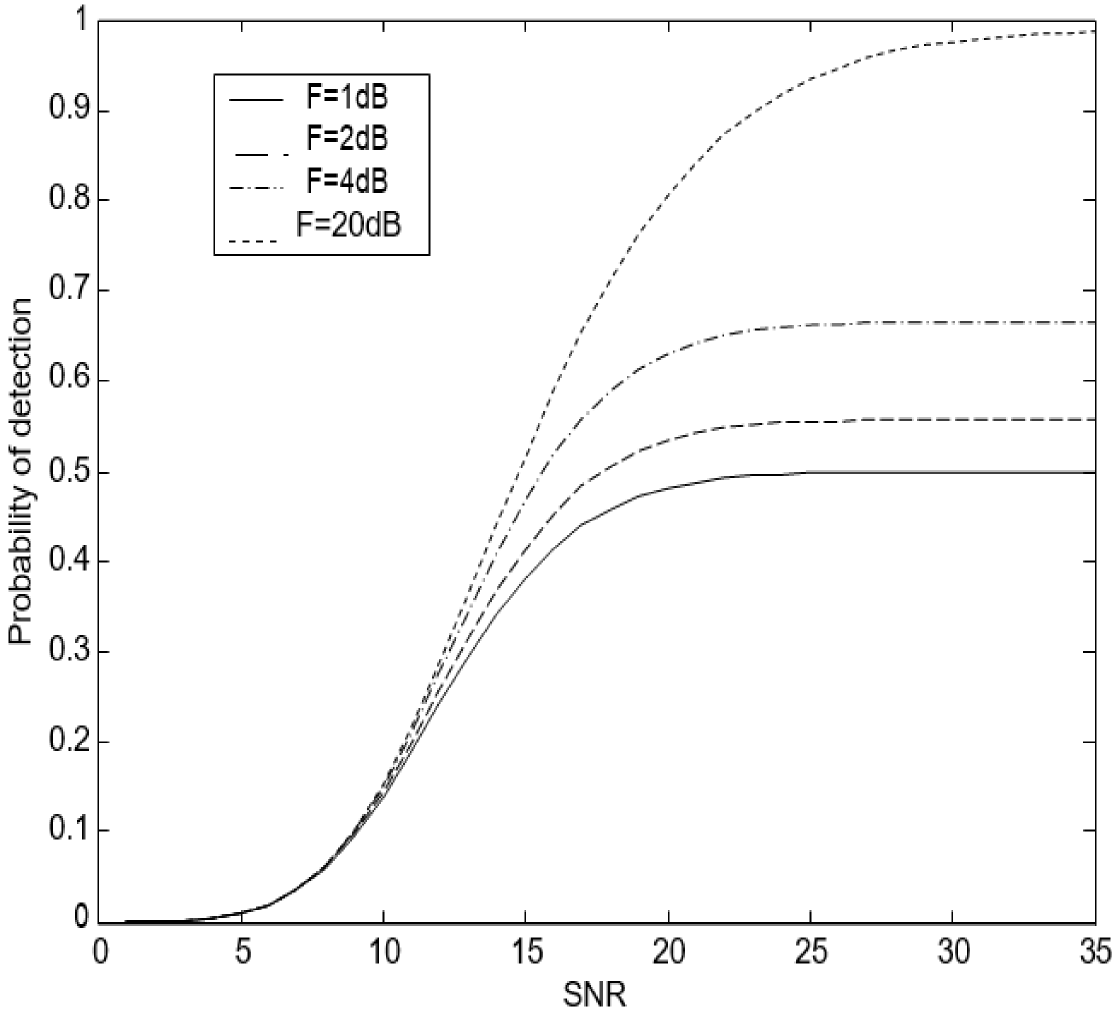


Figure3.9: Probability of detection v.s. SNR and F with PFA=10^{-6} and GA =1dB and N=16

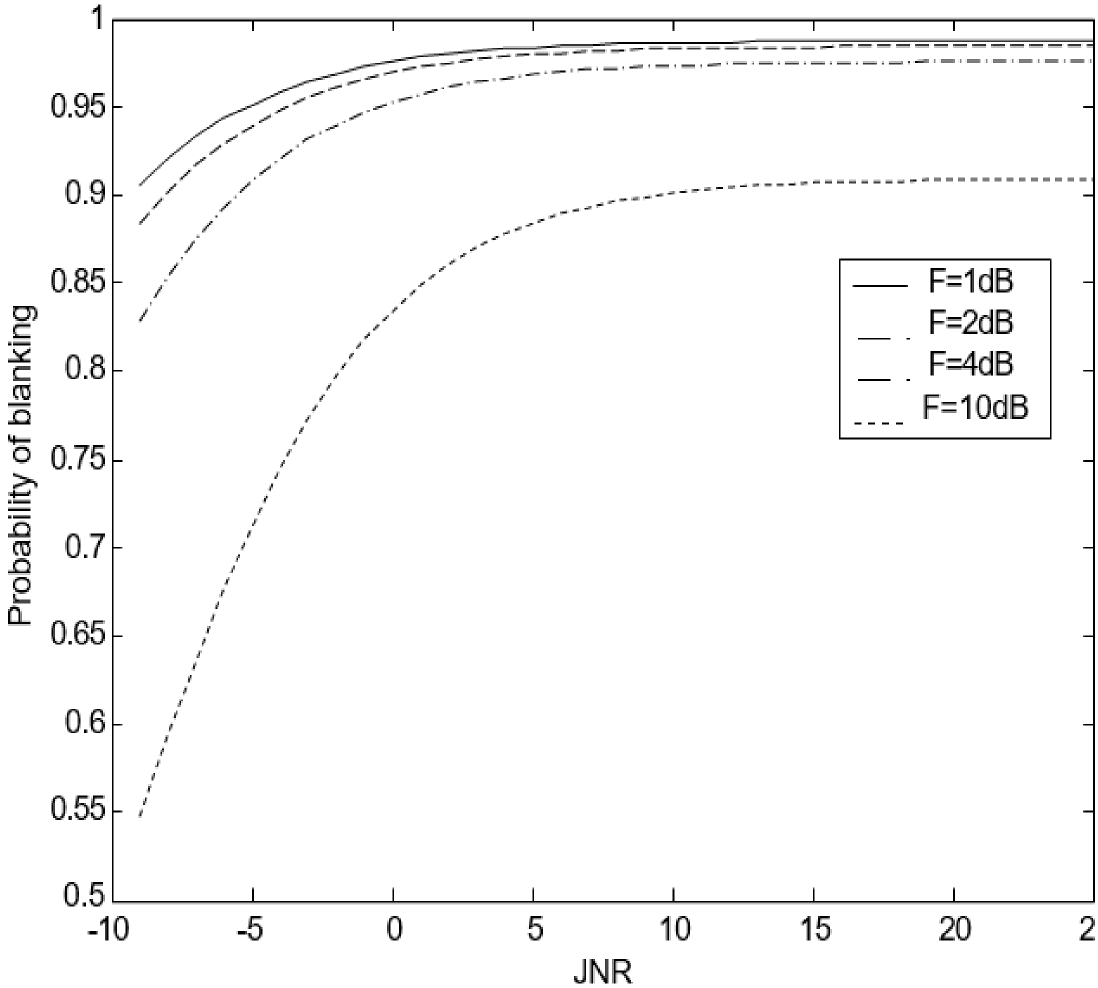


Figure3.10: Probability of blanking vs JNR and F for β^2 =10dB.

III.6. Conclusion:

An adaptive sidelobe blanking (SLB) combined with a constant false alarm rate processor (CFAR) is proposed to prevent acquisition of strong target in the antenna sidelobes and also to reject pulsed interference originating in the sidelobes with maintaining constant the false alarm rate. We assume that the target is a Swerling I target fluctuation model. Closed forms of probabilities of detection, false alarm, blanking and false blanking are determined and the performance of the system SLB/CA-CFAR is analyzed.

General conclusion:

SLB/CA-CFAR can be used to advantage in many situations. Their results make it possible to detect targets embedded in parasitic signals whose powers are unknown while maintaining a constant false alarm rate, unlike conventional fixed threshold detection. The originality of the SLB/CA-CFAR process lies in the estimation of the noise level, this estimation which makes it possible to adapt the detection threshold to the variation of the noise.

We proposed to use the SLB/CA-CFAR in telecommunication systems to prevent the interference coming from other subscriber signals of the neighbored cells. The contribution of this work has been the derivation of closed form expression for the probability PFA of false alarm, the probability of blanking PB and the probability of detection PD. From the results we could observe that the coming interference can be prevented to enter the telecommunication systems with high probability using the SLB/CA-CFAR device.

Future Works :

The purpose of this work was to reduce the side-lobe effects of the antennas by means of SLB/CA-CFAR and it gave satisfactory results when applied to the antennas of 4G cellular communication systems. Therefore, it is necessary to study it and apply it to the new generation 5G networks

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