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Faculty of Engineering
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Performance Enhancement of Spectrum Sensing System Using Antenna Arrays for a Cognitive Radio Applications

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of Master of Science in Electronics and Communications Engineering

By

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Summary

Due to the absence of application complications and processing, one option to diffuse antennas is to reconfigure cognitive radios to utilize the same antenna in both detecting and contact sensing. It's also more popular (in comparison to other ways) because recipients don't need to know which information about the primary users. The output of the energy detector is compared to a threshold that counts above the noise floor to determine the signal. When deciding on the threshold for identifying primary users of the energy detector, there are numerous sensory problems, inability to identify between interference from main users and noise, as well as low performance during signal to noise ratio SNR revaluation. This thesis aims to design a tunable cognitive radio (CR) system based on the Ultra Wide Band. In this thesis, an antenna for cognitive radio that uses ultra-wideband spectrum sensing and a full energy detector is proposed (UWB). Cognitive radio (CR) can improve spectrum management, manage energy more effectively, and increase the flexibility of personal services using spectrum sensing. It offers a quick and inexpensive way to find spectrum holes that cover from 9.30 to 13 GHz in frequency. Frequency is scanned by using a tunable Ultra-Wideband. One of the most essential technological requirements for the development of perceptual radio systems is spectrum sensing. The usage of a microstrip patch antenna in ultra-wideband applications is described. The antenna is small, with ground of 30 mm × 30 mm and 5 gaps that are used as switches and measure 2 mm × 3 mm each. Switches are used to monitor the existence of the principal user (PU) and can offer adjusting capabilities. On a Rogers RT5880 substrate with a relative permittivity (εr) of 2.2, the recommended antenna is constructed and a dielectric thickness of 1.575 mm. This sort of antenna has a number of benefits, including being flexible in terms of band accessibility, compact, cheap, easily produced, small in size, and simple in design. It is also made of copper. The presented low VSWR antenna has the necessary radiation properties to gratify the demands of present and upcoming wireless communications systems; towards the conclusion, both simulated and measured results are given.

Keywords

Cognitive radio, Microstrip antenna, Energy Detector, Tunable antenna, Spectrum sensing

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وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ

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Eng. Rania Ahmed Youssef

Abstract

In this thesis, a tunable Ultra Wide-Band antenna-based cognitive radio (CR) system design is provided. Cognitive radio using ultra-wideband (UWB) and full energy detector-based spectrum sensing. Applying spectrum sensing, cognitive radio (CR) increases the adaptability of personal services and can improve spectrum management and manage energy efficiently. It offers a quick and inexpensive method for effectively finding spectrum holes from 9.30 to 13 GHz in frequency spanning. Frequency is scanned by using a tunable Ultra-Wideband. One of the most essential technological needs for the development of perceptual radio systems is spectrum sensing. The usage of a microstrip patch antenna in ultra-wideband applications is described. The antenna is small, with ground of 30 mm × 30 mm and 5 gaps that are used as switches and measure 2 mm × 3 mm each. Switches are used to monitor the existence of the principal user (PU) and can offer adjusting capabilities. On a Rogers RT5880 substrate with a relative permittivity (εr) of 2.2, the recommended antenna is constructed and having a dielectric thickness of 1.575 mm. This sort of antenna has a number of benefits, including being flexible in terms of band accessibility, compact, cheap, easily produced, small in size, and simple in design. It is also made of copper. The presented low VSWR antenna has the necessary radiation properties to gratify the demands of present and upcoming wireless communications systems; towards the conclusion, both simulated and measured results are given, in the last part of this thesis, using CST microwave studio software, a new design for Tunable Ultra Wide Band (TUWB) is helpful to CR for communication in the desired band, from 9.30 to 13 GHz, the UWB frequency range is provided by the proposed antenna. (TUWB) tunable ultra-wideband frequency tracking is used, and the antenna is made to scan the 9.30 to 13 GHz spectrum. In addition, simple and cheap materials were utilized.

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List of Abbreviations

Abbreviations	Definition
ADC	analogue-to-digital converter
AWGN	Additive White Gaussian Noise
BPF	band pass filter
BW	band width
CCF	Cyclic correlation function
CR	Cognitive radio
CRN	cognitive radio network
CST	computer simulation technology
Db	Decibel
Dbi	Decibel isotropic
DOA	Direction of arrival
ED	Energy detector
ENP	estimated noise power
FCC	Federal Communications Commission
FET	Field Effect Transistor
FFT	Fast Fourier transform
FH	frequency hopping
IEEE	Institute of Electrical and Electronics Engineers
GHz	Gigahertz
KTH	Kungliga Tekniska högskolan
MIMO	multiple input, multiple output
mm	Millimeters
NTRA	National Telecommunication Regulatory Authority
PCB	Printed circuit boards
Pd	probability of detection
Pfa	probability of false alarm
PSD	power spectral density
PU	primary user
Q	Probability
RF	radio frequency
RF MEMS	Radio-frequency microelectromechanical system
ROC	Receiver Operating Characteristic
SNR	signal to noise ratio
SR	secondary receiver
ST	secondary transmitter
SU	secondary user
TED	test statistics energy detector
TH	time hopping

TUWB	tunable ultra wide band
ULA	uniform linear array
UWB	ultra wide band
VSWR	voltage standing wave ratio
WLAN	Wireless Local Area Networks
WPAN	Wireless personal Area Networks
WSS	wide-sense stationary

Glossary of Symbols

Symbols	Meaning
$y(n)$	received signal
$x(n)$	transmitted signal
$w(n)$	Noise
H_0	*signal is absent*
H_1	*signal is present*
N	number of samples
M	number of element
Δ	Distance
A	array factor
λ	Threshold
λ_D	determined threshold
$\lvert S_{11}\rvert$	return loss
εr	relative permittivity
σ_w, σ_s	standard eccentricity of the noise
$Q^{-1}(.)$	reverse of the Q-function
ρ	estimated noise power
$\alpha(\mu_1)$	steering vector
f_c	carrier frequency
c	speed of light
n_i	variance-containing zero-mean circularly symmetric Gaussian variable
$T_{ED(\sigma_w^2)}$	Test statistic of threshold
$y_m(n)$	sampled signal received at m^{th} element
$\lambda_{ED(\sigma_w^2)}$	decision threshold
$\hat{\sigma}_w^2$	estimated noise variance
Γ_{inc}^{-1}	inverse of the gamma function
Q_F^{-1}	inverse of F-distribution function
L	smoothing factor

List of Math Equations and Formulas

Chapter 1
Introduction

1.1 Overview

Cognitive radio (CR) is a one-of-a-kind solution for bandwidth shortages that keep spectrum consumption in check. Dr. Joseph Mitola first suggested the proposal of cognitive radio (CR) in 1999 as a successful spectrum access system to increase spectrum use. There is heavy usage of some frequency bands, while others are hardly used. The CR system's capability to identify, learn, and adapt to the surrounding RF environments is its most distinguishing feature. As a result, reprogrammable radio resources and an intelligent management system are required.

The Federal Communications Commission (FCC) claimed in November 2002 that 70% of the entire spectrum is unemployed at any given moment. This is accomplished through spectrum sensing[1], which is the constant observation of wireless channel activity. A critical technological prerequisite for the realisation of cognitive radio systems is spectrum sensing. Cognitive Radio (CR) needs spectrum sensing to find unused spectrum. This thesis gives a general review of cognitive radio and analyses its qualities and benefits. Because it doesn't ask about transmitted signal properties, channel information, or even the type of modulation, a survey of energy detectors above (AWGN) Additive White Gaussian Noise and the many channels given for spectrum sensing in cognitive radio have resulted in the recommendation and wide use of energy detection-based spectrum sensing. The time-domain and theoretical analysis threshold setting energy detection are examined. Cooperative spectrum sensing and energy detector receptions based on multiple antenna processing are also described.

If the principal user signal is absent, energy detection determines the energy of the received signal as the squared magnitude of the Fast Fourier Transform (FFT) averaged over these. This threshold λ is determined by the received signal levels. It is simple to use and doesn't need for any previously PU knowledge. This approach is simple and much simpler to explain because it doesn't require any prior knowledge of the major user signal.

Making effective use of transmitted energy, time, and frequency are examples of natural resources is the aim of cognitive radio. Spectral efficiency will be more crucial as wireless communication systems in the future support more users and higher performance (such broadband) services. By monitoring the environment, cognitive radio technologies can assist in reducing the importance of secondary systems that increase spectral efficiency and then using their transmissions to fill in the gaps of the unused available spectrum.

1.2 Thesis Motivations and Challenge

Because of the growing interest among consumers in wireless services, radio spectrum demand has risen dramatically. The need for spectrum is projected to grow even more as a result of the need for new applications and mobile internet connectivity. A new communication model is needed to make the most of the already available wireless spectrum because there is a limited amount of spectrum that is accessible and there is poor spectrum use. Because of its adaptability and configurability, cognitive radio provides a solution to this challenge by dynamically accessing the radio spectrum. The research proposes improving an existing spectrum sensing technique and implementing the proposed algorithm in a wireless communication system, as well as developing a cognitive radio application in one of the existing wireless communication systems to improve spectrum usage and signal quality. Spectrum sensing is one of the most fundamental technological requirements for the creation of perceptual radio systems. For ultra-wideband applications, we provide a microstrip patch antenna. The use of microstrip antennas in microwave communication systems is growing due to their lightweight, planar configuration, and low cost of manufacture[2].

Finally, the proposed antenna to meet the specifications for present-day and next wireless communications systems, a low VSWR level offers a desirable radiation characteristic. The simulated and measured outcomes are present.

Natural resources include things like time, energy, and frequency that can be used efficiently. is cognitive radio's main objective. As wireless communication systems in the future accommodate more users and greater performance (such as broadband) services, spectral efficiency will become increasingly important. Cognitive radio technologies can help decrease the importance of secondary systems that boost spectral efficiency by monitoring the environment, and then use their transmissions to fill in the gaps of the unutilized available spectrum.

Several UWB antenna designs with configurability features have been developed successfully. The majority of published research has focused on reconfiguring UWB antennas to work in multiple bands using perfect switches. One of the fundamental difficulties in communication systems using ultra-wideband (UWB) and cognitive radio (CR) is constructing a small antenna with wideband properties over the full operational band. Setting up a reliable spectrum is a simple fix. Secondary users can feel the radio spectrum area due to the cognitive radio system characteristic of sensing or environment within their operational range in order to identify frequency bands intervals or holes that are unoccupied by primary users. Developing a new application for a wireless communication system and enhancing its performance using cognitive radio technology to improve spectrum consumption efficiency and received signal quality is the most difficult challenge. This can be achieved by utilizing antenna arrays rather than single antenna elements in a new spectrum sensing technique.

1.3 Thesis Organization

The following five chapters make up this thesis:

Chapter 1 ─ Introduction: provides a summary, objectives, potential challenges, motivation to meet these requirements, and include the literature review.

Chapter 2 ─ Survey on a cognitive radio system: provides a quick overview of cognitive radio systems and spectrum sensing methods. based on choosing an energy detector.

Chapter 3 ─ Energy detector techniques: explains the proposed energy detector. Multiple antenna-based spectrum sensing method for cognitive radio systems. We derive expressions for test statistics, probability of detection, probability of false alarm, and their thresholds, we provide 32 different scenarios of measurements resulting from different switching configurations. CST Microwave Studio developed the simulation, which displays a new way of improving the performance of spectrum sensing techniques in cognitive radio systems by using antenna arrays beamforming.

Chapter 4- Tunable ultra-wide band antenna design for cognitive radio system*:* describes design a new tunable ultra-wideband antenna (TUWB) for cognitive radio applications, including its design, construction, and measurement.

Chapter 5 ─ Conclusions and recommendations for future study: gives a solution to the thesis. The chapter identifies the main challenges, viewpoints, successes, and suggestions for potential future work.

Chapter 2
Survey on a cognitive radio system

More requirement for additional wireless spectrum and increased data traffic have resulted from the provided great in mobile users and wireless communications. In a 1998 seminar at Stockholm's KTH Royal Institute of Technology, Joseph Mitola III suggested the concept of cognitive radio, this was later published in a 1999 study by Gerald Q. Maguire and Mitola, Jr. It was a label form of wireless communication [7].

The radio frequency spectrum has several of its allocations have already been given to licensed users; as a result, new Radio Frequency (RF) usage systems are developing [4]. A cognitive Radio System (CR) is one of the alternative solutions since it suggests a more intelligent use of the spectrum [8], [9]. To increase spectrum usage, the cognitive radio network (CRN) is presented as an effective spectrum access network. The concept of secondary users occurs in cognitive radio when licensed users or primary users of the RF spectrum are not always using their spectral share of the spectrum. These users can use the channels that become available when the primary users are not sending or receiving data. Essentially, the system must sense the wireless environment and determine when a free space exists in which the secondary user communicates.

To address the aforementioned challenges, existing policies must be reviewed, and new technologies that can use the spectrum efficiently and intelligently must be evaluated, the IEEE 80.22 standard defines cognitive radio as some wireless communication devices have the ability to modify their transmission and/or reception characteristics to communicate more effectively and prevent interference from licensed or licensed-exempt users. The radio environment's internal and external effects, including the radio frequency spectrum, position data, user activity, and network state, are actively monitored in order to adjust the parameters[10].

Cognitive radio (CR) systems must be capable of detecting gaps in the finite RF spectrum that is already being used by other wireless systems regularly. The CR system's transmitter and receiver properties should then be changed to allow it to operate inside the discovered free channels. An antenna for monitoring wireless signals continuously channels and discovers communication opportunities are required to develop a CR system for the interweaving model to send and receive data using the unused channels that have been found, the device additionally requires a reconfigurable antenna[5]. As seen Figure 2-1, the implementation follows a CR chain.

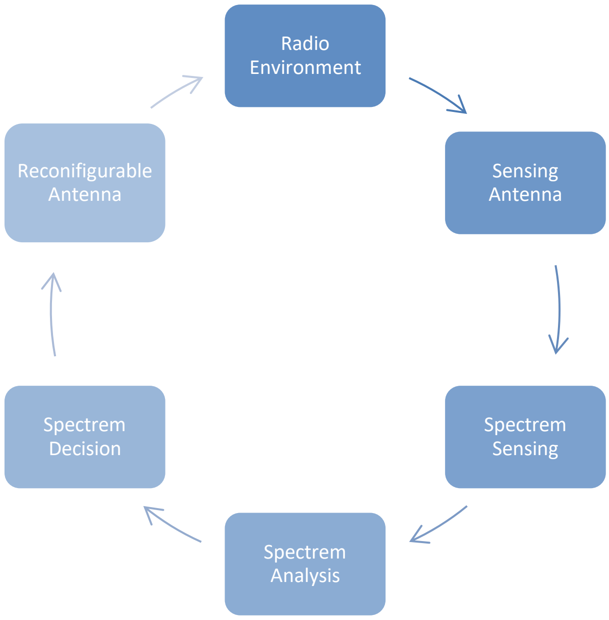


Figure 2-1 Cognitive Radio Chain

2.1 The cognitive radio's primary components

Urban areas frequently have certain frequencies of spectrum that are completely empty, several others that are partially occupied, and the remainder frequency bands that are heavily used[11].

1. Spectrum Sensing: For sensing the spectrum and evaluating whether there are any available spectrum gaps, spectrum sensing is a crucial cognitive radio component.
2. Spectrum Management: Based on the demands of secondary users, spectrum management selects and seizes the most accessible spectrum.
3. Spectrum Mobility: The trading of frequencies between primary and spectrum mobility is the movement of secondary users.

4. Spectrum Sharing: Spectrum sharing is a procedure in which cognitive users are provided with a fair frequency band scheduling method.

2.2 Spectrum sensing

We focus on spectrum sensing, which is important for detecting a spectrum hole in the cognitive radio (CR) cycle. A cognitive radio (CR) device must be able to follow a cycle of three operations, as illustrated in Figure 2-2, to achieve the requisite functionality. The first function is to Sense the RF environment. The second function is to act, which includes transmitting information when a communication opportunity presents itself. The final function is to take in environmental knowledge to predict future communication parameters based on previous experience. According to the context of the requirement, there are numerous spectrum sensing techniques that can be classified as shown in Figure 2-3. Narrowband and wideband approaches are two examples of how these techniques might be categorized, along with others.

The ultimate goal of a cognitive radio network is dual and builds on spectrum sensing and other essential activities:

1. Deliver incredibly dependable communication to all network users whenever and wherever they need it.
2. promote reasonable, cost-effective, and effective use of the radio spectrum.

In a limited frequency range, narrowband spectrum detection techniques provided a single binary decision for the presence of PU traffic. Techniques for wideband spectrum sensing look for the primary activity throughout a wide range of frequencies. The most common spectrum sensing techniques for both categories are based on this classification: energy detection[12], matched filter detection[13], waveform based spectrum sensing[14], spectrum sensing radio using cyclostationary based signals [15], spectrum sensing using identification based signals[16].

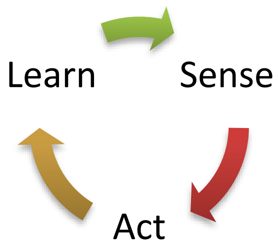


Figure 2-2 A spectrum sensing scheme evaluation.

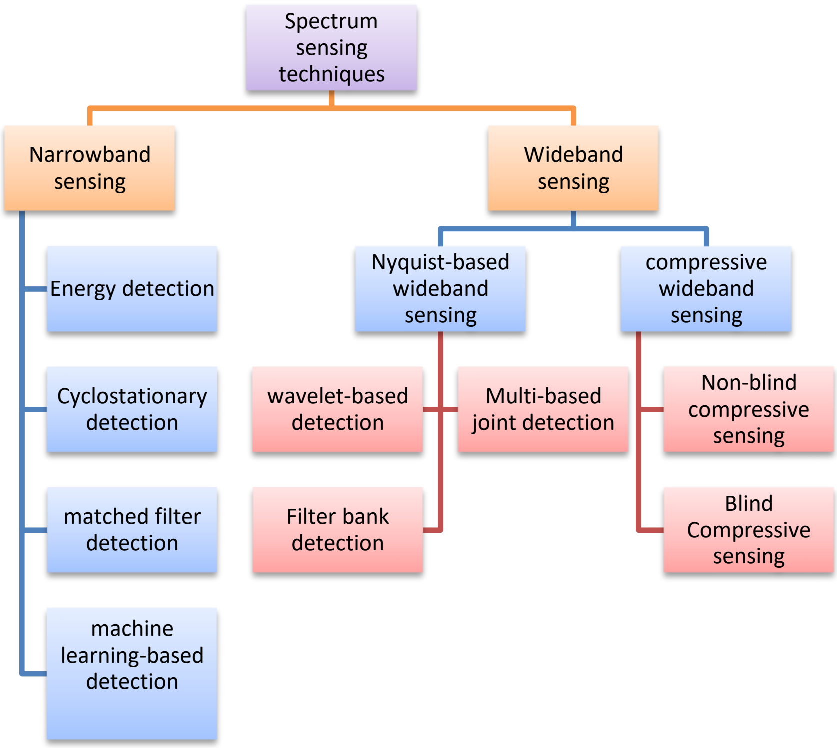


Figure 2-3 A categorization of spectrum sensing techniques [17]

The term "spectrum holes" refers to radio spectrum sub bands that are underused (in part or whole) at a given point in time and in a certain geographical area. The task of spectrum sensing is divided into the following subtasks:

1. Spectrum hole detection.
2. Each spectrum hole's spectral resolution.
3. Spatial direction estimation of incoming interference.
4. Signal classification.

2.3 Awareness of the Multidimensional Spectrum

The common definition of the term using simply the frequency, time, and spectrum space, a "range opportunity" is a band of frequencies that is not currently being used by the major client of that band in a certain location. Typically, traditional sensing techniques focus on detecting the spectrum in these three dimensions. For spectrum potential, there are other issues that need to be further investigated.

Five dimensions can be used to create an opportunistic spectrum[18]. The first dimension is the frequency domain, which is viewed as an opportunity. It is the spectrum's availability in a specific frequency range. The spectrum that is available is split into smaller bands. In this dimension, spectrum opportunity indicates that not all of the bands are in use at once, meaning that some bands may be open to opportunistic use.

The second dimension, time, is viewed as an opportunity for a particular time band. This relates the early accessibility of a certain spectrum region. The band is not continuously used, in other words. It will occasionally be accessible for opportunistic use as shown in

Figure 2-4

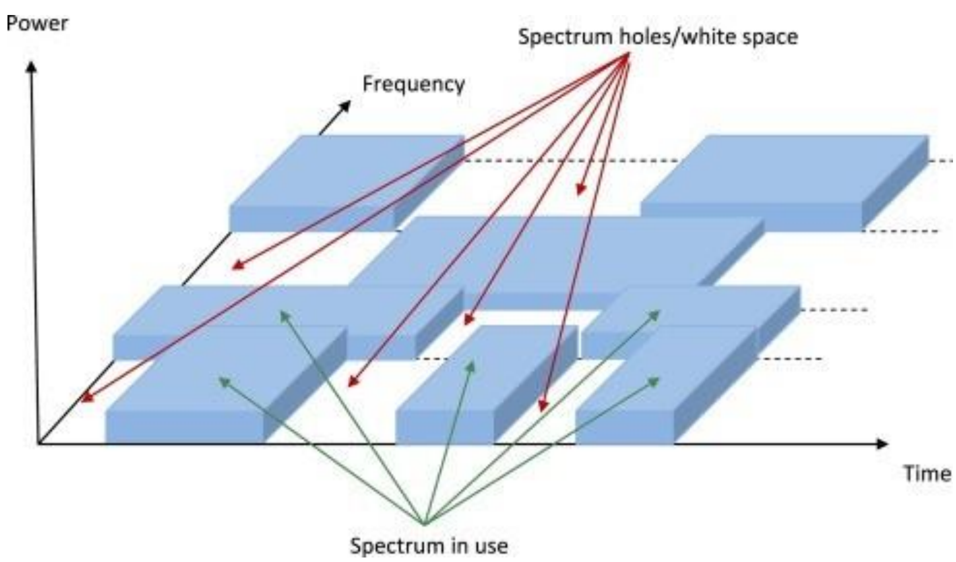


Figure 2-4 Time and frequency dimensions [18]

Figure 2-5 depicts the code dimension, which is the third dimension. The main users employ spreading code, time hopping (TH), or frequency hopping (FH) sequences. Additionally, the timing data is required in order for secondary users to synchronized their transmissions with those of primary users. By using lengthy and erratic code, the synchronization estimation can be avoided. In this instance, though, partial interference is inevitable, this necessitates the opportunity in the code domain, i.e., identifying the used codes in addition to the spectrum utilization and presumably multipath characteristics as well.

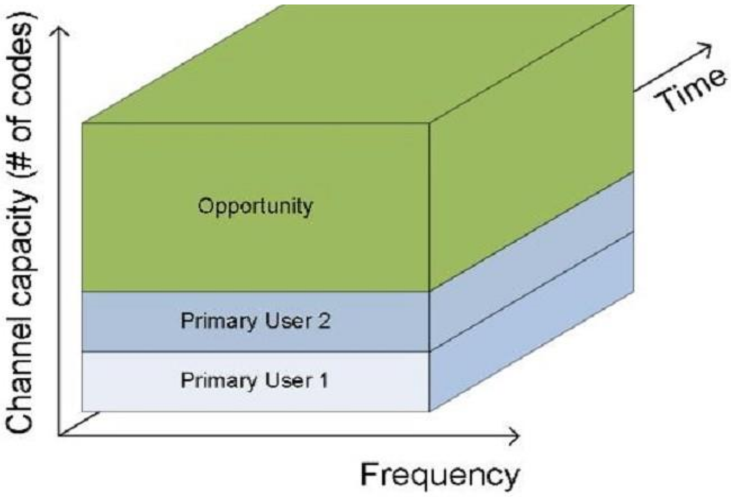


Figure 2-5 Code dimension [18]

the fourth dimension is the angle locations of primary users as well as the azimuth and elevation angles of their beams. Spectrum chances in the angle dimension can be produced along with the understanding of the position, location, or orientation of principal consumers. As illustrated in

Figure 2-6, if a primary user is broadcasting in one way, without interfering with the primary user, the secondary user can communicate in other directions.

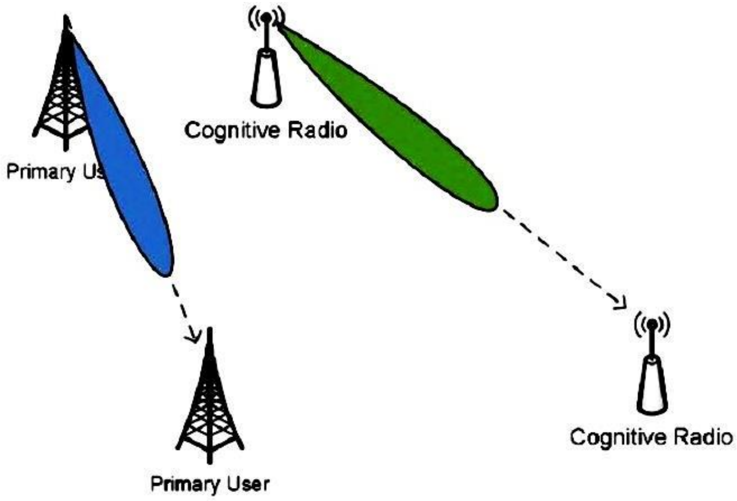


Figure 2-6 Dimension of an angle for cognitive radio [18]

The last dimension is geographical space or the sensing of location (latitude, longitude, and elevation) and separation from the main user. The spectrum may be available in some areas of the region while being used in other areas at a particular time. This makes use of the space-based propagation loss (path loss). The interference level can be used to avoid these measurements. In the absence of interference, there are no local primary user transmissions. However, one must exercise caution due to a hidden terminal issue, Figure 2-7 provides an illustration of this dimension.

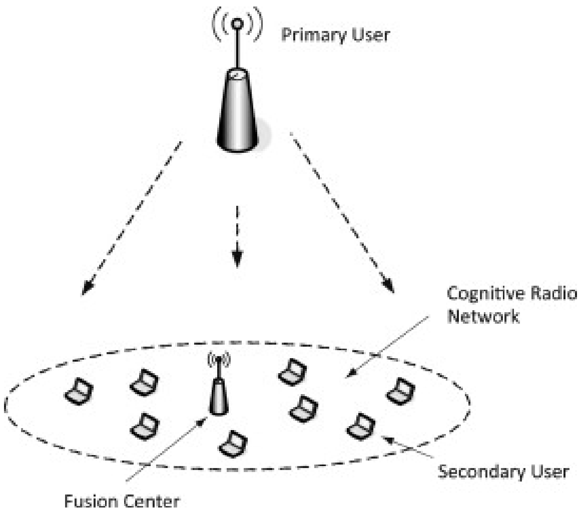


Figure 2-7 Dimensional geographic area [18]

2.4 Radio Spectrum Shortage

The wireless spectrum has been viewed as a static resource that may be broken down into several chunks. Radio regulatory authorities, such as the National

Telecommunications Regulatory Authority (NTRA) in Egypt, place restrictions on access to radio spectrum, making it challenging to use. The present wireless spectrum allocation policy statically grants licensees or services long-term exclusive rights over broad geographic areas, licensed radio services are given access to significant portions of the radio spectrum in a process known as command-and-control. Overlay sharing, or having unrestricted access to an open spectrum, is typically not allowed. The radio spectrum as a whole contains very little unlicensed spectrum.

Nevertheless, this approach has excitingly led to a wide range of additional wireless systems, technology, and capabilities over the last few decades, including Wi-Fi, the well-known IEEE 802.11 Wireless Local Area Networks (WLANs), and Bluetooth for IEEE 802.15 Wireless Personal Area Networks (WPANs). A more flexible, open spectrum access may be preferable to the current radio regulatory authority given the demonstrated commercial viability of wireless communication systems operating in unlicensed spectrum and the sheer quantity of radio systems utilizing this area of the radio spectrum, radio waves are a limited resource. The electromagnetic frequencies between 3 kHz and 300 GHz are referred to as the radio spectrum. Figure 2-8 shows the frequency range that is typically thought of as the radio spectrum.

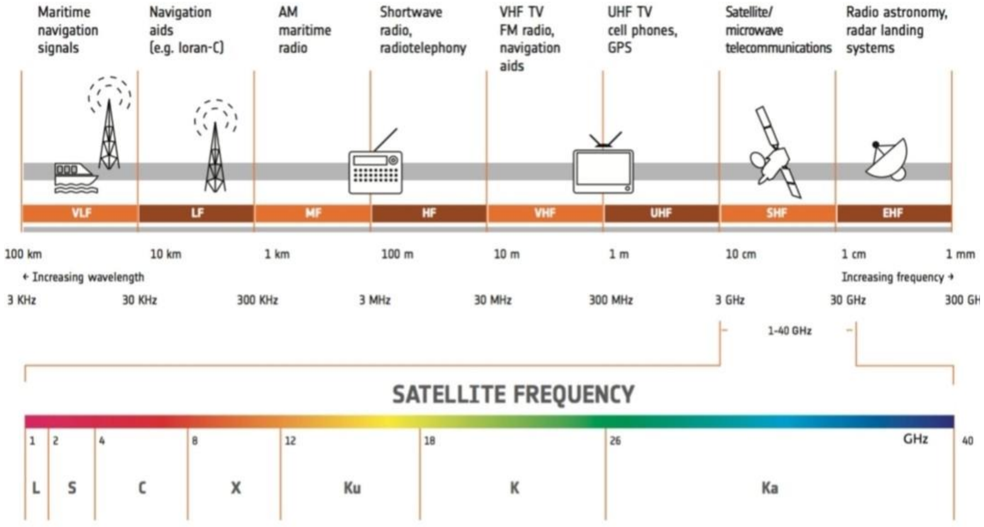


Figure 2-8 The frequency range known as the radio spectrum ranges from 3 kHz to 300GHz

The Federal Communications Commission (FCC) in the United States and the National Telecommunication Regulatory Authority (NTRA) in Egypt conduct auctions that determine the frequency allotment and award a specified spectrum block to the highest bidder. The chart for allocating radio spectrum in Egypt is shown in Figure 2-9 [19].

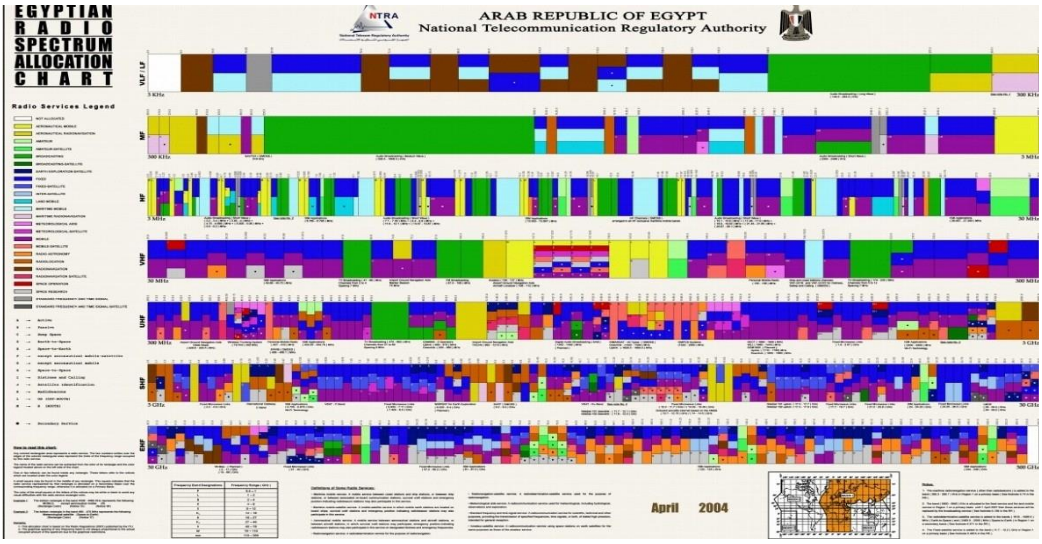


Figure 2-9 Allocation of radio spectrum in Egypt [19]

Primary Users (PU) are those who have greater priority or legacy rights over the use of a specific area of the spectrum, in accordance with cognitive radio terminology. On the other hand, secondary users (SU), who are given less priority, use this spectrum in a manner that doesn't interfere with primary users. Therefore, cognitive radio skills are needed for secondary users, such as the ability to accurately sense the spectrum to determine if a primary user is utilizing it and the capacity to change radio parameters to benefit from the unused area of the spectrum [18].

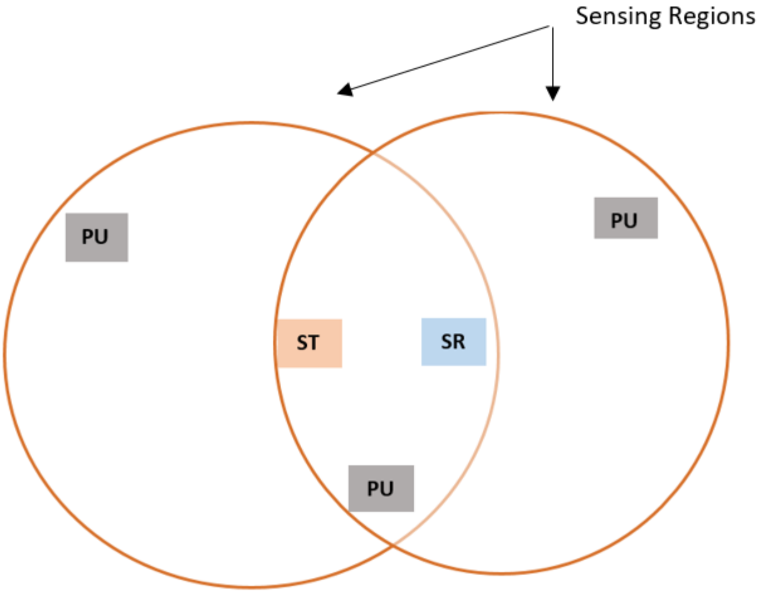


Figure 2-10 System for Cognitive Radio.

As depicted in Figure 2-10. where the primary users, the secondary transmitter (ST), and the secondary receiver (SR) are all present (PU). It is expected that within their respective sensing zones, the secondary transmitter and secondary receiver can both flawlessly identify primary signals.

2.5 Spectrum Sensing Techniques

Continuous spectrum sensing is performed by CR systems, which dynamically identify the primary systems' licensed spectrum bands that are not currently in use and take advantage of any gaps in the spectrum that may exist. Therefore, the essential capability for enabling the deployment of CR systems is spectrum sensing, to detect the transmission of the PU signal, a variety of spectrum sensing methods have been suggested. These methods give SUs greater opportunity to use the spectrum without interfering with or affecting PUs[20].

2.5.1 Waveform Based Spectrum Sensing

Well-known patterns are frequently utilized in wireless networks for synchronization and other functions. Examples of these patterns include midambles, preambles, spreading sequences, routinely aired pilot patterns, etc. While a preamble is a predetermined sequence provided prior to each burst, a midamble is information transmitted in the center of a burst or slot. By comparing the received signal to a known duplicate of itself in the presence of a recognized pattern, sensing can be carried out.

Only systems with well-established signal patterns can use this technique, which is also known as waveform-based sensing or coherent sensing referred to as coherent sensing or waveform-based sensing. Energy detector-based sensing is outperformed by the waveform-based sensing algorithm. On the other hand, when the known signal pattern lengthens, the sensing algorithm's performance grows. Although the waveform-based sensing method only needs a brief measurement period, synchronization problems can still occur [18].

2.5.2 Cyclostationary Based Spectrum Sensing

Utilizing the cyclostationarity properties of the received signals, finding cyclostationarity characteristics is a technique for identifying primary user transmissions. Cyclostationary features can be purposely created to help with spectrum sensing, or they can be brought about by periodicity in the signal or autocorrelation and the mean are examples of its statistics. Cyclic correlation function (CCF) is used to find signals in a spectrum rather than power spectral density (PSD). The signals from primary users can be distinguished from background noise via cyclostationarity-based detection techniques. Due to the redundant nature of signal periodicities, modulated signals are cyclostationary with spectral correlation, whereas noise is wide-sense stationary (WSS) with no correlation. Cyclostationarity can also be applied to distinguish between various transmission kinds and principal consumers [18].

2.5.3 Matched Filtering Based Spectrum Sensing

When the broadcast signal is identified, matched-filtering is recognized as the best technique for identifying principal users. In comparison to other techniques, the key benefit of matched filtering is the speed with which a certain probability of false alarm or probability of lost detection may be reached. However, cognitive radio is necessary for matched-filtering in order to demodulate received signals [21]. As a result, it necessitates complete understanding of the fundamental signaling characteristics of the users, including band width, operating frequency, pulse shaping, modulation type and order, and frame format. Additionally, because cognitive radio requires receivers for every sort of signal, the implementation complexity of the sensing unit is too high. Large power consumption is extra drawback of match filtering because numerous receiver algorithms must be run in order to detect signals [18].

2.6 Spectrum sensing based on energy detector

Considering how simple it is, energy detection has rekindled interest in recent research efforts among spectrum sensing techniques such as matched filter, cyclostationary feature identification, and eigenvalue detection. The energy associated with the received signal is measured using a conventional energy detector over a predetermined time and bandwidth. An energy detector can draw conclusions even with scant previous information of the broadcast signal. The choice statistic of an energy detector, following appropriate filtering, sampling, squaring, and integration, is a measurement of the received signal energy.

The frequency band is sensed using an energy detection approach. At a particular frequency slot, the energy detector picks up the spectrum. It measures the signal's energy at the receiver's end and compares it to the threshold value to determine if the signal is primary or not. It is able to detect energy in both the time and frequency domains. In the mentioned energy detection paradigm, the signal is first transformed into the frequency domain using the FFT $x(t)$ before being measured for energy in order to choose the band with a band pass filter. Next, evaluate the signal's energy in relation to the threshold value. The threshold is only calculated using features of the received data statistical output when there is noise. [12], [22]–[24].

To classify the attendance of primary users in this architecture, we used energy detection methods for spectrum sensing. This happens if the received signal levels are advanced a specific threshold λ ; else, the main user signal is turned off. This approach is easy to implement and doesn't call on any previous PU expertise. The energy detection method, which is implemented in MATLAB, calculates the probability of false alarm, probability of detection, SNR, and number of samples. The probability of detection was calculated using the ratio between the number of times the signal exceeds the threshold value and the total number of traces [25], and Due to its low processing and application measure of complication. This is the most optimum technique to adjust when the noise is known, the unknown signals due to it having low processing and application measure of complication.

Chapter 3
Energy Detector Techniques

Using a specific bandwidth and duration, an energy detector detects the energy received. The presence or absence of the sent signal is then determined by comparing the measured energy to a threshold. Urkowitz was first introduced (ED) in his classic paper[26]. For the purpose of finding deterministic signals in white Gaussian noise, which Digham et al. investigated further[27]. The energy detector has a cheap construction cost because it does not need channel gains or other parameter estimates. However, when there is a lot of noise and a lot of background interference, its performance decreases [28]. To classify the attendance of primary users in this model, we used energy detection algorithms for spectrum sensing. This occurs when the received signal levels exceed a predetermined threshold λ; If not, the main user signal is turned off. This approach is easy to implement and doesn't need any prior PU knowledge. The energy detection method is implemented in MATLAB and evaluates the SNR, probability of false alarm, the number of samples, and probability of detection. The probability of detection was calculated using the ratio between the number of times the signal exceeds the threshold value and the total number of traces [25]. And Due to its low processing and application, measure of complication, when the noise is known, this is the most effective method for correcting unknown signals. Because it is easy in both processing and application, this method is the best one for adjusting unknown signals when the noise is known.

In time-domain implementations, two primary types of the traditional energy detector are taken into consideration for theoretical model: An analogue energy detector consists of a pre-filter, a square-law device, and a limited time integrator Figure 3-1 (a) [26], The well before limits the noise bandwidth and modifies the noise variance. The energy of the input waveform influences the integrator's output, a digital energy detector is made up of a square-law device followed by an integrator, which converts continuous signals into discrete digital signal samples, a low pass noise pre-filter that limits noise and nearby signals, and an analog-to-digital converter (ADC) Figure 3-1 (b).

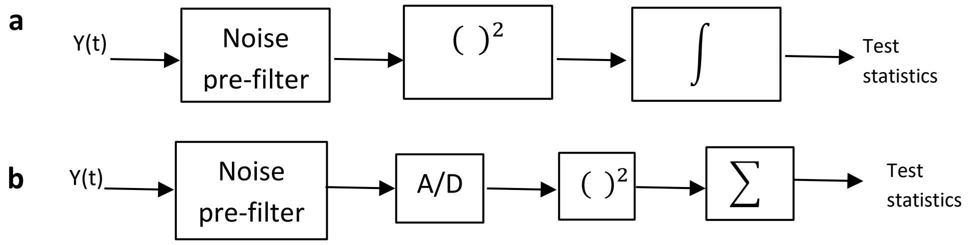


Figure 3-1 The traditional energy detectors in both (a) analog and (b) digital forms.

Spectrum sensing is the most important phase of the cognitive radio cycle. It primarily seeks to distinguish between the two states: principal user signal is absent H_0 or primary user signal is present H_1. The following provides examples of these two states:

$$H_0: y(n) = w(n) \quad \textit{where } n=1, \ldots, N \qquad 3\text{-}1$$

$$H_1: y(n) = x(n) + w(n) \qquad 3\text{-}2$$

Where *N* is the number of samples, *y(n)* is the received signal, *x(n)* means the transmitted signal, and *w(n)* means the noise effecting the transmitted signal.

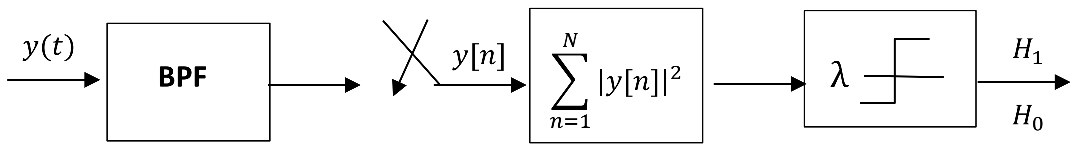


Figure 3-2 block diagram of energy detector

As seen in Figure 3-2, first measure the signal's energy to choice the band with a band pass filter, and next take the signal's FFT x(t) to transform the signal into the frequency domain. Following, compare the signal's energy to the threshold value. The threshold is only set based on the test statistics *TED* characteristics of the received data when noise is present. As shown in Figure 3-1. Block diagram for Decision Statistic *TED* calculation. P_{FA} is linked to the threshold λ [12], [24], [29], [30] using the following equation:

$$\mathrm{TED} = \sum_{n=1}^{N} (Y[n])^2 \qquad 3\text{-}3$$

This technique has the problem of being unable to identify between signal types, simply determining their existence [26], [31], [32]. This is the most effective method for identifying unidentified signals when the noise power is known.

The sensing choice is then complete by comparing the energy *TED* to a predetermined threshold λ_D:

$$\mathrm{TED} > \lambda_D : \mathrm{PU} \quad \textit{signal is absent}$$

$$\mathrm{TED} < \lambda_D : \mathrm{PU} \quad \textit{signal is present}$$

The algorithm's detection display can be evaluated using the probabilities of false alarm P_{FA} and detection P_d. The probability of detection is computed by dividing the number of true detections (PU present) by the total number of sensing experiences, whereas the chance of false alarm is determined by dividing the number of times the PU is wrongly identified.by the total number of sensing experiences. The following are the probabilities:

$$P_d = \Pr(TED < \lambda_D; H_1) \qquad 3\text{-}4$$

$$P_{FA} = \Pr(\mathrm{TED} < \lambda_D; H_0) \qquad 3\text{-}5$$

λ_D is the sensing threshold, and TED works with the energy of N samples as defined by equation 3-3 Following[24].

The center limitation theorem can be used to calculate the test statistic if *N* is large enough (*N* > *250*). [33].

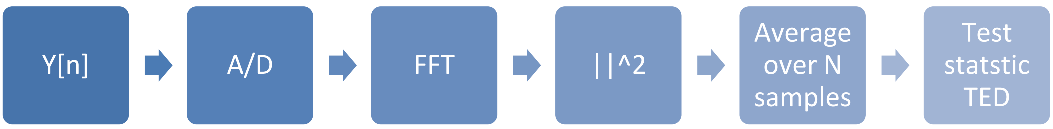


Figure 3-3 Block diagram for calculating the Decision Statistic *TED*

The formulas for false alarm probability P_{FA} and detection probability P_d are as follows:

$$P_d = Q\left(\frac{\lambda - N(\sigma_W^2+\sigma_x^2)}{(\sigma_W^2+\sigma_x^2)\sqrt{2N}}\right) \quad 3\text{-}6$$

$$P_{FA} = Q\left(\frac{\lambda_D - N\sigma_W^2}{\sigma_W^2\sqrt{2N}}\right) \quad 3\text{-}7$$

Where Q-function $Q(x)= \frac{1}{2\pi}\int_x^{\infty} exp\left(\frac{-u^2}{2}\right) du$, N is the number of samples, and σ_w, σ_s are the noise's and the PU signal's standard eccentricities.

threshold λ_D, that is obtained Equation 3-7 and served :

$$\lambda_D = \sigma_W^2 \left(Q^{-1}(P_{FA})\sqrt{2N} + N\right)\right) \quad 3\text{-}8$$

Where $Q^{-1}(.)$ is the reverse of the Q-function.

The goal probability of a false alarm, the noise contrast, and the sample count are the basis for this threshold. To construct an accurate threshold, previous information of the amount of noise that affects the received signal is essential, if the number of samples used in the procedure is not limited, energy detector-based sensing can satisfy any required P_d and P_{FA} simultaneously. The minimum number of samples needed is dictated by the SNR and can be calculated as follows:

$$N = 2[(Q^{-1}(P_{FA}) - Q^{-1}(P_d))SNR^{-1} - Q^{-1}(P_d)]^2 \quad 3\text{-}9$$

A large number of samples are necessary to have a reasonable detection performance if SNR<< 1, for spectrum sensing, the probability of a false alarm should be weak. The detector detects the major signal H_1 instead of signal H_0 to avoid making a mistaken choice. The secondary user wouldn't use it because the detector in this state lost the chance of finding the free channel.

3.1 Design parameters

The number of samples and the threshold are the most key design factors for the energy detector. The performance of the energy detector is impacted by SNR and noise variance, designers have very little control over these parameters because they are dependent on the wireless channel's behaviour.

3.1.1 Threshold

Identifying the target signal's presence or absence, a threshold λ_D must be defined. All performance metrics, P_d and P_{FA}, are determined by this threshold λ_D.

As a result of the operational threshold's ability can be selected with reference to the target output of the efficiency signal and might range from 0 to ∞, it is important to choose the correct one. The interest operating system both P_{FA} and P_d decrease (or increase) as the threshold increases (or decreases). The standard approach to setting the threshold for knowing N and σ_w is to use a constant false alarm probability P_{FA}, such as $P_{FA} \leq 0.1$. Equation 3-8 can be used to determine the chosen threshold depending on P_{FA}. However, the energy detector may still miss the target with this threshold. Thus, it is possible to think about threshold selection as a balancing act between two competing goals in an optimization method. (i.e., maximise P_d and minimising P_{FA}).

3.1.2 Number of Samples

Another important design element for ensuring that detection and false alarm requirements are met is the number of samples N. For a given false alarm probability $P_{FA}$and detection probability P_d, the minimum number of samples needed can be determined as a function of SNR. By eliminating threshold from P_{FA} in equation 3-7 and P_d in equation 3-6, when the noise power is fully known, increasing N allows the signal to be identified even in areas with extremely low SNR. This is because function $Q^{-1}(.)$. has a monotonically declining characteristic (.). With very low SNR, energy detector requires more samples [34].

3.1.3 Noise Effect

The noise power affects the threshold selection. Only if the receiver's noise power is correctly understood can a proper threshold selection be performed, as shown in equation 3-8. When the SNR is low ($\gamma \to 0$), as in equation 3-6, the number of samples rises N. This means that using a high number of samples ($N \to \infty$), the given P_{FA} and P_d can be obtained even with a low SNR. This is only achievable if the noise power is known exactly [34]–[36].

Accurately estimating noise power is not always simple, the additive white Gaussian noise (AWGN) properties of the resulting noise (wideband noise with a constant spectral density) may be lost as a result of the noise's potential inclusion of nearby interference from other data transmission, temperature variations, weak signals, and filtration impacts, which may affect how much noise power can be estimated.[37].

The performance of the energy detector can be significantly decreased by estimation errors, which are referred to as noise uncertainty. The estimated noise power is thought to be in the range $(\frac{1}{\rho}\sigma_W^2, \rho\sigma_W^2)$, when there is noise uncertainty, where (ρ >1) is the noise uncertainty parameter [32]. Equation 3-10, utilizing the low-SNR approximation 2 γ +1 and the noise uncertain effects, can be used to calculate the necessary number of samples for the conventional energy detector to acquire given P_{FA} and P_d .

$$N \approx \frac{(Q^{-1}(P_{FA}) - Q^{-1}(P_d))}{(\gamma - (\rho - \frac{1}{\rho}))^2} \qquad 3\text{-}10$$

This means that an endlessly large number of samples are needed to attain the appropriate false-alarm and detection probability when $\gamma \to (\rho - \frac{1}{\rho})$, there must be an endless number of samples. When a suitable energy detector cannot be built at this SNR level, the SNR wall phenomena takes place.

A practical energy detector's test statistic using estimated noise power *(ENP)* [38].

$$\text{ENP} = \frac{1}{2\widehat{\sigma_W^2}N}\sum_{n=1}^{N} |Y(n)|^2 \qquad 3\text{-}11$$

where $(2\widehat{\sigma_W^2})$ is the noise variance estimated The SNR wall is derived as:

$$\gamma_{\min} = \frac{1 - Q^{-1}(P_d)\sqrt{\emptyset}}{1 - Q^{-1}(P_{FA})\sqrt{\emptyset}} - 1 \qquad 3\text{-}12$$

where $\emptyset = Var\left(\frac{\widehat{\sigma_W^2}}{\ddot{\sigma}_W^2}\right)$in this case. In practise, noise can be measured with noise-only samples, which is the same as the claim made under H_0. M stands for the number of noise-only samples. Then $\emptyset$ it's possible to give as $\emptyset = \sqrt{\frac{N+M}{M}}$ [38].

3.2 Detection performance evaluation

Figure 3-4 shows how MATLAB plots the probability of detection against the probability of false alarm. The simulated curve is based on one microstrip antenna element, M=1, a small number of samples, *N*=1000, and a low signal-to-noise ratio, SNR= -20dB.

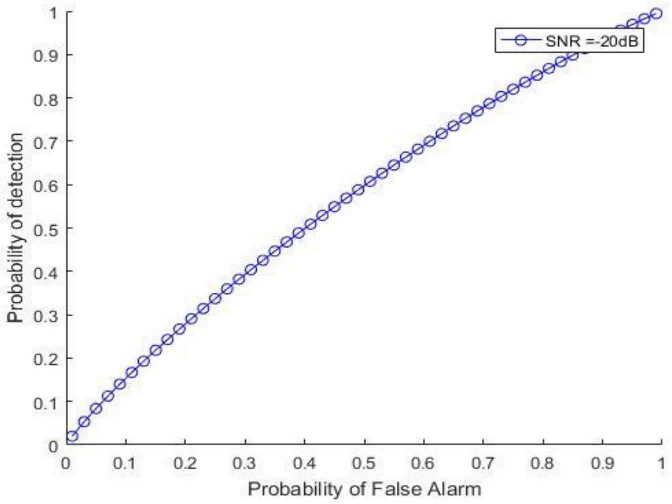


Figure 3-4 probability of detection P_d against the probability of false alarm P_{FA} curve are at proposed energy detector at M=1, N=1000 samples, and SNR= -20dB.

3.3 Noise effect on detection performance

The exhibited energy detector's detection performance is rated, as well as the effect of white Gaussian noise. Figure 3-5 shows the simulated probability of detection against SNR at M=1 element, *N*=1000 samples, and P_{FA} =0.1. it shows the highest performance, especially at SNR ($\geq -7\ dB$). It supplies the highest probability of detection over the entire range (-20dB $\leq$ SNR $\leq 20\ dB$).

3.4 impact of number of samples on P_d

The number of received signal samples *N* is a very leading parameter to realize the detection requirements. Any increase in *N* will lead to perfection in detection performance. So, the probability of detection against the number of samples is plotted as shown in Figure 3-6 using M=1 element and P_{FA} =0.1 at SNR = -20 dB for *N*=3000, the P_d of the suggested energy detector reached the maximum value. Energy detectors exhibit high performance whatever *N* increases.

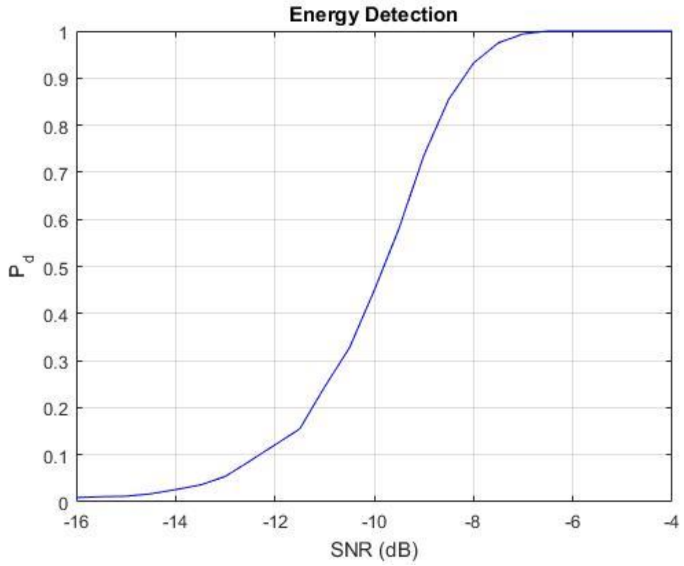


Figure 3-5 probability of detection against SNR for the proposed energy detector at M=1, N=1000 samples, and P_{FA} =0.1

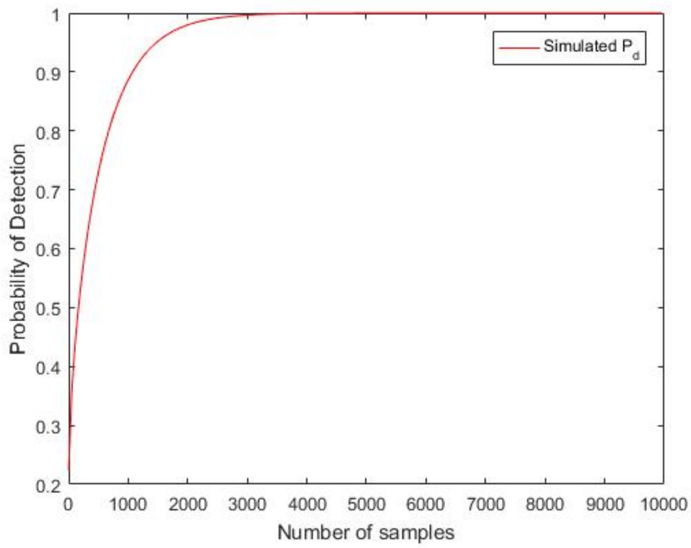


Figure 3-6 probability of detection against number of samples using M=1 and P_{FA} =0.1 at SNR = -20 dB

3.5 Impact of Antenna Array

In the case of an antenna array, identical antenna elements are employed in a uniform linear array (ULA). By an alignment of ($\Delta = \lambda / 2$), where is the signal's wavelength λ that is being received. The ULA is designed to capture signals that primary users receive in narrowband. The antenna array's antennas receive the following signals:

$$y(n) = Ax(n) + w(n) \quad \text{where } n=1, \ldots, N \qquad \text{3-13}$$

$$y(n) = [y_1(n) y_2(n) \ldots y_M(n)]^T \qquad \text{3-14}$$

$$x(n) = [x_1(n) x_2(n) \ldots x_d(n)]^T \qquad \text{3-15}$$

$$w(n) = [w_1(n) w_2(n) \ldots w_M(n)]^T \qquad \text{3-16}$$

The assumption for the noise is that it is a complex white Gaussian noise (CWGN) with a zero mean, where *x(n)* and *w(n)* are the signal and noise column vectors, respectively. The operator for transposing is $[.]^T$. A is the M × d steering matrix, can be written as follows:

$$A = [\alpha(\mu_1)\alpha(\mu_2) \ldots \alpha(\mu_d)] \qquad \text{3-17}$$

Where $\alpha(\mu_1)$ is the steering vector which is given by

$$\alpha(\mu_1) = [e^{-j\mu_1} e^{-j2\mu_1} \ldots . e^{-j(M-1)\mu_1}]^T, i = 1,2,\ldots,d \qquad \text{3-18}$$

The steering matrix can be recast as follows by replacing equation 3-17 with equation 3-18:

$$A = \begin{matrix} 1 & 1 & \cdots & 1 \\ e^{-j\mu_1} & e^{-j\mu_2} & \cdots & e^{-j\mu_d} \\ \vdots & \vdots & \ddots & \vdots \\ e^{-j(M-1)\mu_1} & e^{-j(M-1)\mu_2} & \cdots & e^{-j(M-1)\mu_d} \end{matrix} \qquad \text{3-19}$$

It depends on spatial frequencies $\mu_i = \frac{2\pi f_c}{c} \Delta sin\theta_i$,where the carrier frequency is f_c, c is the speed of light and $\theta_i$is the direction of arrival DOA source. On the receiving end, it is assumed that the direction of approach is specified. The additional phase shifts caused by propagation delays from each element to the first reference point are represented as spatial frequencies[39].

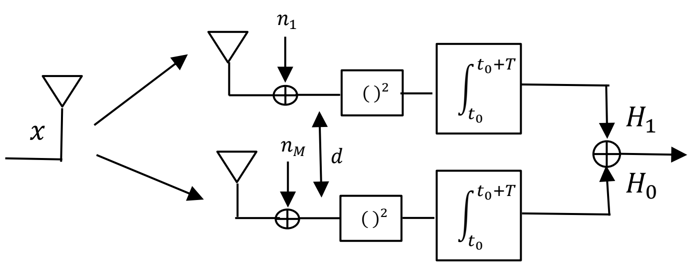


Figure 3-7 block diagram of the proposed energy detector based on the antenna array

We take into consideration a system in which individual data stream is data stream is transmitted from a single antenna. Block diagram of the proposed energy detector using a large number M of antennas is depicted in Figure 3-7. The system uses time-division duplexing to operate, with n_i being a variance-containing zero-mean circularly symmetric Gaussian variable σ_n^2 with $d = \lambda/2$. Every device, whether an access control list or user terminals, is thought to have a sizable antenna array. With each device using one antenna when transmitting and the entire array when receiving. It is assumed that the first component is at the starting point. The issue with binary hypothesis testing is now presented as

$$H_0: y(n)= w(n) \tag{3-20}$$

$$H_1 : y(n) = Ax(n) + w(n) \tag{3-21}$$

When the noise variance is known, one of the most common detectors is the traditional energy detector using several antenna elements. It includes a test statistic provided by [38]

$$T_{ED(\sigma_w^2)}(y) = \frac{1}{MN\sigma_w^2}\sum_{m=1}^{M}\sum_{n=1}^{N}|y_m(n)|^2 \tag{3-22}$$

$$T_{ED(\sigma_w^2)}\begin{cases} > \ \lambda_{ED(\sigma_w^2)}\ , H_1 \\ < \ \lambda_{ED(\sigma_w^2)}\ , H_0 \end{cases} \tag{3-23}$$

Where $y_m(n)$ is the sampled signal received at m^{th} element and $\lambda_{ED(\sigma_w^2)}$ the decision threshold, when the variance of the noise is unknown, the estimated noise variance $\hat{\sigma}_w^2$ is used instead of σ_w^2 . This estimate may not be correct and is subject to mistake [40]. This inaccuracy is additionally known as noise uncertainty α, the anticipated range for the estimated noise power is $[\frac{1}{\alpha}\sigma_w^2 , \alpha\sigma_w^2]$ where $\alpha > 1$.

Additionally, to achieve the appropriate false alarm probability under low SNR scenarios, a high number of samples are required. This issue is also known as SNR wall [41]. A summary of test statistics and theoretical thresholds for the energy detector method are shown in Table 3-1

Table 3-1 Formula for test statistics and theoretical thresholds of the energy detector

Method	Test statistic	Theoretical threshold
ED(σ_w^2)	$\frac{1}{MN\sigma_w^2}\sum_{m=1}^{M}\sum_{n=1}^{N}\lvert y_m(n)\rvert^2$	$2\Gamma_{inc}^{-1}(1-P_{FA}, MN)$
ED($\hat{\sigma}_w^2$)	$\frac{1}{MN\hat{\sigma}_w^2}\sum_{m=1}^{M}\sum_{n=1}^{N}\lvert y_m(n)\rvert^2$	$Q_F^{-1}(1-P_{FA}, MN, L)$

Where $2\Gamma_{inc}^{-1}$ is the inverse of the gamma function that is incomplete, Q_F^{-1} is the inverse of F-distribution function, and L is used as a smoothing factor

3.5.1 Detection performance evaluation

One of the most popular Receiver Operating Characteristic (ROC) curves is provided in this case to evaluate the effectiveness of the energy detector The difference between the probability of detection P_d and probability of false P_{FA} proposed energy detector compared with 15 elements. Figure 3-8 and Figure 3-9 showing the small size ULA with M = 15 elements, N = 50 samples, and a low signal to noise ratio of SNR = -10dB.

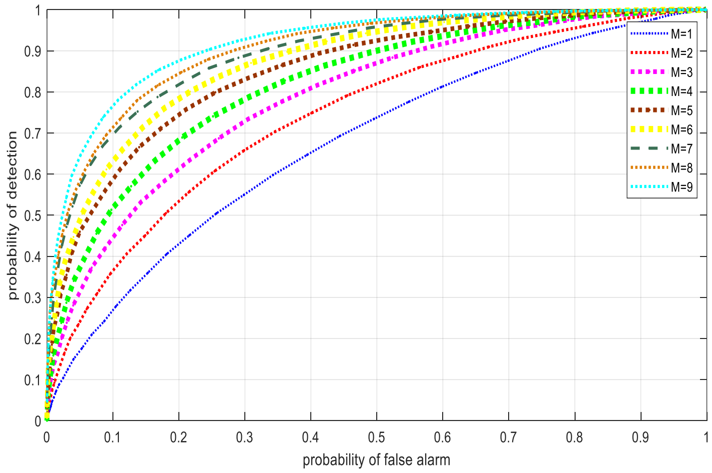


Figure 3-8 **Probability of detection P_d versus probability of false P_{FA} for energy detector using single antenna element M=1 and ULAs up to M=9 elements, N = 50 samples, and a low signal to noise ratio of SNR = -10 dB**

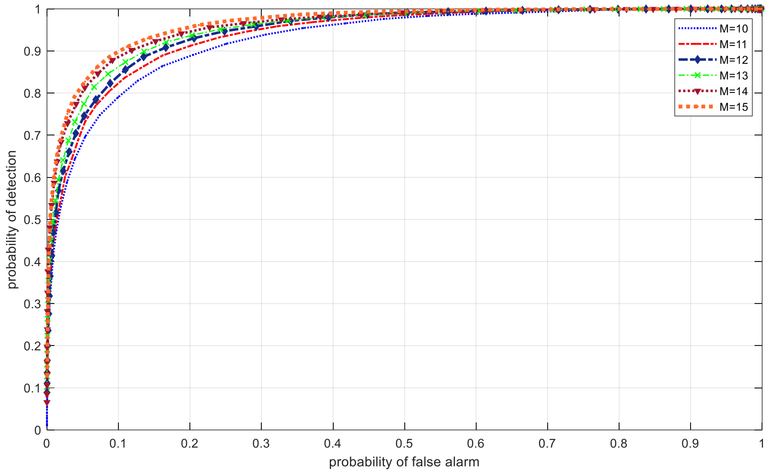


Figure 3-9 **Probability of detection P_d versus probability of false P_{FA} for energy detector using ULAs consisting of M=10 elements up to M=15 elements, N = 50 samples, and a low signal to noise ratio of SNR = -10 dB**

3.5.2 Noise effect detection performance employing different number of antenna elements

In this test case, the proposed energy detector's detection capabilities are evaluated in relation to the impact of CWGN. The simulated probability of detection P_d versus SNR at M = 10 elements, N = 100 samples, and P_{FA} = 0.1 is shown in Figure 3-10 The proposed energy detector's great noise immunity is immediately obvious. It offers the probability of detection across the entire SNR range $-25\ dB \leq SNR \leq 5\ dB$. It is clear that as the number of antenna elements increases, the probability of detection increases under the same noise effect.

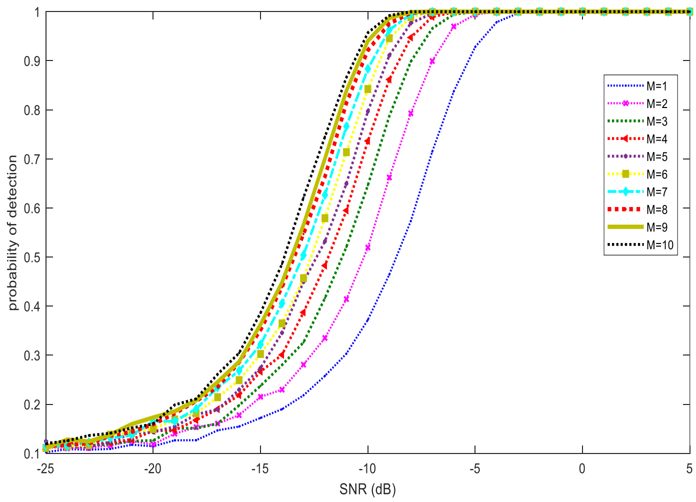


Figure 3-10 **Probability of detection P_d versus SNR at using single antenna element and ULAs consisting of M=2 elements up to M = 10 elements, N = 100 samples, and P_{FA} = 0.1.**

3.5.3 Impact of Number of Samples on P_d

N samples of the received signal must be present in order to meet the detection requirements. Better detection performance should obviously follow from any increase in *N*. As a result, for $N \geq 250$, the probability of detection is plotted against the number of samples using M = 10 elements and P_{FA} = 0.1 at SNR = -20dB ,as shown in Figure 3-11.

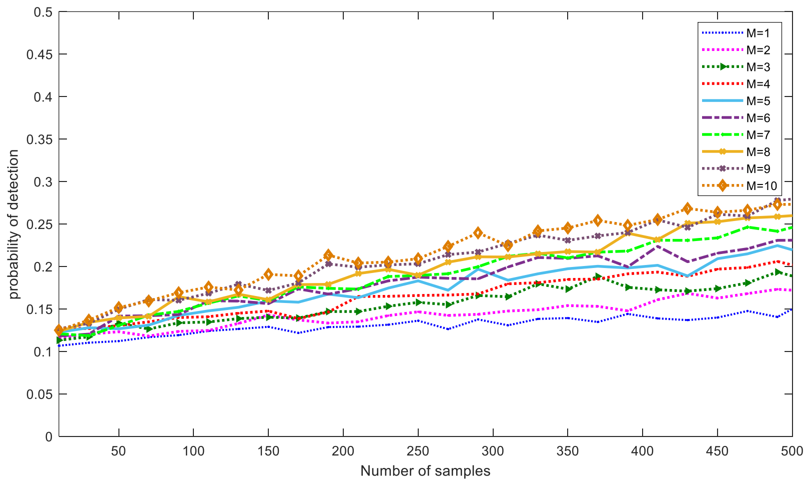


Figure 3-11 Probability of detection versus number of samples for $N \geq 250$, M = 10 elements and P_{FA} = 0.1 at SNR =- 20dB

Chapter 4

Tunable UWB Antenna Design for Cognitive Radio Systems

4.1 Introduction

Major fundamental difficulties in cognitive radio (CR) and Ultra Wideband (UWB) communication technologies is constructing a small antenna with wideband properties over the full operational band. Because of their wideband matching qualities and omnidirectional emission patterns, printed wide antennas have gotten a lot of interest in these systems. Furthermore, they have physically appealing characteristics such as a simple structure, compact size, and inexpensive cost. This work proposes a compact antenna for UWB applications with radiating patch and a defective ground construction. The main goal of the switch is to get a lot of frequencies that will help us transfer the secondary user when the Primary user wants to get its own frequency.

Increasing Personal Area Networks, medical imaging, cognitive radio systems, and radar imaging are just a few of the uses for UWB antennas. As a result, achieving high gain-bandwidth characteristics while decreasing size and cost is one of the most typical issues faced while designing UWB antennas. A number of new broadband antenna designs have lately been created [42]–[45].

Recently, a number of methods, like creating gaps in the antenna's metal components or employing different radiating sections, have been proposed to build multiband antennas[6], [46]. You can interact in a number of set frequency bands by adjusting the ultra-wideband (UWB) sensor antenna. With the creation of various UWB antenna designs for portable, short-range applications, the ability to reconfigure has been effectively achieved. Published research has looked into the use of perfect switches to convert ultra-wideband antennas to operate in ultra-wideband antenna [47], [48]. UWB systems can be viewed as a gradient that runs from short-range communications, ground and object penetrating radar, security systems, vehicular radar, and measurement applications [49]. Due to their low power requirements, wide package for multipath interference, and high data rate. The suggested antenna for UWB systems presents significant challenges due to its wide coverage of frequency bands and high data rates. In addition to having a large bandwidth, high efficiency, and a small size, the antenna should respond very well to the developed UWB antenna applications listed in[50].

The other resonant frequency changes concurrently with the tuning of one resonant frequency. In other words, altering the gap or changing the size of one of the antenna's elements will also change the other resonance's features at once[51].

The purpose of this thesis is to examine the effects of switching on antenna parameters such as gain, return loss, VSWR, and directivity. In this thesis, a basic ultra-wideband, UWB square microstrip patch antenna with an operational frequency range of 9.30 to 13 GHz is shown. Due to the many switching configurations presented in this thesis, we have 32 different scenarios of measurements. CST Microwave Studio was used to perform out the simulation. Finally, we can state that the primary characteristics of this antenna, such as its high gain, high directivity, main beam angle, and various pattern shapes, vary based on the specific UWB applications. In this thesis, we provide a new UWB antenna design that may be applied to all the applications.

4.2 Proposed tunable antenna design

In this section, a small UWB antenna with a circular radiating patch and a defective ground construction is suggested for use in applications using cognitive radio spectrum sensing. In this subsection, a microstrip patch antenna design for ultra-wideband applications is explained. Using Ultra-wideband frequency scanning, Figure 4-2 illustrates the simulated $|S_{11}|$ parameter of the antenna element without switch. Dimensions of the antenna in millimeters are shown in Table 4-1. The structure of the proposed UWB antenna element is depicted in Figure 4-1 and consists of a microstrip patch antenna with a partial ground measuring 30 mm ×30 mm and a Switch measuring 2 mm × 3 mm. The principal user's (PU) presence is monitored via the switch.

The ground, switches, and patch antenna are all composed of copper and are attached to a Rogers RT5800 substrate with a thickness of 1.575 mm and a dielectric constant of εr=2.2. The proposed UWB antenna element structure. This shape is utilized as it provides wide operating frequency band, and the proposed slots can be covered by a small copper disc to form a manual switch that changes the operating frequency of the antenna. Table 4-1 list the antenna's dimensions in millimeters (mm). Computer simulation technology (CST) microwave studio software was used to build the design. Figure 4-3 shows the total antenna gain is Q9 (without switch), the Simulated |*S*11| parameter of the antenna element 10GHz, bandwidth (BW) 0.43 GHz and gain 8.40dbi.

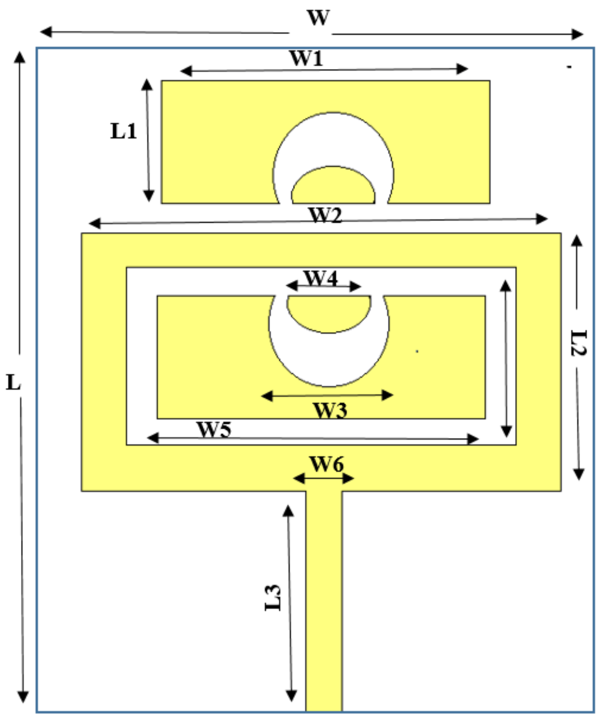


Figure 4-1 ***Structure of the proposed UWB antenna element***

Table 4-1 Dimensions of the antenna in millimeters (mm)

Symbol	Value In (mm)	Symbol	Value In (mm)
W	30	W6	4
W1	16	L	30
W2	24	L1	5.5
W3	4	L2	13

W4	3.64	L3	8
W5	18	L4	9

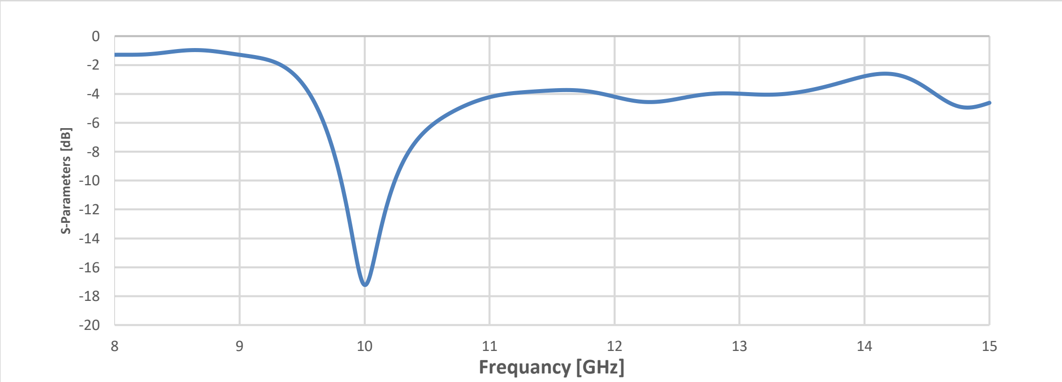


Figure 4-2 Simulated $|S_{11}|$ parameter of the antenna element without switch

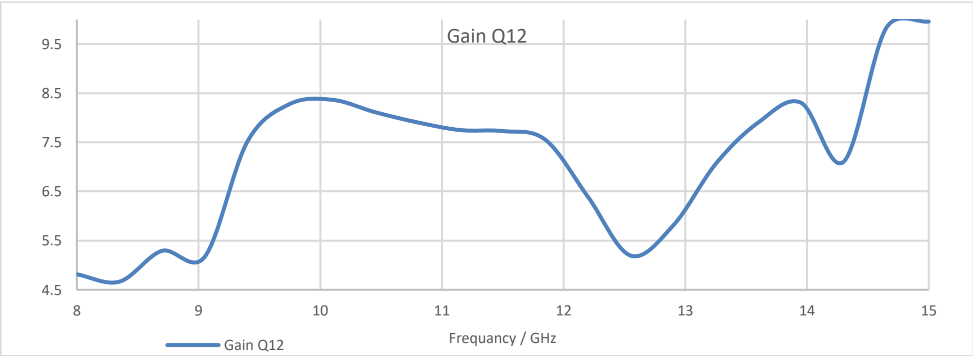


Figure 4-3 The total antenna gain is Q12 (without switch)

A wireless system's antenna is its most crucial component because it is in charge of transmitting and receiving data on the physical layer. Various advantages can be derived from an antenna that has been properly tuned. It can increase a wireless device's operational range while using less power. This design has five copper switches that are 2 mm × 3 mm of copper that we can physically move, giving us the potential for 32 switches to be present. We designated this probability (Q) we have from Q1 to Q32 and 32 resonance frequencies. Existence switch means (1), non-existence means (0). (12 frequencies out of the range, 20 frequencies in the range), **Error! Reference source not found.** shows Simulated $|S_{11}|$ parameter $\leq -10dB$ from Q1 to Q32.

Several switch types including pin diodes[52],varactor diodes[53], RF MEMS[3], [54] , and FET switches [55], can be used to provide frequency agility. A lot of pin diodes are needed to switch between different bands, which raises complicates the biasing circuitry and increases the insertion loss. [56]. Varactor diodes are employed in reconfiguration, however they lack linearity and have a limited continuous tuning range. Although RF MEMS have a low planar loss, their deployment is costly[57].

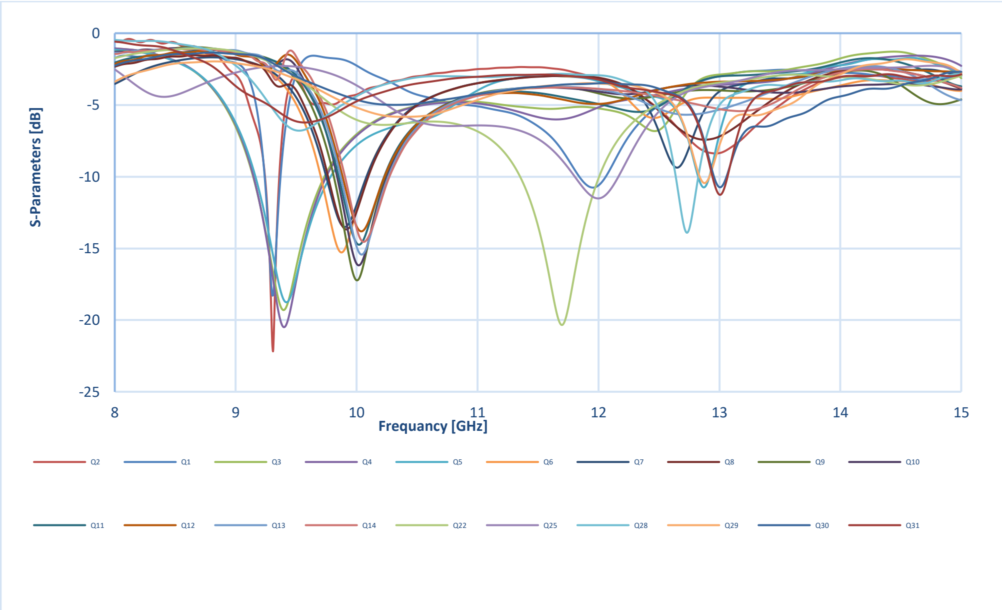


Figure 4-4 Simulated $|S_{11}|$ parameter $\leq -10dB$ from Q1 to Q32

Table 4-2 32 frequency Q1 to Q32 frequency, $|S11|$, and BW (White option in the range < -10 dB, grey selection outside the range, layout depending on frequency ascending)

A	B	C	D	E	Q	Frequency	S11	B.W
0	1	0	1	1	Q1	9.30	-18.27	0.13
0	1	0	1	0	Q2	9.30	-22.16	0.12
0	0	1	0	0	Q3	9.39	-19.29	0.59
1	0	1	0	0	Q4	9.4	-20.49	0.60
1	1	1	0	0	Q5	9.42	-18.75	0.62
1	1	0	0	0	Q6	9.87	-15.28	0.38
1	1	1	1	0	Q7	9.90	-13.50	0.33

1	1	0	1	0	Q8	9.91	-13.67	0.33
0	0	0	0	0	Q9	10	-17.22	0.43
1	0	0	0	0	Q10	10.01	-16.18	0.41
0	0	1	1	0	Q11	10.02	-14.73	0.37
1	0	1	1	0	Q12	10.03	-13.81	0.34
0	0	0	1	0	Q13	10.04	-15.42	0.39
1	0	0	1	0	Q14	10.05	-14.54	0.37
0	0	0	0	1	Q15	10.54	-5.78	-
1	0	0	0	1	Q16	10.55	-5.60	-
0	0	1	1	1	Q17	10.91	-5.45	-
1	0	1	1	1	Q18	10.94	-5.17	-
0	0	0	1	1	Q19	11.06	-3.91	-
1	0	0	1	1	Q20	11.08	-3.65	-
0	0	1	0	1	Q21	11.5	-5.36	-
0	1	1	1	1	Q22	11.69	-20.33	0.65
1	0	1	0	1	Q23	11.72	-6.30	-
0	1	0	0	1	Q24	11.91	-6.83	-
1	1	1	1	1	Q25	11.99	-11.51	0.36
1	1	0	1	1	Q26	12.24	-5.38	-
0	1	0	0	0	Q27	12.37	-7.72	-
0	1	1	1	0	Q28	12.73	-13.90	0.18
1	1	1	0	1	Q29	12.87	-10.44	0.08
0	1	1	0	1	Q30	13.00	-10.74	0.1
0	1	1	0	0	Q31	13.00	-11.26	0.12
1	1	0	0	1	Q32	13.39	-5.78	-

Table 4-2 shown 32 frequency Q1 to Q32 frequency, $|S11|$, and BW (White option in the range ≤-10 dB, grey selection outside the range, layout depending on frequency ascending) 9.30 to 13 GHz UWB microstrip antennas.

Table 4-3 The antenna's simulated VSWR, Gain, and Directivity (White option in the range < -10 dB, grey selection outside the range, layout depending on frequency ascending)

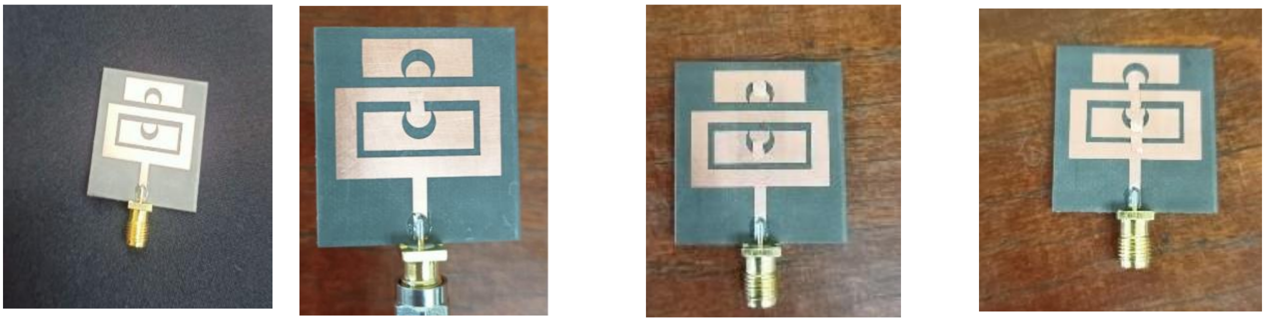
Q	VSWR	Gain	Directivity
Q1	1.27	5.84	4.05
Q2	1.16	5.46	5.711
Q3	1.24	8.3	7.19
Q4	1.20	8.46	8.76
Q5	1.26	8.27	7.58
Q6	1.41	7.76	5.88
Q7	1.53	7.73	4.65
Q8	1.52	7.67	5.75
Q9	1.31	8.40	5.51
Q10	1.36	8.53	5.3
Q11	1.44	8.49	5.87
Q12	1.51	8.65	8.34
Q13	1.40	8.46	7.59
Q14	1.46	8.61	7.09
Q15	3.21	5.45	7.34
Q16	3.20	5.46	6.55
Q17	3.28	5.65	7.75
Q18	3.45	5.75	8.38

Q19	4.51	5.81	8.58
Q20	4.81	5.92	4.66
Q21	3.34	8.12	6.18
Q22	1.21	8.15	6.81
Q23	2.87	8.02	6
Q24	2.66	7.08	6.836
Q25	1.72	7.25	6.16
Q26	3.23	6.59	7.35
Q27	2.39	5.28	8.211
Q28	1.5	5.59	7.73
Q29	1.85	4.9	6.66
Q30	1.81	5.65	8.536
Q31	1.75	5.04	9
Q32	3.11	6.97	7.44

The gain comparison method is used to determine the antenna gain. The antenna ceases radiating in the rejection band while maintaining a large gain at other frequencies, as shown by the measured VSWR, directivity, and gain values in Table 4-3. shows the simulated $|S_{11}|$ parameter $\leq -10dB$ from Q1 to Q32.

4.3 Measurement and fabrication of the Proposed Antenna

Figure 4-5 shows the fabricated proposed a PCB machine's antenna fabrication process. The $|S11|$ parameter was measured using the ROHDE & SCHWARZ ZVB vector network analyzer, as shown in Figure 4-6 and Figure 4-10illustrates a small antenna test that simulated in CST the radiation pattern (a) Q12, (b) Q29 radiation pattern , With 20 frequencies in the range and 5 switches, we may increase the use and significance of the antenna by touching the patch of the antenna by placing the switch on a 0.4mm gap at the junction point, as shown in Table 4-3 displays VSWR, gain, and directivity. Antenna without switches, five switches putting on the gap of 0.4mm, by a switch between them, allows us to obtain. From a single design, several frequencies can be achieved. Results from the $|S11|$ simulation and measurement are compared in Table 4-4.



00000 (Q9) 00100 (Q3) 10010 (Q14) 01111 Q(22)

Figure 4-5 the fabricated proposed antenna at different switching conditions.

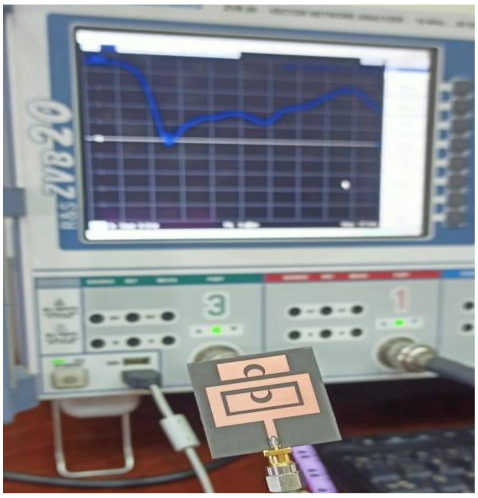


Figure 4-6 The $|S_{11}|$ parameter was measured using the ROHDE & SCHWARZ ZVB vector network analyzer

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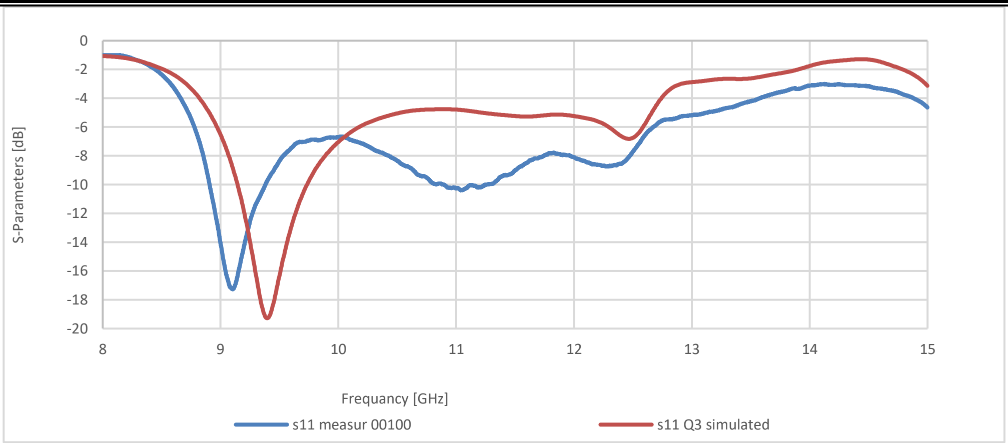
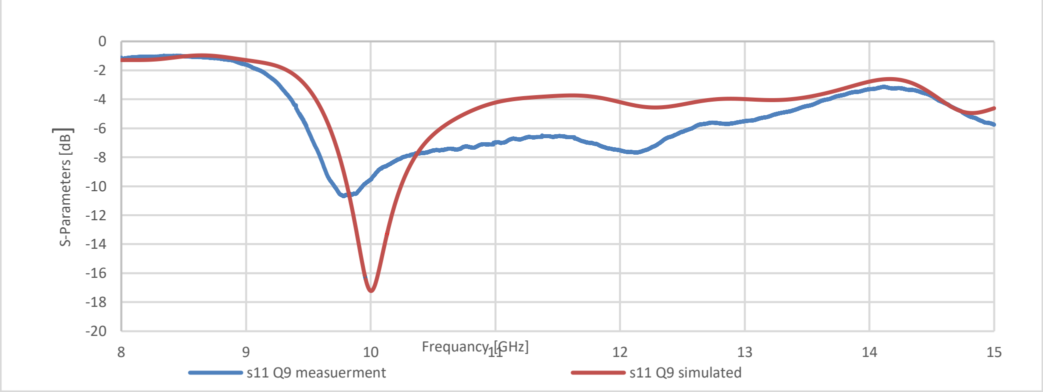
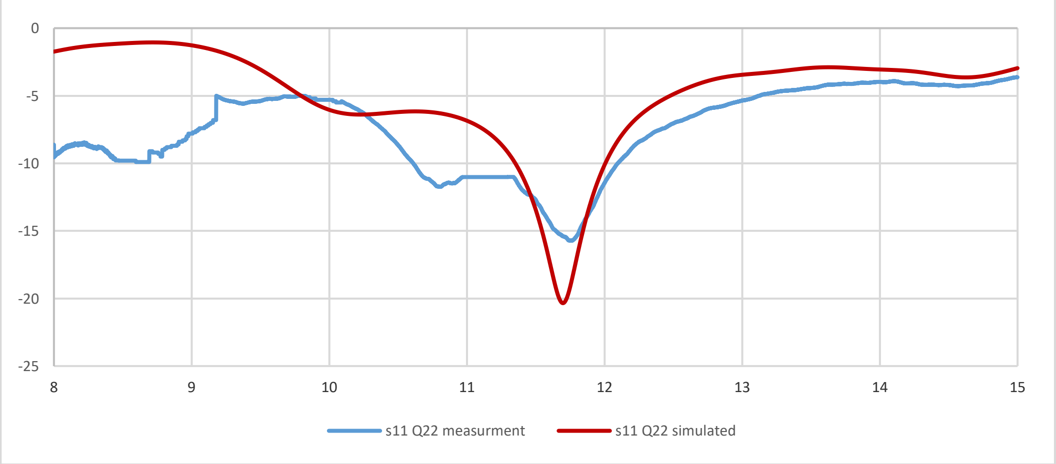

S-Parameters [dB]
Frequancy [GHz]
s11 measur 00100
s11 Q3 simulated


S-Parameters [dB]
Frequancy [GHz]
s11 Q9 measuerment
s11 Q9 simulated


s11 Q22 measurment
s11 Q22 simulated

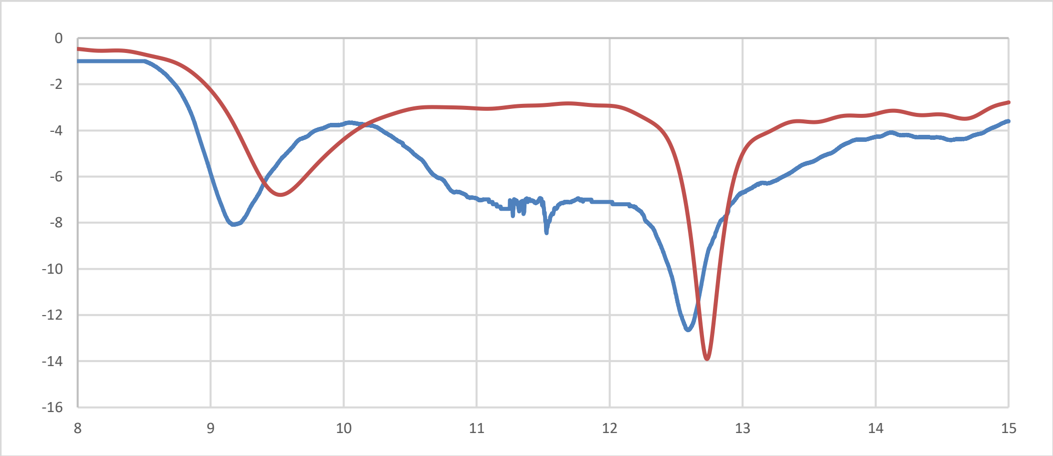
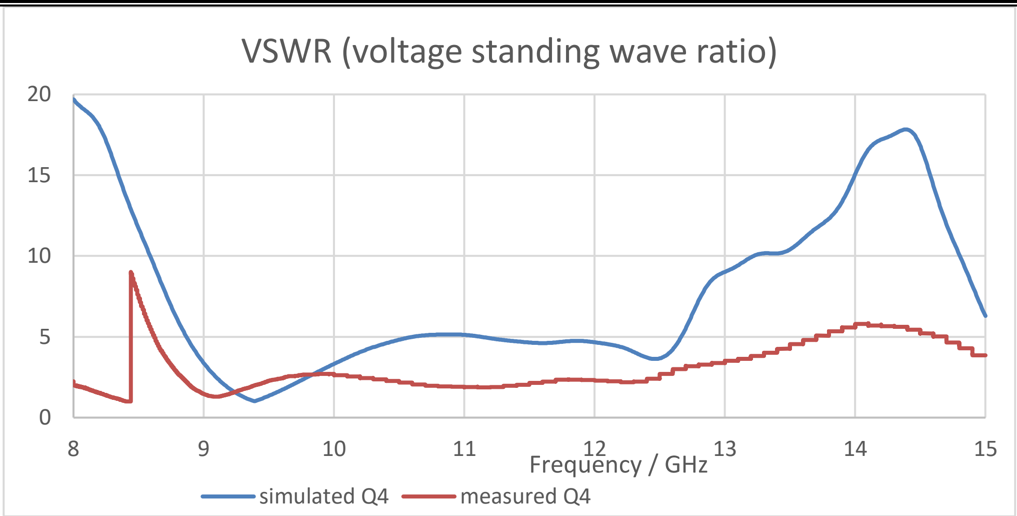


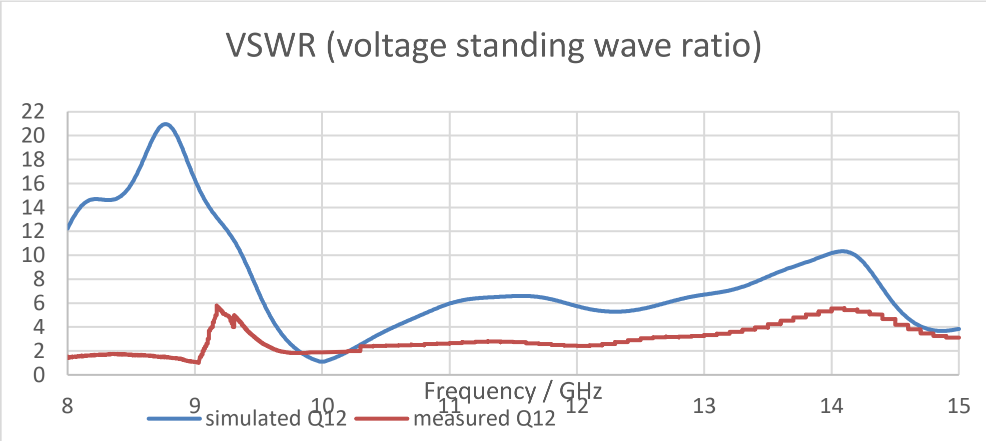
Figure 4-7 the results of return loss simulation and measurement using the $|S_{11}|$ model

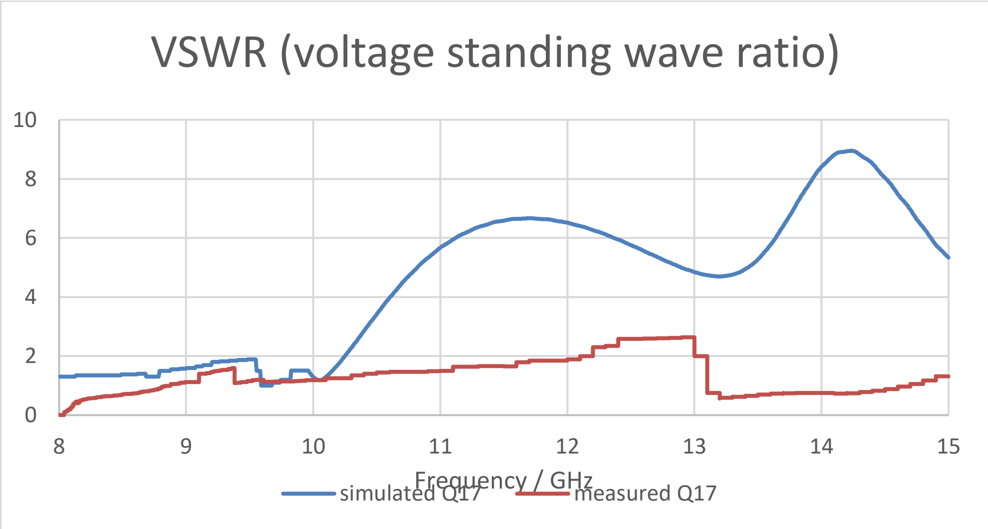
Table 4-4 Comparison of measured and CST simulated $|S_{11}|$ results

S11	**simulated**	**Measured**
S11 Q(3)	-19.29	-17.41
S11 Q(9)	-17.22	-10.6
S11 Q(22)	-20.33	-15.38
S11 Q(28)	-13.90	-11.99

Figure 4-7 shows the results of return loss simulation and measurement using the $|S_{11}|$ model. A Furthermore, $|S_{11}|$ measurements are close to $|S_{11}|$ simulated ,with $|S_{11}|$ being less than -10dB, Table 4-4 displays a comparison of measured and CST simulated |S11| results


VSWR (voltage standing wave ratio)
20
15
10
5
0
8
9
10
11
12
13
14
15
Frequency / GHz
simulated Q4
measured Q4


VSWR (voltage standing wave ratio)
22
20
18
16
14
12
10
8
6
4
2
0
8
9
10
11
12
13
14
15
Frequency / GHz
simulated Q12
measured Q12


VSWR (voltage standing wave ratio)
10
8
6
4
2
0
8
9
10
11
12
13
14
15
Frequency / GHz
simulated Q17
measured Q17

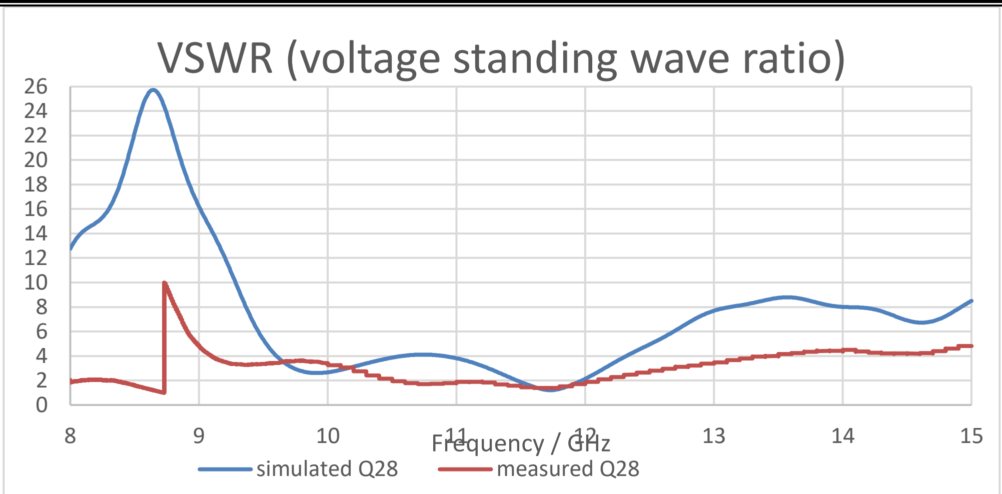
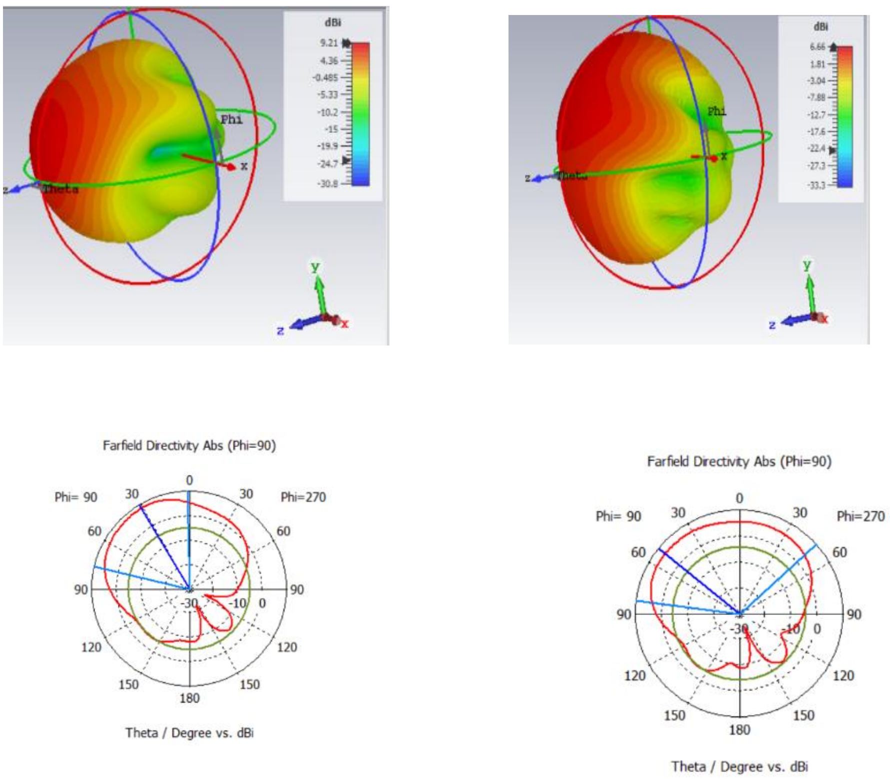


Figure 4-8 the results of VSWR (Voltage Standing Wave Ratio) simulation and measurement

Table 4-5 Comparison of measured and CST simulated VSWR results

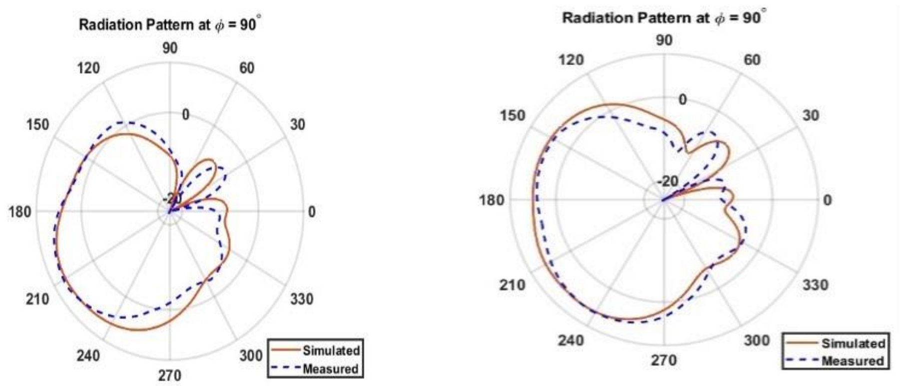
VSWR	Simulated	measurements
VSWR Q(4)	1.02	1.31
VSWR Q(12)	1.06	1.83
VSWR Q(17)	1.18	1.19
VSWR Q(28)	1.2	1.39

Changing the switches and multiplicity frequency improves the overall VSWR because the feedline to microstrip transfer is more smooth, shown in Figure 4-8 the results of VSWR (Voltage Standing Wave Ratio) simulation and measurement. Additionally, VSWR data are close to the simulated value of VSWR which VSWR < 2, showing Comparison of VSWR results simulated in CST and measured.



(a) **(b)**

Figure 4-9 simulated in CST the radiation pattern (a) Q12, (b) Q29



(a) **(b)**

Figure 4-10 measured the radiation pattern (a) Q12, (b) Q29

explains the radiation patterns of the antenna each pattern is normal to the top value of the corresponding plane, which is normalized to the value at 10 GHz and has a high gain of 8.65dbi, for the purpose of comparison,

Figure 4-10 depicts radiation patterns of the presented antenna indicating the comparison between simulated and measured radiation patterns (normalized (a) Q9, (b) Q28).

4.4 summery

To solve the gain issue with the traditional wide slot. This chapter introduces a small antenna using a square microstrip antenna for Ultra-Wide Band (UWB) communication applications. The suggested antenna operates over a wide frequency range of 9.30 to 13 GHz. Using CST Microwave Studio programmer, the antenna is created. The suggested antenna is made of a copper ground and patch antenna with a relative permittivity (r) of 2.2 and a dielectric thickness of 1.575 mm on a Rogers RT5880 substrate. The redesigned antenna offers positive gain over the whole operating frequency range as compared to the traditional antenna, and the recently presented low voltage standing wave ratio (VSWR) antenna has the proper radiation properties to meet the needs of both present and future wireless communication systems. A good gain-bandwidth characteristic was achieved by the suggested UWB antenna, according to measurements and simulation results.

Chapter 5

Conclusions and recommendations for future work

5.1 Conclusions

The wireless communication industry faces significant challenges as a result of the rising demand for RF spectrum. A cutting-edge method of allocating spectrum is called cognitive radio. Unlicensed users are permitted to access the primary users' licenced spectrum for a set amount of time without interference or distortion. As a result, the primary responsibility of the CR receiver, which should constantly keep an eye on PU activity, is spectrum sensing.

This thesis introduces a thorough investigation of cognitive radio systems. Cognitive radio as a principle is defined, along with the need for such a standard.

In the first part of this research, design a microstrip patch antenna and look into how switching impacts antenna characteristics including return loss, gain, VSWR, and directivity. There are a total of 32 resonance frequencies. In this thesis, the numerous switching arrangements are discussed. The simulation was performed by CST (computer simulation technology), and the switches operate perfectly.

In the second part of this research, explains the proposed energy detector spectrum sensing method based on multiple antenna elements for cognitive radio systems. We derive expressions for test statistics, probability of detection, probability of false alarm, and their thresholds. In this study, we provide 32 different scenarios of measurements resulting from different switching configurations. CST Microwave Studio developed the simulation, which displays a new way for improving the effectiveness of spectrum sensing of spectrum sensing techniques in cognitive radio systems by using digital antenna arrays beamforming.

In the third part of this research, small antenna with a square microstrip antenna is introduced in this chapter for applications of UWB communication. The suggested antenna has a broad frequency range between 9.30 to 13. Using the CST Microwave Studio programmer, the antenna is created. The proposed antenna is made of a copper ground and patch antenna with a relative permittivity (εr) of 2.2 and a dielectric thickness of 1.575 mm on a Rogers RT5880 substrate, using tunable ultra-wideband (TUWB) frequency monitoring, the results without a switch Q9 in frequency 10 GHz, gain 8.40dbi, and BW 0.43 GHz, in addition, easy and cheap materials were employed. According to tests and observations, the proposed CR method is more effective and reliable.

5.2 Future work

The research described in this thesis raises a number of issues that will require discussion and resolution in further work. We offer the following areas for potential further research:

For theoretical study

1. Providing various array configurations, such as a circular array, rectangular array, or non-uniform linear array, to the cognitive radio receiver to help it function even better.
2. Researching how attackers' actions affect the effectiveness of spectrum sensing techniques and the overall CR systems.
3. When the cognitive radio is shadowed, an issue known as the concealed terminal problem occurs, is one of the most important problems with spectrum sensing. Cooperative cognitive radio can currently be used to resolve receiver uncertainty, shadowing, and multi-path fading issues.
4. Creating a cognitive radio system with multiple input, multiple output (MIMO).

For practical work

1. Introducing a new design for an ultra-wide band antenna based on a band pass filter with exceptional selectivity and tenability to cover the designated frequency ranges.
2. Using various microstrip antenna structures and researching how they affect the functionality of the cognitive radio system.
3. Increasing performance through the use of antenna arrays

4. Use different materials instead of Rogers RT5880 like Fr4 and study the difference between them and the best in terms of efficiency and cost
5. Use a variety of switch types, such as pin diodes, FET switches, and varactor diodes, RF MEMS.

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List of Publications

- **Published:**

1- R. Ahmed, M. A. Mohammed and A. A. Kabeel, "Characterization of tunable Ultra-Wideband Square Microstrip antenna with several gaps," 2022 International Telecommunications Conference (ITC-Egypt), 2022, pp. 1-6, doi: 10.1109/ITC-Egypt55520.2022.9855686.

2- R. Ahmed, M. A. Mohammed and A. A. Kabeel, " Evaluation of Energy Detection-Based Spectrum Sensing for Cognitive Radio Applications," Mansoura university journal,

الملخص بالعربي

" تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي"

نظرًا لغياب تعقيدات التطبيق والمعالجة ، فإن أحد خيارات نشر الهوائيات هو إعادة تكوين أجهزة الراديو المعرفية لاستخدام نفس الهوائي لكل من الاستشعار واستشعار الاتصال. كما أنها أكثر شيوعًا (مقارنة بالطرق الأخرى) لأن المستلمين لا يحتاجون إلى معرفة المعلومات المتعلقة بالمستخدمين الأساسيين. من خلال مقارنة خرج كاشف الطاقة بالعتبة التي يتم احتسابها على أرضية الضوضاء ، يتم تحديد الإشارة. توجد العديد من المشكلات المتعلقة بالحس ، والفشل في التمييز بين مستخدمي التداخل الأساسيين والضوضاء ، وضعف الأداء أثناء إعادة تقييم نسبة الإشارة إلى الضوضاء (SNR)عند تحديد عتبة الكشف عن المستخدمين الأساسيين لكاشف الطاقة. الهدف من تصميم هذه الأطروحة لنظام الراديو المعرفي (CR)على أساس نطاق Ultrawide قابل للضبط. تم اقتراح الهوائي في هذه الأطروحة ، الراديو المعرفي هو مستشعر الطيف القائم على كاشف الطاقة بالكامل بواسطة النطاق العريض للغاية (UWB). يعزز الراديو المعرفي (CR)مرونة الخدمات الشخصية باستخدام استشعار الطيف ويمكنه تحسين إدارة الطيف وإدارة الطاقة بكفاءة. إنه يوفر حلاً سريعًا ومنخفض التكلفة لاكتشاف ثقوب الطيف بكفاءة التي تمتد على نطاق تردد من 9.30 إلى 13 جيجاهرتز. يتم فحص التردد باستخدام نطاق فائق الاتساع قابل للضبط. يعد استشعار الطيف أحد أهم المتطلبات التكنولوجية لتحقيق الأنظمة الراديوية الإدراكية ، حيث يتم تقديم هوائي microstrip patch لتطبيقات النطاق العريض للغاية. يحتوي الهوائي على حجم صغير مع تأريض جزئي 30 مم × 30 مم ، ويستخدم 5 جابس 2 مم × 3 مم كمفتاح. يمكن أن توفر المفاتيح إمكانية الضبط وتستخدم لمراقبة وجود المستخدم الأساسي (PU). تم تصنيع الهوائي المقترح على ركيزة روجرز RT5880 ، بسمك عازل 1.575 مم وسماحية نسبية 2.2. (εr) هوائي أرضي وترقيع مصنوع من النحاس ، وهناك مزايا مختلفة لهذا النوع من الهوائي ، مثل الهوائي الصغير الحجم ، وغير المكلف من حيث التكلفة ، والبسيط في البناء ، وسهل التصنيع ، والمرن من حيث إمكانية الوصول إلى النطاق. يحتوي هوائي VSWR المنخفض المقدم على خصائص إشعاع مناسبة لتلبية ضرورة أنظمة الاتصالات اللاسلكية الحالية والمستقبلية ، في النهاية يتم عرض كل من المحاكاة والقياسات.

تم اقتراح تصميم جديد لنظام الراديو المعرفي (CR) على أساس هوائي واسع النطاق قابل للضبط في هذا البحث ، والذي يوفر حلاً سريعًا ومنخفض التكلفة للكشف الفعال عن ثقوب الطيف في نطاق التردد من 9.30 إلى 13 جيجا هرتز. يتم استخدام مراقبة تردد النطاق العريض القابل للضبط (TUWB) ، وتم تصميم الهوائي لمسح نطاق الطيف من 9.30 إلى 13 جيجاهرتز ، ومكاسب عالية وكفاءات إشعاعية بأعلى مقادير تبلغ 8.65 ديسيبل و 80٪ عند 10 جيجاهرتز ، كما أن الهوائي ممتاز خصائص الإشعاع و VSWR المنخفض <2. يتم تغذية رقعة ذات مستوى أرضي جزئي عبر خط 50 ميكروستريب في الهوائي المقترح. علاوة على ذلك ، تم استخدام مواد بسيطة وغير مكلفة. نظام CR المقترح أكثر كفاءة ودقة ، وفقًا للنتائج المحاكاة والمقاسة في توافق جيد.

تتضمن هذه الرسالة خمسة فصول كالتالي:

الفصل الأول

يقدم ملخصًا ، وأهدافًا ، وتحديات محتملة ، ودافعًا لتلبية هذه المتطلبات ، وموجزًا للرسالة.

الفصل الثاني

خلفية عن تكنولوجيا الراديو الإدراكي و طرق استشعار الطيف. على أساس اختيار كاشف للطاقة و تأثير الفجوات

الفصل الثالث

تقنيات كاشف الطاقة: يشرح تقنية استشعار طيف كاشف الطاقة المقترحة لأنظمة الراديو الإدراكية بناءً على عناصر الهوائي المتعددة. نشتق تعبيرات لإحصاءات الاختبار ، واحتمالية الكشف ، واحتمال الإنذار الخاطئ ، وحدودها. في هذه الدراسة ، نقدم 32 سيناريو قياس مختلفًا ناتجًا عن تكوينات تبديل مختلفة. طور CST Microwave Studio المحاكاة ، والتي تعرض طريقة جديدة لتحسين أداء تقنيات استشعار الطيف في أنظمة الراديو الإدراكية باستخدام تشكيل حزم الهوائيات الرقمية و تحسين الاداء عن طريق مصفوفه الهوأئي باستخدام برنامج المحاكاه MATLAB.

الفصل الرابع

تصميم هوائي عريض النطاق غير قادر على نظام الراديو المعرفي: هذا الفصل يصف هوائي النطاق العريض القابل للضبط المقترح ((TUWBللتطبيقات الراديوية الإدراكية ، بما في ذلك تصميمه وبنائه وقياسه.

الفصل الخامس

خاتمة وتوصيات للعمل المستقبلي: يحتوي هذا الفصل على عرض لملخص ما تم التوصول اليه في الرسالة من نتائج وما تم تحقيقه من خلال البحث وأقتراح بعض النقاط للبحث المستقبلي.

و تنتهي الرسالة بقائمة من الأبحاث المرجعية.

جامعة المنصورة
كلية الهندسة
قسم هندسة الإلكترونيات والاتصالات

صفحة السادة المشرفين

عنوان الرسالة: تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي

اسم الباحثة: رانيا احمد يوسف

الدرجة العلمية: ماجستير العلوم في هندسة الإلكترونيات والاتصالات

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مجلس رئيس القسم	وكيل الكلية لشئون الدراسات العليا والبحوث	عميد الكلية
أ. د. شريف السيد كشك	أ. د. شريف مسعود البدوي	أ. د. محمد عبد العظيم محمد

جامعة المنصورة
كلية الهندسة
قسم هندسة الإلكترونيات والاتصالات

صفحة السادة اعضاء لجنة الحكم والمناقشة

عنوان الرسالة: تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي

اسم الباحثة: رانيا احمد يوسف

الدرجة العلمية: ماجستير العلوم في هندسة الإلكترونيات والاتصالات

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رئيس القسم	وكيل الكلية للدراسات العليا والبحوث	عميد الكلية
أ.د شريف السيد كشك	أ.د.شريف مسعود البدوي	أ.د.محمد عبدالعظيم محمد

جامعة المنصورة

كلية الهندسة

قسم هندسة الإلكترونيات والإتصالات

إقرار

تقر الباحثة / رانيا احمد يوسف

المسجلة لدرجة/ ماجستير العلوم في هندسة الالكترونيات والاتصالات

بالالتزام بقوانين جامعة المنصورة وأنظمتها وتعليماتها وقرارتها المتعلقة بإعداد رسالة الماجستير عندما قمت بإعداد الرسالة العلمية تحت عنوان:

" تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي "

"Performance enhancement of spectrum sensing system using antenna arrays for a cognitive radio application"

كجزء من متطلبات البحث للحصول على درجة ماجستير العلوم في هندسة الالكترونيات والاتصالات تحت إشراف:

- **أ.د.محمد عبد العظيم محمد**– (أستاذ بقسم هندسة الإلكترونيات والاتصالات – كلية الهندسة – جامعة المنصورة).
- **د. احمد عبد النبي قابيل**- (مدرس بقسم هندسة الإلكترونيات والاتصالات – المعهد العالي للهندسة و التكنولوجيا بدمياط الجديدة).

والإقرار بحداثة موضوع الدراسة البحثية و أنه لم يسبق تناول الموضوع و العنوان البحثي بصورته النهائية الكاملة أو نشره سابقاُ في أي رسائل أو أطاريح أو كتب أو أبحاث علمية و ذلك بما يتفق مع الأمانة العلمية المتعارف عليها في كتابة الرسائل أو الأطاريح العلمية. وقد تم قبول بحث النشر وهو بعنوان:

Evaluation of Energy Detection-Based Spectrum Sensing for Cognitive Radio Applications

في مجلة متخصصة في مجال الهندسة وهي :

IEEE Xplore , MEJ. Mansoura Engineering Journal

1. R. Ahmed, M. A. Mohammed and A. A. Kabeel, "Characterization of tunable Ultra-Wideband Square Microstrip antenna with several gaps," 2022 International Telecommunications Conference (ITC-Egypt), 2022, pp. 1-6, doi: 10.1109/ITC-Egypt55520.2022.9855686.
2. R. Ahmed, M. A. Mohammed and A. A. Kabeel, " Evaluation of Energy Detection-Based Spectrum Sensing for Cognitive Radio Applications," Mansoura university journal,

وان البحث المنشور مستخرج من الرسالة المذكورة بعالية و ان أسماء السادة المشرفين موجودة على البحث.

وهذا إقرار منى بذلك,,,,,

المقر

رانيا احمد يوسف

المشرف الرئيسي

أ.د محمد عبد العظيم محمد

الإدارة العامة للمكتبات

ملخص الرسالة (   ) بالمكتبة

الكلية	الهندسة	القسم	هندسة الإلكترونيات والاتصالات	رقم:	
الاسم	رانيا احمد يوسف	الدرجة العلمية	ماجستير العلوم في هندسة الإلكترونيات والاتصالات	التاريخ:	
عنوان الرسالة	تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي				

الملخص العربي للرسالة

نظرًا لغياب تعقيدات التطبيق والمعالجة ، فإن أحد خيارات نشر الهوائيات هو إعادة تكوين أجهزة الراديو المعرفية لاستخدام نفس الهوائي لكل من الاستشعار واستشعار الاتصال. كما أنها أكثر شيوعًا (مقارنة بالطرق الأخرى) لأن المستلمين لا يحتاجون إلى معرفة المعلومات المتعلقة بالمستخدمين الأساسيين. من خلال مقارنة خرج كاشف الطاقة بالعتبة التي يتم احتسابها على أرضية الضوضاء ، يتم تحديد الإشارة. توجد العديد من المشكلات المتعلقة بالحس ، والفشل في التمييز بين مستخدمي التداخل الأساسيين والضوضاء ، وضعف الأداء أثناء إعادة تقييم نسبة الإشارة إلى الضوضاء (SNR)عند تحديد عتبة الكشف عن المستخدمين الأساسيين لكاشف الطاقة. الهدف من تصميم هذه الأطروحة لنظام الراديو المعرفي (CR)على أساس نطاق Ultrawide قابل للضبط. تم اقتراح الهوائي في هذه الأطروحة ، الراديو المعرفي هو مستشعر الطيف القائم على كاشف الطاقة بالكامل بواسطة النطاق العريض للغاية (UWB). يعزز الراديو المعرفي (CR)مرونة الخدمات الشخصية باستخدام استشعار الطيف ويمكنه تحسين إدارة الطيف وإدارة الطاقة بكفاءة. إنه يوفر حلاً سريعًا ومنخفض التكلفة لاكتشاف ثقوب الطيف بكفاءة التي تمتد على نطاق تردد من 9.30 إلى 13 جيجاهرتز. يتم فحص التردد باستخدام نطاق فائق الاتساع قابل للضبط. يعد استشعار الطيف أحد أهم المتطلبات التكنولوجية لتحقيق الأنظمة الراديوية الإدراكية ، حيث يتم تقديم هوائي microstrip patch لتطبيقات النطاق العريض للغاية. يحتوي الهوائي على حجم صغير مع تأريض جزئي 30 مم × 30 مم ، ويستخدم 5 جابس 2 مم × 3 مم كمفتاح. يمكن أن توفر المفاتيح إمكانية الضبط وتستخدم لمراقبة وجود المستخدم الأساسي (PU). تم تصنيع الهوائي المقترح على ركيزة روجرز RT5880 ، بسمك عازل 1.575 مم وسماحية نسبية 2.2. (εr)هوائي أرضي وترقيع مصنوع من النحاس ، وهناك مزايا مختلفة لهذا النوع من الهوائي ، مثل الهوائي الصغير الحجم ، وغير المكلف من حيث التكلفة ، والبسيط في البناء ، وسهل التصنيع ، والمرن من حيث إمكانية الوصول إلى النطاق. يحتوي هوائي VSWR المنخفض المقدم على خصائص إشعاع مناسبة لتلبية ضرورة أنظمة الاتصالات اللاسلكية الحالية والمستقبلية ، في النهاية يتم عرض كل من المحاكاة والقياسات تم اقتراح تصميم جديد لنظام الراديو المعرفي (CR) على أساس هوائي واسع النطاق قابل للضبط في هذا البحث ، والذي يوفر حلاً سريعًا ومنخفض التكلفة للكشف الفعال عن ثقوب الطيف في نطاق التردد من 9.30 إلى 13 جيجا هرتز. يتم استخدام مراقبة تردد النطاق العريض القابل للضبط (TUWB) ، وتم تصميم الهوائي لمسح نطاق الطيف من 9.30 إلى 13 جيجاهرتز ، ومكاسب عالية وكفاءات إشعاعية بأعلى مقادير تبلغ 8.65 ديسيبل و 80٪ عند 10 جيجاهرتز ، كما أن الهوائي ممتاز خصائص الإشعاع و VSWR المنخفض <2. يتم تغذية رقعة ذات مستوى أرضي جزئي عبر خط 50 ميكروستريب في الهوائي المقترح. علاوة على ذلك ، تم استخدام مواد بسيطة وغير مكلفة. نظام CR المقترح أكثر كفاءة ودقة ، وفقًا للنتائج المحاكاة والمقاسة في توافق جيد.

الكلمات المفتاحية هوائي microstrip ، كاشف الطاقة ، هوائي مضبوط ، راديو معرفي ، استشعار الطيف

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تحسين أداء نظام استشعار الطيف باستخدام مصفوفات الهوائيات لتطبيقات الراديو الإدراكي

مقدمة من

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بكالوريوس هندسة الإلكترونيات والاتصالات

رسالة مقدمة كجزء من متطلبات الحصول على درجة درجة ماجستير العلوم في الهندسة الإلكترونية والاتصالات

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