INTEROPERABILITY AND DIRECT MODE BETWEEN TETRA AND EDACS

By

Naveed Zafar

A thesis submitted to faculty of Electrical Engineering Department Military College of Signals, National University of Sciences and Technology, Rawalpindi in partial fulfillment of the requirements for the degree of MS in Electrical Engineering

APRIL 2012

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ABSTRACT

The project investigates the mechanisms of interoperability and direct mode operation between two systems TETRA and EDACS. The basic aim of interoperability is to allow users from different agencies or areas, to use any base system of the network to communicate. This will allow agencies of the federal state / provincial government or private sector such as law enforcement, ambulance services and crisis management agencies to communicate more effectively with each other when required. Interoperability provides an smart solution at low or no signal strength of the parent base system. The interoperability between these two systems is a step towards developing a platform where all 6 systems of Project 25, TETRA, TETRAPOL, EDACS, DIMRS, FHMA, IDRA will be made interoperable. The inspiration for direct mode is that a subscriber may go in some region where he may not be in contact with any base system. For such an instance, direct access system would be developed, by which a mobile subscriber can talk to any other mobile subscriber in range, without use of base station.

The motivation of this research was more pronounced after "2004 Indian Ocean earthquake and Tsunami" which distraught the communication infrastructures in their respective areas. In order to carryout multination disaster operations, it is important to introduce a system that is able to use all available means of communications, including swiftly deployable networks, to handle with large scale disasters and to apply precautionary measure. In this research, interoperability between two wireless communication systems TETRA (TErrestrial Trunked RAdio) and EDACS (**Enhanced Digital Access Communications System**) has been developed on basis of modulation identification. Both EDACS and TETRA are digital radio systems, working on GFSK and Pi/4 PSK as their parent modulation schemes. The individuality of these modulation schemes has been used for system identification through "Linear Predictive Coding".

The focus of this thesis is to implement interoperability between the said public safety communication standards on basis of modulation identification.

DECLARATION

No portion of the work presented in this dissertation has been submitted in support of another award or qualification either at this institution or elsewhere.

DEDICATION

In the name of Allah, the Most Merciful, the Most Beneficent

All efforts are dedicated to my family and teachers who have been a constant source of encouragement for me throughout the Thesis. May Allah bless them with prosperous and happy lives and always provide me their loving and thorough guidance.

ACKNOWLEDGEMENTS

All praises to the Almighty Allah, who enlightened me with the requisite knowledge to accomplish the Thesis goals that I set for myself prior to the start of the thesis, and on a broader level towards completion of my degree.

I would thank my Thesis supervisor Dr. Adnan Khan, Thesis Co Advisor Imtiaz Ahmed Khokhar and all my guidance and evaluation committee for their constant guidance, support and help whenever I needed it. I would also thank all those who helped me to accomplish the goals of my thesis in whatever capacity they were.

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INTRODUCTION

1.1 Introduction to the Project

The project investigates the mechanisms of interoperability and direct mode operation between two systems TETRA and EDACS. The basic aim of interoperability is to allow users from different areas, to use any base system of the network to communicate. This will allow agencies of the federal / provincial government and private sector such as "law enforcement, ambulance services and crisis management agencies" to communicate more effectively with each other when required. Interoperability provides an attractive solution at low or no signal strength of the parent base system. The interoperability between these two systems is a step towards developing a platform where all 6 systems of Project 25, TETRA, TETRAPOL, EDACS, DIMRS, FHMA, and IDRA will be made interoperable. The proposal for direct mode is that a subscriber may go in some region where he may not be in contact with any base system. For such an instance, direct access system would be developed, by which a mobile subscriber can talk to any other mobile subscriber in range, without use of base station.

Project 25 (P25) is a combined endeavour between the "public safety communications community and industry manufacturers" whose purpose is the publication of a suite of standards that allow the offering, procurement, and functioning of interoperable digital wireless communications products and systems that meets the operational needs of public wellbeing practitioners. Project 25 with members from local, state, and federal government departments have grouped together to assess advanced technologies for private land mobile radio systems. A User defined Committee guides the process, making all purposeful decisions. Project 25 was started in 1989. "Telecommunications Industry Association" (TIA) joined the group in 1991and a Memorandum of concurrence was signed to make use of the possessions of the TIA to fulfil the vital technical support requirements of the project.

Project 25 works on the digital communications standards, to be used by state, federal, and local public safety agencies. This will further facilitate the important government machinery to share the communication resources and critical operational intelligence with each other and quick reaction teams in state of emergencies [1] and [2]. Project 25 (P25) standards are being created with the mutual efforts of "Association of Public Safety Communications Officials International" (APCO), the "National Association of State Telecommunications Directors" (NASTD), the "National Communications System" (NCS), and the selected Federal Agencies. After formalisation these will be standardized under the "Telecommunications Industry Association" (TIA). It is very crucial today to develop a communication system that can use all available communications resources including speedily deployable networks, so that the big natural disaster and terrorist operations could be responded well and proper, saving precious lives. P-25 is a step forward in achieving all these requirements. TETRA, TETRAPOL, DIMRS, IDRA, EDACS, FHMA are the six systems that would be made interoperable by P25. The systems being considered by Project 25 are globally functioning in more than sixty countries, in six continents [3]. The Project 25 is supervised and controlled by an eleven-member guiding committee comprising of nine U.S. local governments, federal, and state functionaries and two co-directors. It is a user driven project that characterizes communication system architectures of digital radios making them able to serve the requirements of Government and Public Safety organizations [4]. The standards include digital LMR services for state/provincial, local and federal public safety groups and agencies. The compliant radios will be able to communicate in both analog and digital modes through interoperability [5].

Project 25 has four main objectives:-

"Ensure competition in system life cycle procurements through Open Systems Architecture".

"Allow efficient, effective, and reliable inter-agency and intra-agency communications".

"Offer improved functionality and capabilities with concentration on public safety needs

Improve radio spectrum efficiency”.

1.2 **Motivation**

The corporation of public safety communications organizations and industry manufacturers under the umbrella of Project 25 has initiated work on developing interoperability between communication resources of government, private sector law enforcement agencies, ambulance services and crisis management centers, in order to allow them to communicate more effectively with each other when out of their coverage area. Interoperability will provide an attractive alternate solution to communicate with the infrastructure of different communication system at low or no signal strength of the parent system.

The motivation of this research was more pronounced after 2004 “Indian Ocean earthquake and Tsunami” which shattered the communication infrastructures in their respective areas. In order to assist the international calamity relief operations, the department of ITU “Telecommunications for Disaster Relief (TDR)” has started work in establishing worldwide standards of interoperability which will overlay a most important role in availability of communication during natural calamities.

The idea of interoperability between two “Public Safety Communication standards”, TETRA and EDACS is a step towards the availability of communication on the day of need as a global cause.

1.3 **Problem Statement**

In order to carryout multination emergency operations, it is important to introduce a communication system that is able to use all available means of communications, including rapidly deployable networks, to cope with large scale disasters or/and to implement preventive measure. In this research, interoperability between two wireless communication systems “TETRA (TErrestrial Trunked RAdio) and EDACS (**Enhanced Digital Access Communications System**)” has been developed on basis of modulation identification. Both EDACS and TETRA are digital cellular trunked radio systems, working on GFSK and Pi/4 PSK as their parent modulation schemes. The individuality of these modulation schemes has been used for system identification through “Linear Predictive Coding”.

The focus of this thesis is to implement interoperability between the two said public safety communication standards on basis of modulation identification.

1.4 Thesis Organization

Chapter 1 introduces the research work, its motivation and defines the problem statement. **Chapter 2** give the brief concept of Project 25 and discusses the TETRA and EDACS wireless communication standards in detail alongwith basic concept of interoperability and simulator Lab View. **Chapter 3** illustrates the simulation of sub VIs used in Lab View 8.6. These includes sub VIs used for simulating TETRA and EDACS standards and different interoperability scenarios. **Chapter 4** illustrates the complete physical layer design of TETRA and EDACS transceivers and Interoperability scenarios in the forms of complete VIs. In **Chapter 5**, the results of individual simulated systems, interoperability solution through Modulation Identification and their implementation have been discussed in detail. **Chapter 6** concludes the work and defines the future work.

2.1 Project 25

Project 25 (P25) is a combined endeavour between the "public safety communications community and industry manufacturers" whose purpose is the publication of a suite of standards that allow the offering, procurement, and functioning of interoperable digital wireless communications products and systems that meets the operational needs of public wellbeing practitioners. Project 25 with members from local, state, and federal government departments have grouped together to assess advanced technologies for private land mobile radio systems. A User defined Committee guides the process, making all purposeful decisions. Project 25 was started in 1989. "Telecommunications Industry Association" (TIA) joined the group in 1991and a Memorandum of concurrence was signed to make use of the possessions of the TIA to fulfil the vital technical support requirements of the project.

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2.1.1 Objectives

Project 25 has four main objectives:-

“Ensure competition in system life cycle procurements through Open Systems Architecture”.

“Allow efficient, effective, and reliable inter-agency and intra-agency communications”.

“Offer improved functionality and capabilities with concentration on public safety needs

Improve radio spectrum efficiency”.

2.1.2 Types of systems

It defines two types of system configurations, trunked and the usual non trunked. All P 25 obedient radios will have the “conventional non trunked and the trunked” system configuration modes [2].

2.1.2.1 Trunked

Trunked system configuration normally provides administration of all operating features of a radio system, including channel access and routing. Mostly all features are under automatic control. Thus a trunked system is defined by a controller, which manages the channel assignment to each call [2].

2. 1.2.2Non-trunked (Conventional)

Conventional (Non-trunked) system configuration will have no centralized administration / management of user operations. The user controls all kinds of radio operations manually. The operational modes within non trunked conventional system configuration, contains direct (radio-to-radio) and repeated (through an RF repeater) operation [2].

2.1.3 Radio aspects of P25

The radio interfaces are available in two frequency bands i.e. VHF (136–174 MHz) and UHF (403 – 512 MHz, 806 – 870 MHz). Phase 1 technology of P25 has also been accepted by the "Federal Communication Commission" as the interoperability frequency range which is (746 – 806 MHz) [5].

2.1.4 P25 PHASES

P 25 has three phases in which it will be evolved. The radio systems of Phase 1, functions in 12.5 KHz analog, digital or mixed channel modes. Phase 1 radios use "Continuous 4 level FM (C4FM) non-linear modulation" for digital transmissions. The compliant radio systems have the rearward compatibility and interoperability with traditional radio systems, regardless of system infrastructure. It also provides an open RF interface to the Sub-Systems to aid interlinking of different vendors' systems.

Phase 2 radios will have one voice channel or a minimum of 4800 bps data link per 6.25 kHz bandwidth. The P25 Phase 2 FDMA solution is formulated (CQPSK) and an alternate TDMA solution is presently under progress. Implementation of Phase 2 will achieve the most important goal of better spectrum utilization. It will also have features like interoperability with old traditional equipment, interfacing between repeaters and other sub-systems, better spectrum efficiency and channel reuse.

Implementation of Phase 3 will allow public-safety users to have high-speed data exchange. Phase 3 will take on the operation and functionality of a new "aeronautical and terrestrial wireless digital wideband / broad band public safety radio standard" that could be used for the transmission and reception of voice, video and high-speed data in wide area, multiple-agency networks. The "European Telecommunications Standards Institute"

(ETSI) and TIA are working jointly on Phase 3, known as "Project MESA (Mobility for Emergency and Safety Applications)".

2.1.5 P25 Radio System Architecture

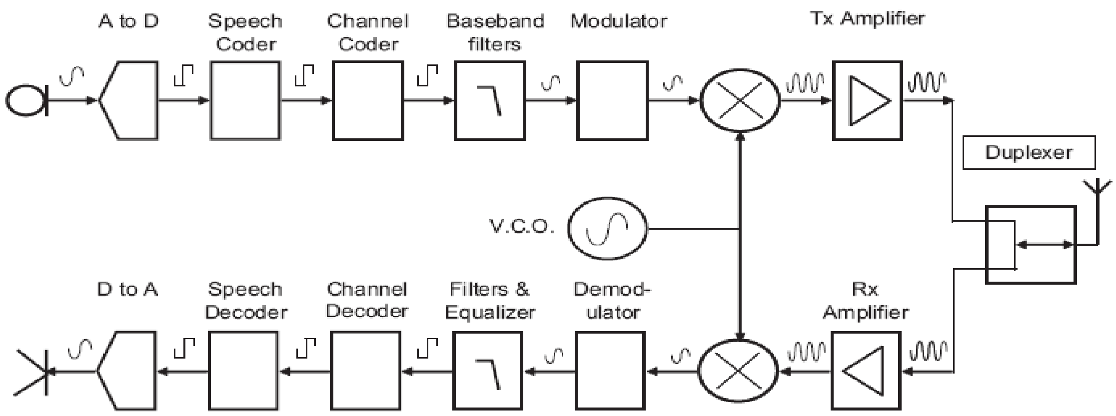


Figure 2-1 System Architecture

The P25 standard after the analog to digital conversion, uses a advanced and up to date technique of digitized voice (i.e. speech coding) known as "Improved Multi-Band Excitation (IMBE)". The "Improved Multi-Band Excitation" voice encoder / decoder (i.e. vocoder). It takes the audio samples, extracts certain characteristics and then sends only the extracted features instead of the speech signal to represent the speech.

At the receiver end, the sent features are used to develop the synthetic equivalent of the input signal. The "Improved Multi-Band Excitation" is generally designed and optimized for human speech whereas sounds other than human speech are very difficult to recreate on the receiver end. It also gives good results in creating and recreating "dual-tone multi-frequency" (i.e. DTMF) tones. Input from microphone is sampled in a way that it produces 88 bits of encoded speech in every 20 milliseconds then the vocoder creates speech characteristics at a rate of 4400 b/s.

Channel Coding is a technique in which the digital communication systems use error detection / correction and data protection schemes to make sure that the data may it be voice or control signals are correctly received and recovered. Channel codes are planned and used to add redundancy so it could be used for error detection and correction at the receiver end, thus improving the performance of equipment. Interleaving is also used to cater for deep channel fades

12.5 KHz frequency channel is used in Phase 1 to transmit C4FM modulated digital information. In Phase 2, digital information will be transmitted over a 6.25 KHz bandwidth channel by using the modulation format of CQPSK. The CQPSK modulates the phase (i.e. frequency) as well as the amplitude of carrier to decrease the pulse width thus producing an amplitude modulated waveform.

2.1.6 P25 System Working

The radios of P25 works just like the old time conventional analog frequency modulated radios. This capability makes them rearward compatible with the traditional analog radio systems. When these radios are made to function in digital mode, the incoming bits are arranged in two bits thus requiring 4 different combinations for their transmission. In modified 4 levels FSK this is achieved through offsetting the frequency carrier in 4 levels.

In digital mode, the P25 compliant transmitters will change all analog audio to packets of digital information by using an IMBE™ vocoder, and then converts the information back to analog audio speech in the receiver. Error detection / correction i.e. channel coding is inserted to the digital voice information as well as other digital information. Analog "CTCSS and DCS" are replaced by digital "NAC codes" (as well as TGID, Source and Destination codes for selective calling). Encryption is added to protect the voice speech, and other digital information before transmission.

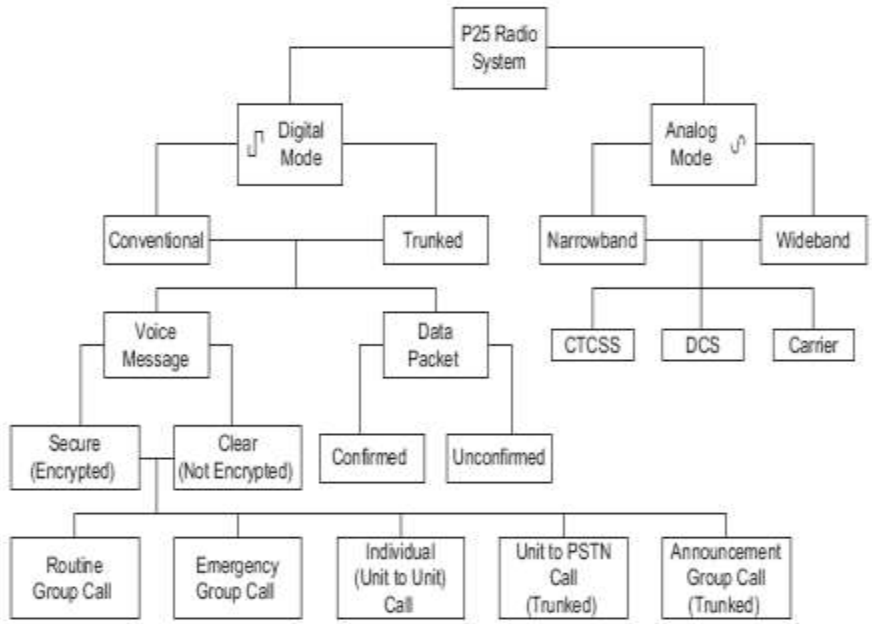


Figure 2-2 Modes of operation

Figure 2-2 shows the different working modes of P25 compliant Radio Systems in digital and analog modes. The systems use the "Common Air Interface (CAI)". This interface standardises and defines the type and content of signals transmitted on P25 defined radios. A P25 radio using the CAI would be able to talk to any other P25 radio irrespective of the manufacturing firms.

Secure transmissions will be activated through enabling digital encryption. The algorithms specified for use by P 25 complaint radios are "Advanced Encryption Standard" (AES) algorithm, "Data Encryption Standard" (DES-OFB) algorithm, and other encryption algorithms. There are added standards and conditions for over-the-air rekeying features. This feature allows users to manage encryption keys through a radio network.

2.1.7 P25 services

Routine Group Call is a broadcast that is intended for a collection of subscribers in a radio system. In a typical manner, it is a call type that is most conventional. This is established when the push-to-talk switch is asserted.

Emergency group call is similar to a Routine Group Call, but this call is only used in a emergency condition. An emergency condition is described by the users of radio system. By simply pushing the Emergency switch the call gets initiates.

Emergency switch: when the radio user presses the emergency switch, the action sets the emergency condition up to the time till it is released by some other action, i.e. by turning off the radio.

Group calls: The activation of the push-to-talk switch now starts calls that are much like the described above routine group call. The only dissimilarity in the procedure is that to show an emergency condition, the emergency bit is set. Group calls can be created repetitively, and every group call will show the emergency condition.

Emergency termination: By turning off the radio the emergency condition is cleared. When the radio is turned on again, routine group calls gets initiated after push-to-talk switch is asserted and the emergency condition is cleared.

Individual call is a transmission which is meant for a particular single radio. The address of the distant individual radio is known as the destination address. These calls are generally established after destination address go into the radio. The unit ID of the single radio to be called can come into the radio through a keypad or by some other way like a attached key board. This turns out to be the call's destination ID. The method for group calls is going to be followed, with the small difference.

2.1.8 Benefits of P25

P25 has an array of advantages in quality, efficiency, capabilities and performance. The main benefits of P25 are discussed in following paras.

2.1.8.1 Interoperability

Radio equipment which is compatible with P25 standards will let the users from different agencies or areas to communicate directly with each other. This will allow people from agencies on the federal state / provincial or local level (or any other agency) to communicate more freely and purposefully with each other when required (emergencies, law enforcement, etc.)

2.1.8.2 Multiple Vendors

The P25 open standard will allow competing products from multiple vendors to be interoperable. This will allow customers of the P25 product to benefit from multiple manufacturing sources (decreased costs, open bidding, non-proprietary systems).

2.1.8.3 Backwards Compatibility

A basic requirement for Phase 1 P25 digital radio equipment is the rearward compatibility with standard analog Frequency Modulated radios. This will support an organized shifting into mixed analog and digital systems, enabling users to steadily trade out radios and infrastructure equipment. By selecting products and systems that fulfil the P25 standards, agencies are guaranteed that their investment in the latest technology has a clear migration path for the future.

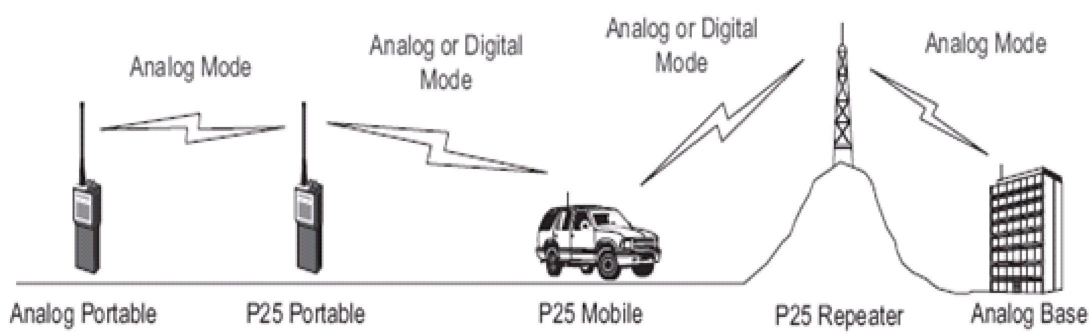


Figure 2-3 P25 Backwards Compatibility

P25 radios will keep operating in analog mode to older analog only radios, and either analog or digital mode to other P25 radios. Phase 2 P25 radio systems will have an Phase 1 conventional mode for backwards compatibility with Phase 1 P25 equipment.

2.1.8.4 Encryption Capability

The P25 standard includes a requirement for shielding digital communications (voice and data) with encryption capability. The encryption used in P25 is elective, allowing the user to select either clear (un-encrypted) or secure (encrypted) digital communication methods. The encryption keys can also be re-keyed by digital data over a radio network. This is referred to as "Over the Air Re-keying" (OTAR). This capability permits the radio systems administrators to remotely change encryption keys.

2.1.8.5 Spectrum Efficiency

P25 increases spectrum effectiveness by reduction in bandwidth. The RF spectrum is an insufficient resource used by all countries in the world. The Spectrum efficiency frees up additional channels for the use of radio.

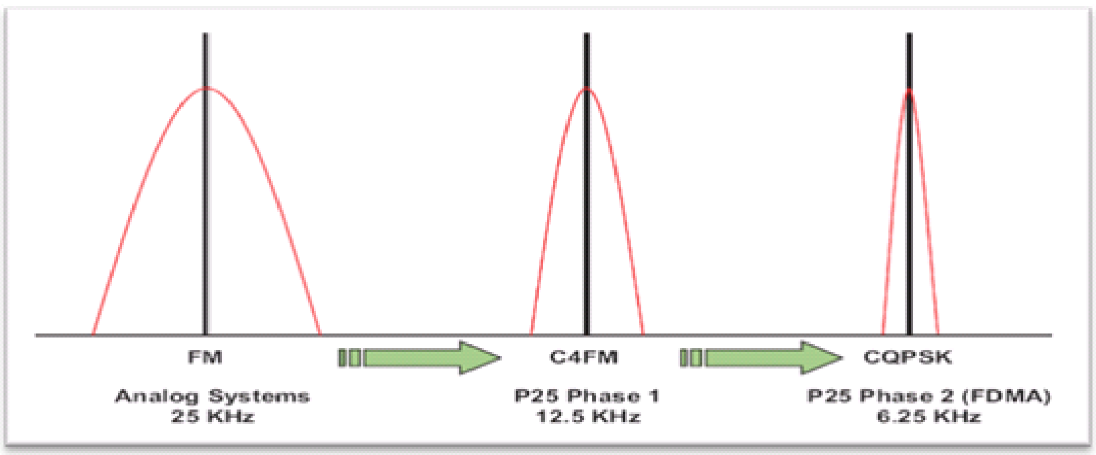


Figure 2-4 P25 Spectrum Efficiency

2.1.8.6 Improved Audio Quality

With 2800 bits per second of the total 9600 bits per second channel capacity allocated to error detection / correction, P25 digital signals have enhanced voice quality over standard analog signals, especially at low or noisy RF carrier levels. The "IMBE™ voice coder" changes voice information into digital data and then the data is protected using error detection / correction codes. The error correction is able to correct for small errors in the received signal. As the audio is digitally encoded thus the background noise present in analog systems is also removed.

2.2 TETRA SYSTEM

Public security services (PSS) users in the majority of European countries use over-aged analogue radio communication systems. These systems normally have local coverage and transfer of critical information between different districts and the communication between different user organizations is very difficult.

The cross border group communication is not supported by these independent radio systems. This is considered as a major handicap, for example, highway patrol's has to register every time while moving over a district border. This procedure is time taking and the delay may be significant in emergency situations when police forces need to rely on proper communication means. Other limitations to the operation are "absence of authentication" of the radio terminals and "air interface encryption", calls between different agencies is barely possible, calls are limited to a small geological area and low data transmission rates.

The vital situation has been realized and in most countries basic decisions have been made that the PSS networks should be replaced by new, digital technology. ETSI confirmed in 1996 that TETRA, which is the only standard for PSS accepted by ETSI, fulfils the requirements [22].

"TETRA (Terrestrial Trunked Radio)" is an spectrum proficient digital trunked ("Trunked is a computer controlled communications system, which allocates communication channel for a call" (either voice or data) from a "common pool" [23] of available channels, and at the end of that call, returns them to the same "pool" to be reallocated / reused for the next call) land mobile system designed by the ETSI, it has been planned to fulfill the needs of the most necessitating professional mobile radio users such as emergency services (ambulance, police forces, fire department), government agencies, , Military services, rail transport staff and for convey services [21]. There are currently 1076 projects of TETRA are being developed around the world and the growing trend is still positive. The market of TETRA has expended over to eighty eight countries throughout the world [12].

TETRA depends on digital trunking. TETRA based products have built-in encryption features to guarantee the secrecy and privacy of sensitive voice/data communications [14]. These products also have the capability to broadcast / transmit data at a faster rate than seen earlier in the mobile communications [24].

2.2.1 Radio aspects of TETRA

TETRA uses a wide range of frequency bands both in VHF and UHF bands. TETRA services were initially setup in Europe in a "20 MHz band between 380 and 400 MHz with two 5 MHz bands with a 10 MHz duplex separation" [19, 20]. For civil communications in Europe, the frequency bands in "385-389.9MHz, 395-397.9MHz, 410-420MHz, 420-430MHz, 450-460MHz, 460-470MHz, 870-876MHz and 915-92MHz" range have been dedicated for TETRA. For emergency communications in Europe the earmarked frequency bands are "380-383MHz and 390-393MHz". TETRA's digital modulation scheme is known as π/4 DQPSK [11, 17]. Its symbol (baud) rate is 18000 symbols per second, and each symbol containing 2 bits, thus the gross rate is 36000 bits/s [2].

The downlink (i.e. the output of the base station) is usually a nonstop transmission consisting of exact communications with mobile(s) such as synchronizations or other general broadcasts. The base station transmits the control and identification information. "System identification e.g. country code, operator code, area code etc, Requests for system registrations and Information such as paging messages addressed to a particular mobile or group of mobiles are transmitted on call to call basis" [1].

The Information which is exchanged between the infrastructure and mobile includes:-

"Wake up (if a battery is in economy mode)"

"Presence check on control channel (if required)"

"Transfer to the traffic channel"

"Acknowledgement on traffic channel (if required)"

"Transfer of traffic information (voice or data)"

2.2.2 Technical Overview

Base stations depending on the area to be illuminated, couple of switches and dispatch centers, depending on the load and indeed the user terminal make up a TETRA system as shown in figure 2-5.

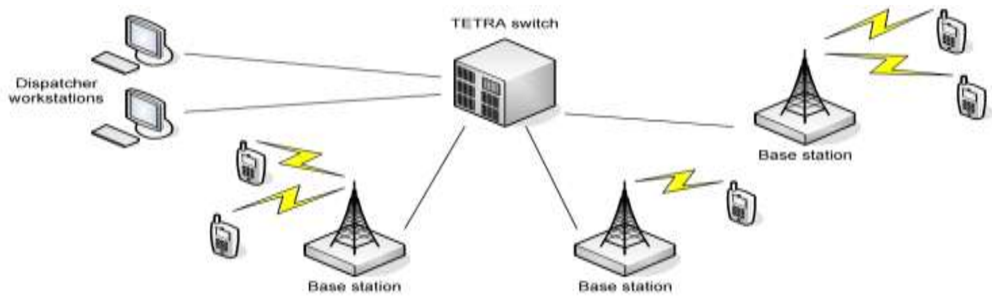


Figure 2-5 A TETRA System

2.2.2.1 Data transmission

In order to establish a call first of all the subscriber transmits the “GTSI to the SwMI on MCCH (Main Control Channel)”. The SwMI dedicates one communication channel on a piece site bounded by the group area and asks for the call. The precedence queues are used for the allocation of resources. Group calls are setup as the half duplex calls for all users. [9].

2.2.2.2 Block Diagram

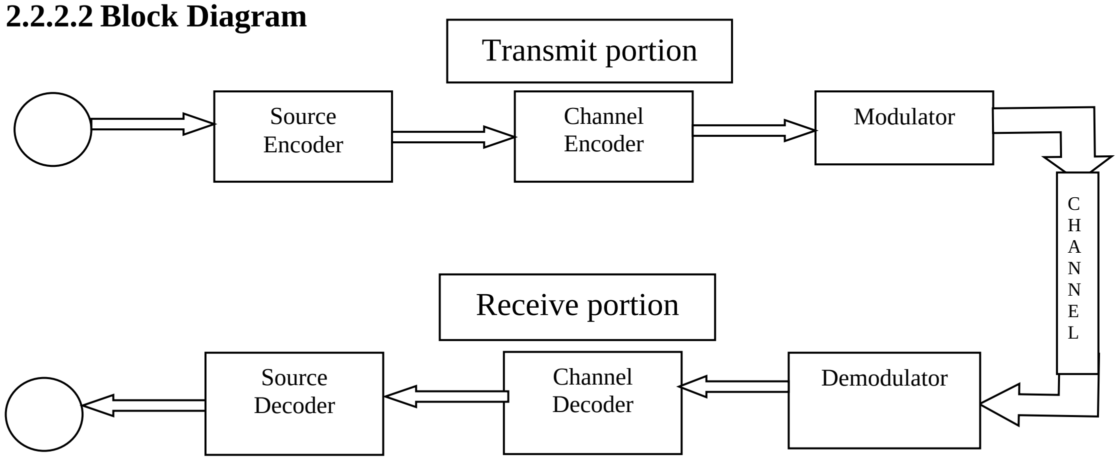


Figure 2-6 Block Diagram of TETRA

In TETRA, a digital modulation of pi/4 DQPSK is used. All the blocks of the above diagram have been discussed in chapter 1 in great detail.

2.2.3 Modes of TETRA

Mobile hand set of TETRA can transfer data by three ways [16].

2.2.3.1 Direct Mode

The direct mode DMO [2] of TETRA facilitates a single radio user to talk to the other radio user directly without involving the base station and the core network resources. The direct mode is very useful in congested, closed areas and areas where the base station has completely broken down or has malfunctioned. In gateway function a single mobile can act as a relay for nearby mobiles which are out of the range from the desired subscriber. In this mode, intercommunication of mobile stations is independent of the network, i.e. without intervention of base stations.

2.2.3.2 Group calling mode

In this Group-calling mode, the transfer of information takes place between the calling party and multiple predefined groups. In group calling modes a user will be put through to other users in a chosen call group and/or a dispatcher ("dispatchers accept calls from someone who call for help from law enforcement services or Emergency Medical Services. At the moment information is received from the subscriber, these dispatchers aerate the services essential to answer to the type of the call for help") only by pushing a single button on TETRA terminal.

2.2.3.3 Repeater Mode

In this mode communication is established through repeaters. Figure 2-7 below shows the direct mode, trunked mode and repeater mode.

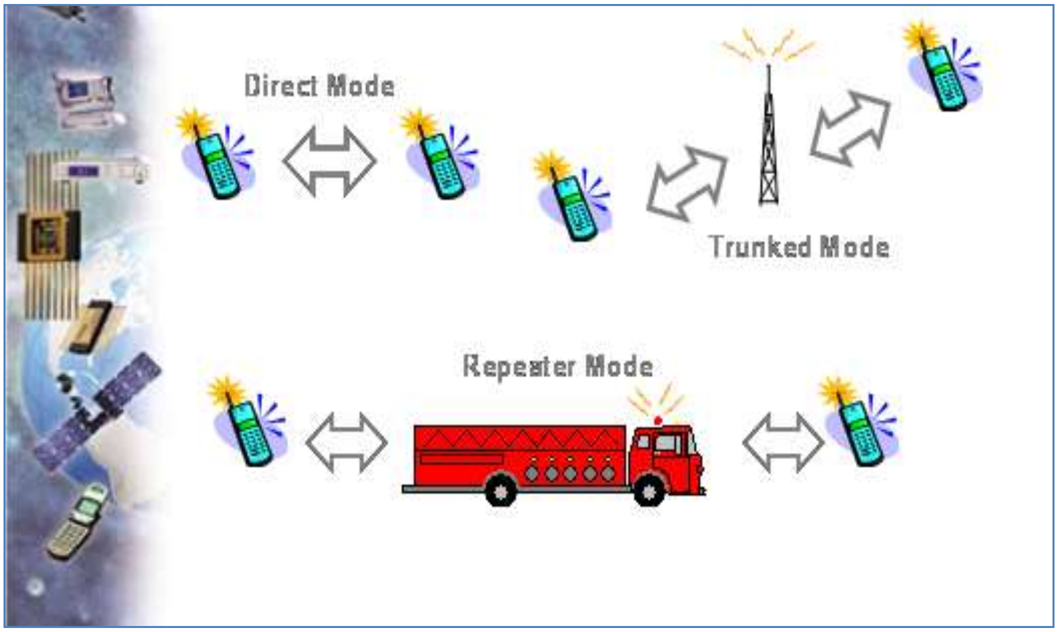


Figure 2-7 Different Modes of TETRA

2.2.4 Network security

The importance of security doesn't require any further elaboration; therefore the professional Organizations also require high network security while exchanging their critical information over air. The network thus should ensure that not only one, who is not the member of the group, is capable to eavesdrop the communication but also no one is able to disrupt the flow of transfer of information. The main features related to security are discussed in following paras. [9]

2.2.5 TETRA Connectivity

TETRA can connect to different other networks as shown in the figure.

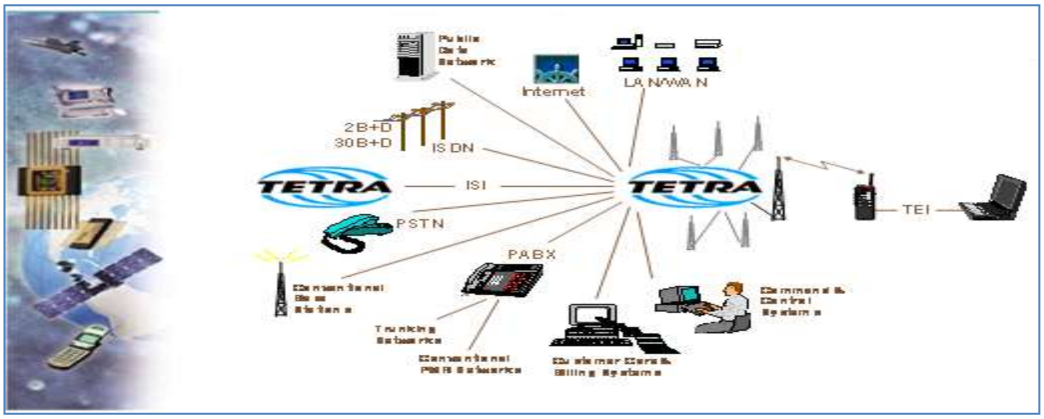


Figure 2-8 TETRA Connectivity

2.2.6 Advantages of TETRA [22]

The advantages of TETRA are discussed below.

2.2.6.1 Security

In comparison to analogue radio based systems and GSM solutions, TETRA systems has a much better security implementation and it can't be eavesdropped by standard radio scanners. The speech is digitalized and TETRA also offers several level of key encryption to achieve superior level of security.

Secure communication Stolen or lost equipment can also be barred from the network thus making it unusable and ensuring the avoidance of any possibility of security breaches by using stolen equipment.

2.2.6.2 Call Type and Call Quality

TETRA provides digital voice quality and multiple channels per transceiver, which improves communication enormously. TETRA also offers selective calling, as each user has a unique number which could be used to make specific call without bothering other users in the networks.

2.2.6.3 Integrated Voice and data capability

Due to TETRA's open standard and interfaces it can support a number of external applications. ANT with its tested and proven track record in system integration can support to put together customer defined applications into complete communication solution.

2.3 EDACS SYSTEM

EDACS is a communications system which can be used for high-speed, wireless analog or digital speech and data transmission and reception. It is being used by 450 organizations, including USA Army. It’s a modern full duplex trunked radio system functioning on 25 kHz or 12.5 kHz channel bandwidths in VHF, UHF frequency bands. The present enhancements and development of specifications based on EDACS technology would address the problems of backward compatibility and interoperability with the large existing base of EDACS equipment and systems, globally. The EDACS modernization would provide features and functions anticipated on satisfying needs of industry, public safety and commercial users.

2.3.1 Communication Modes

The following communication modes are supported:

“Digital Voice: All call types, “group, group emergency, individual and system calls”, are supported”.

“Digital Data: personal calls are supported”.

“Encryption: Encrypting the already digitized speech would provide much protected communications even against modern eavesdroppers. Encryption provides a very high degree of security with no / minimal loss of speech quality. The feature of Encryption through DES algorithm is optional”.

“Analogue**:** Analogue Frequency Modulated signaling is in accordance with “TIA-603” standard”.

2.3.2 Main Features of EDACS

The productivity of EDACS has improved many folds by providing voice and data Communications in both point-to-multi-point (group) and point-to-point modes, with the following main characteristics:-

With Group-oriented transmissions along with special handling of emergency calls, the users can stay in touch with their fellow workers and superiors at all times and emergency calls still get established as quickly as possible. Communications are more proficient and security is improved as there is always a consistent communication path to a point from which help can be sought.

Incorporated voice and high-speed data (9.6kbit/s) helps users to gather and save data in a central database. Portable data facilities have, in effect brought the office out into the field, thereby enhancing efficiency.

Fast Trunked call establishment which is even less than 0.5 seconds, ensures that the users can contact with each other with the minimum possible delay. It also enhances radio channel effectiveness, because less radio frequencies are required to handle the same number of users.

"Wide-area ability of EDACS gives economical coverage to all users from a small factory to a whole region or country".

2.3.3 Services Offered By EDACS

Each radio has a unique ID number in EDACS system. This makes it able to address any individual call from the dispatch centre or from another radio subscriber unit that is authorised to do so. Individual calls are actually one-to-one conversation which is meant for only two individual users, such a call is not overheard by anyone else on the system.

Group calls are the standard calls initiated on a trunked radio system. Groups are the trunked correspondent of traditional channels. The key features / advantages of group calls are:-

"Well synchronized operations by letting personnel to make calls to each other immediately".

"Enhanced safety in performance of operations through fast and reliable radio operations".

There is no requirement for users to write and remember numbers or codes to reach an individual subscriber. A group call can be initiated to another group without having to know who is currently in that group list.

Groups are generally collections of users who have to make calls to each other regularly. For example, within a single citywide system, the East and West fire services could each have their own groups, and the police force could be further arranged into several operating geographical area groups. A user only need to press the PTT button on his radio and a group call gets initiated. All subscribers who have checked that talk group on their respective radios will hear the conversation in that group.

Priority group scan allows radios to monitor a number of groups, helping ensure that no important calls are missed. Authorized radio units are directed into a group call if it is listed in the user's scan list. If the radio is equipped with encryption or digital voice, it will also scan into encrypted or digital voice groups.

With this facility, the individual ID of the caller's radio unit is automatically displayed on the receivers' radios each time the caller makes a group, emergency, or individual call. Radios with alphanumeric displays can be programmed to show a name or alias rather than a numeric ID.

SIMULATION INDIVIDUAL SYSTEMS

The work has been systematically divided into three portions.

Simulation of TETRA transceiver

Simulation of EDACS transceiver

Simulation of Modulation Identifier

Lab VIEW 8.6 has been used as simulation tool because of its reusability of Virtual Instruments in different modules and its capability to run on testing equipment without conversion or conflicts. The methodology followed in each of the above sub modules is explained in the following sections.

3.1 TETRA SYSTEM

TETRA (Terrestrial Trunked Radio)" is an spectrum proficient digital trunked ("Trunked is a computer controlled communications system, which allocates communication channel for a call" (either voice or data) from a "common pool" [23] of available channels, and at the end of that call, returns them to the same "pool" to be reallocated / reused for the next call) land mobile system designed by the ETSI, it has been planned to fulfill the needs of the most necessitating professional mobile radio users such as emergency services (ambulance, police forces, fire department), government agencies, , Military services, rail transport staff and for convey services [21]. There are currently 1076 projects of TETRA are being developed around the world and the growing trend is still positive. The market of TETRA has expended over to eighty eight countries throughout the world [12].

TETRA depends on digital trunking. TETRA based products have built-in encryption features to guarantee the secrecy and privacy of sensitive voice/data communications [14]. These products also have the capability to broadcast / transmit data at a faster rate than seen earlier in the mobile communications [24].

3.1.1 Transmitter Module

The transmitter side of the TETRA system consists of generation of message bits, applying synchronization and reference bits, convolutional encoding for error detection and correction followed by interleaving to avoid deep channel fades and at the last modulation and finally transmission over the AWGN channel.

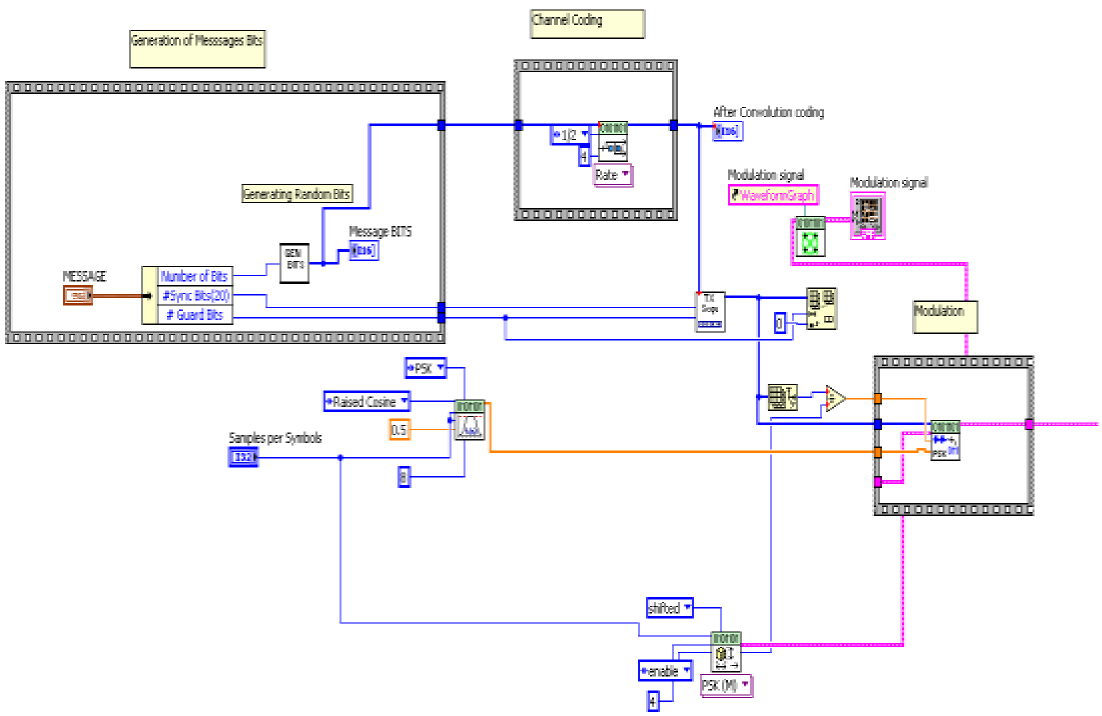


Figure 3-1 Block Diagram of Transmitter of TETRA

3.1.1.1 Message Bits Generation

Message bits are generated using the random bits generator. The length of the frame containing message bits was varied between 500 to 1000 bits in different situation to check the system parameters. The message bits were than divided into blocks of 120 bits. Protected data of 20 bits was separated using the delete array block. Associated Signalling bits and the 'D' bit was added to these 20 bits before it was sent for convolutional coding. D bit specifies whether the frame contains coded voice or it contains data.

3.1.1.2 Channel Coding

Channel coding is introduced to provide redundancy to the transmitted data and reduce the effects of channel. It helps to protect data sent over the channel for storage or retrieval even in the presence of noise. The message bits after necessary padding of synchronization and reference bits goes through the channel coding, in this case its convolutional code to add redundancy for error detection and correction at the receiver end. The used code rate is 1/3. The encoded bits were passed through an interleaver so that in case of deep channel fades it should be helpful in error detection and finally correction.

3.1.1.3 Modulator

The modulation scheme used in tetra is pi/4 PSK, after the channel encoding, the interleaved bit stream is fed to the modulator. To initialize modulator there are number of parameters which are required to be set. These are PSK system parameters, synchronization parameters and the pulse shaping filter parameters. The modulated bit stream is depicted in form of constellation points shown in diagram 3-2, x and y axis contains I and Q components respectively.

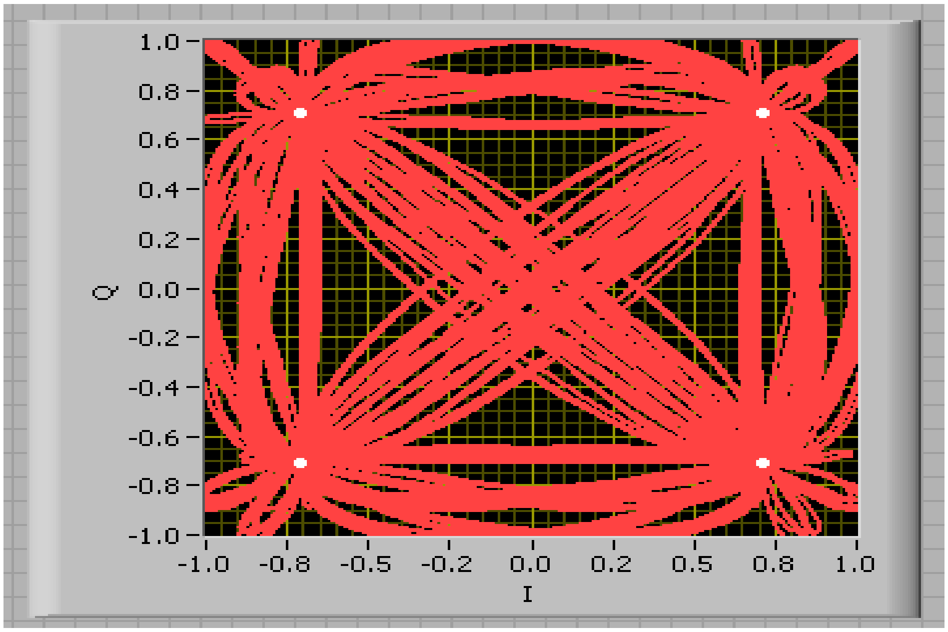


Figure 3-2 Constellation Graph of TETRA Modulator

3.1.2 Channel

Additive White Gaussian Noise (AWGN) channel is used in the analysis of modulated bit streams. The channel parameters were varied between 0 dbs to 15 dbs and the effect of channel are recorded accordingly. The results shall be discussed in coming chapters. Figure 3-3 shows the simulated channel diagram whereas figure 3-4 shows the channel effects on the modulated symbols after passing through the channel.

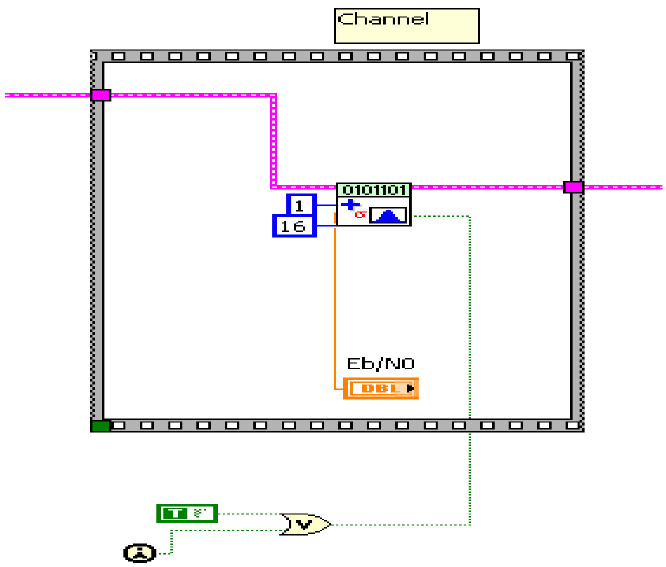


Figure 3-3 Block diagram of Channel of TETRA

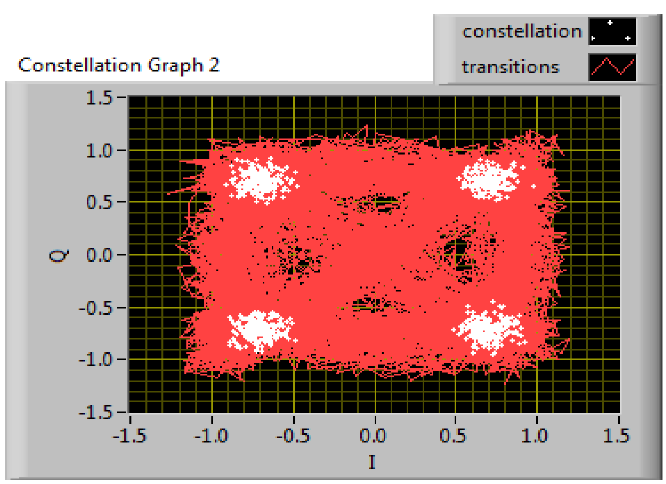


Figure 3-4 Channel effects on modulated symbols

3.1.3 Receivers Module

At the receiver side, the received complex waveform was demodulated to recover the transmitted bit stream. Then the functions of Deinterleaving, channel decoding were applied to recover the original message bits. Figure 3-5 shows the Receiver block of TETRA in LabView.

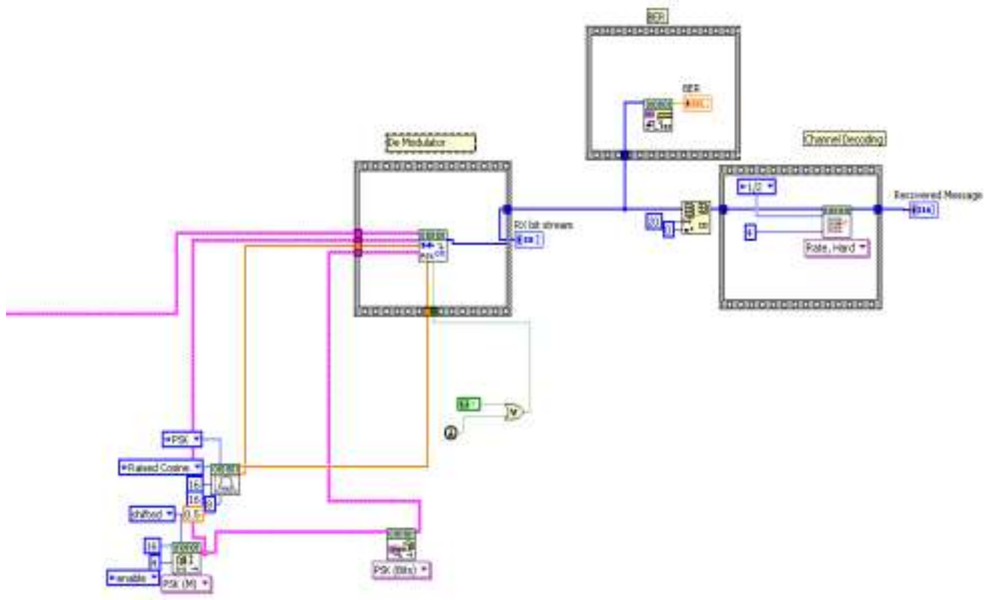


Figure 3-5 Block Diagram of Receiver of TETRA

3.1.3.1 PI/4 PSK Demodulator

The demodulator modules makes use of the PSK system parameter, Synchronization parameter, matched filter coefficients and pulse shaping coefficients to perform demodulation of the complex waveform and recovers the message bit streams.

3.1.3.2 Channel Decoder

At the receiver side channel decoder was used to decode the convolutionally encoded bits using the same parameters of rate and constraint length as used in the convolutional encoder.

3.1.3.3 Bit Error Rate

The Bit Error Rate was calculated at the receiver end to ascertain the channel effects on the transmitted message bits.

3.1.4 TETRA Simulation Parameter used in LABVIEW

Message Signal Parameter	
Number of bits	More than 500
Number of Sync Bits	20
Number Of Guard Bits	2
Convolution Encoder/Decoder Parameter	
Constraint length (k)	4
Rate (k/n)	1/2
$\pi/4$ DQPSK Modulation/Demodulation Parameter	
Differential PSK	enable
M-PSK	4
Shifted	PSK Type
Channel Impairments	
E_b/N_o	10db-15db
Samples per Symbols	16
Bit per Symbols	1

3.1.5 Simulation Result of TETRA

In this Front panel diagram at Figure 3-10, message and transmitted bits and the bits recovered at the receiver end, Constellation graph for modulator and demodulator, BER during the transmission and Eb/N0 used for AWGN channel are shown. We can analyse the result by considering the constellation graph, comparing the transmitted and received message bits, and also by checking the BER (bit error rate).

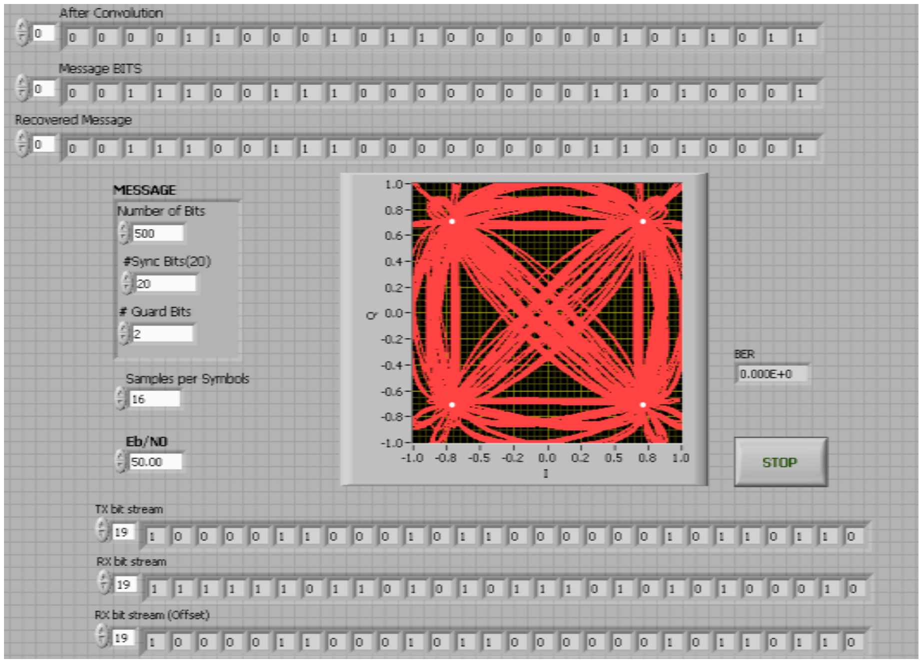


Figure 3-6 Simulation Results of TETRA system

3.2 EDACS System in LabVIEW

EDACS is a two way digital trunked radio system mainly designed for North America. The simulation and performance is discussed.

3.2.1 Transmitter

In EDACS GFSK is used to modulate the message sequence. GFSK is a form of FSK with a pre modulation Gaussian filter, which is used between the digital input signal and the modulator stage to reduce the carrier occupied bandwidth.

In LABVIEW the message bits are generated through random bits generator. Then they are fed to “TX Sequence” Block, in which guard bits and synchronization bits were added to them.

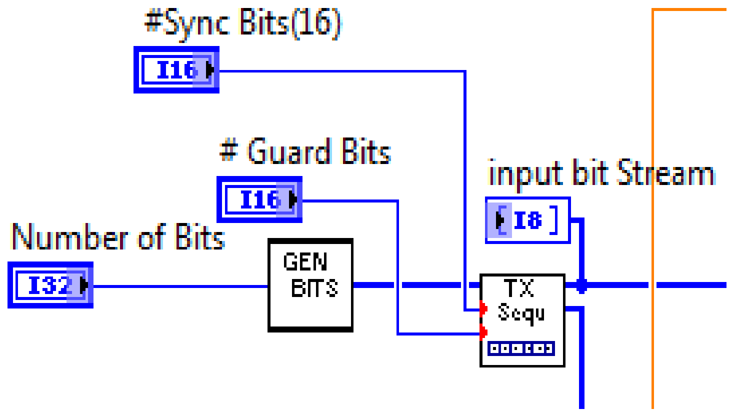


Figure 3-7 message bit generation

"TX sequ" Block works as under

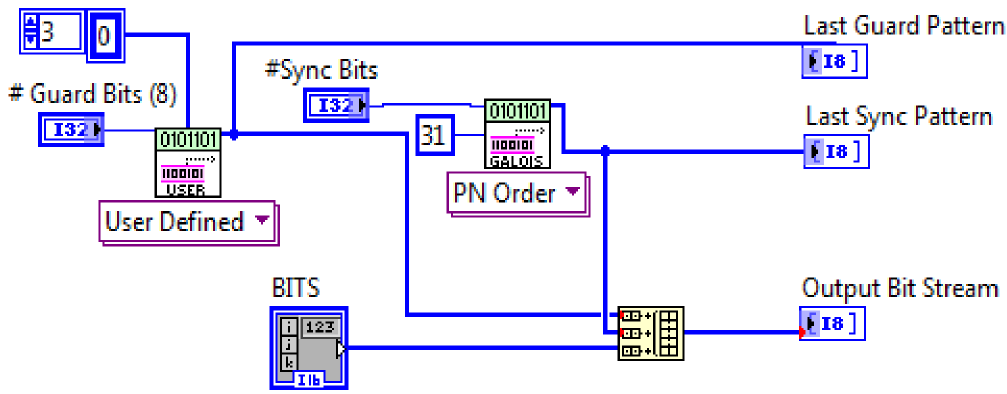


FIGURE 3-8 Transmitted Sequence

FSK system parameters were generated by using Generate system parameter sub-vi. Frequency deviation and symbol rate of 9600 were fed to it. Then pulse shaping filter coefficients and matched filter coefficients were generated for the Gaussian pulse shaping filter and FSK.

Table 3-1 System Parameters

Type	FSK
Pulse Shaping Filter	Gaussian
Filter Parameter	0.7
Filter Length	8

Pulse Shaping Samples per Symbol	16
Matched Samples per Symbol	16

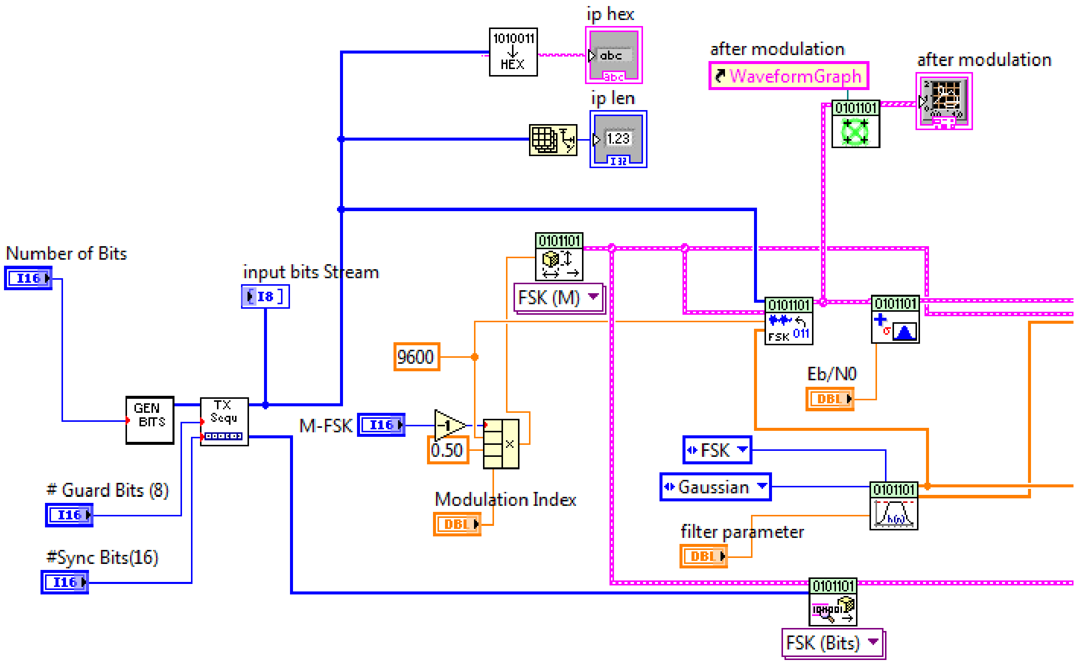


Figure 3-9 Modulation EDACS

3.2.2 Channel Impairments

The complex waveform was passed through AWGN channel.

Figure 3-10 AWGN Channel

3.2.3 Receiver

At the receiver side the transmitted complex waveform was demodulated using Demodulate FSK sub-vi to recover the transmitted bit stream and constellation diagram was generated.

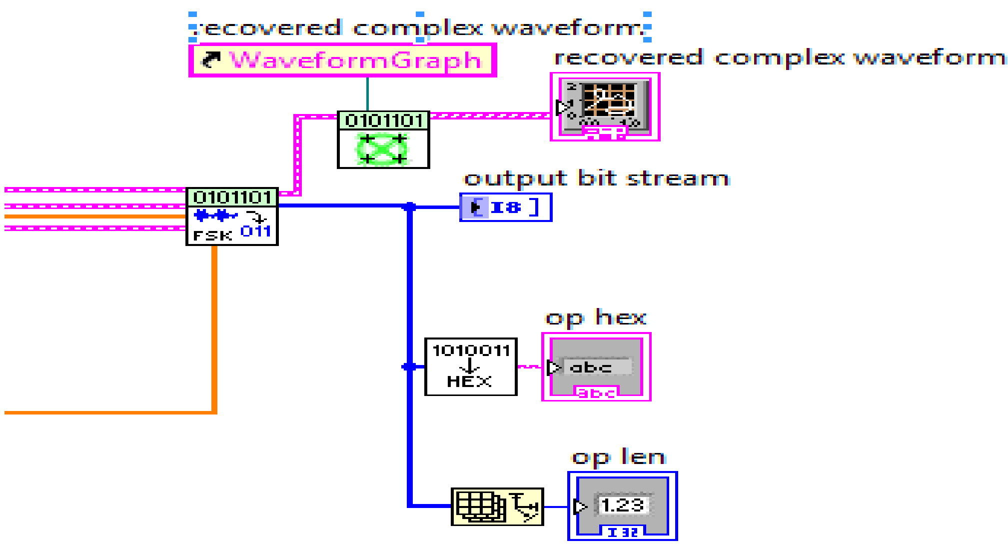


Figure 3-11 Demodulation EDACS

BER was calculated by dividing "the difference between bits before modulation and bits after modulation" to "the total no of bits". Figure 3-16 shows the vi to compute the BER in LabVIEW.

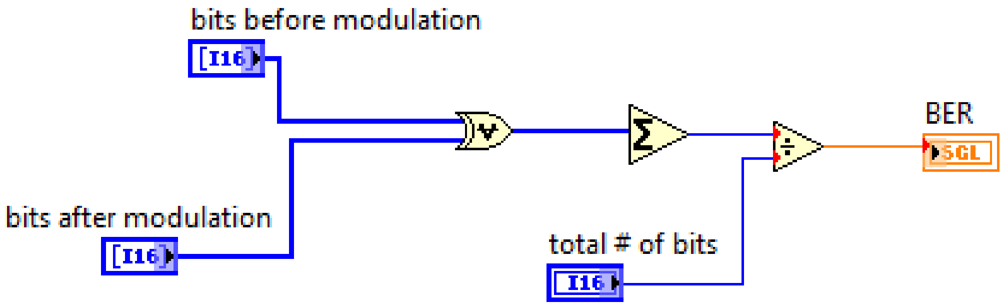


Figure 3-12 BER

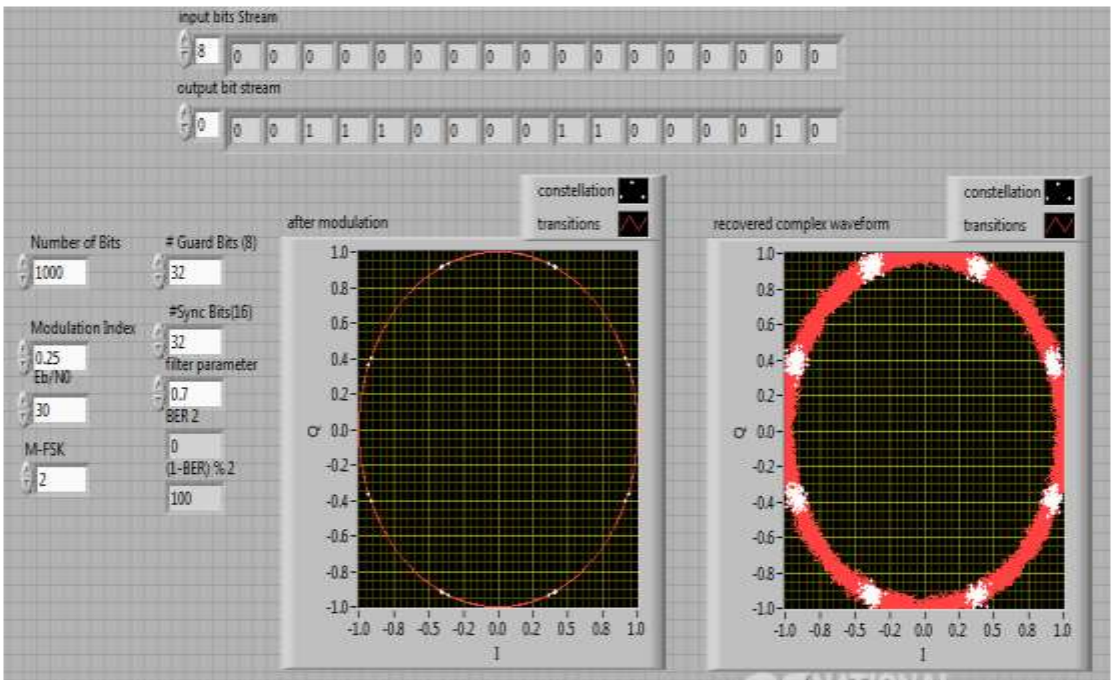


Figure 3-13 EDACS System

3.2.4 Simulation Results

In the figure 3-17, transmitted bits and the bits recovered at the receiver end are displayed for EDACS system. Constellation graph for modulator and demodulator, BER during the transmission and E_b/N_0 used for AWGN channel are also displayed. The results can be analysed by considering the constellation graph, comparing the transmitted and received message bits, and also by checking the BER (bit error rate). The results prove that the system is working perfectly.

3.3 Lab VIEW Simulation of Identifier

In LabVIEW, AR coefficients were generated by using adaptive filter tool kit.

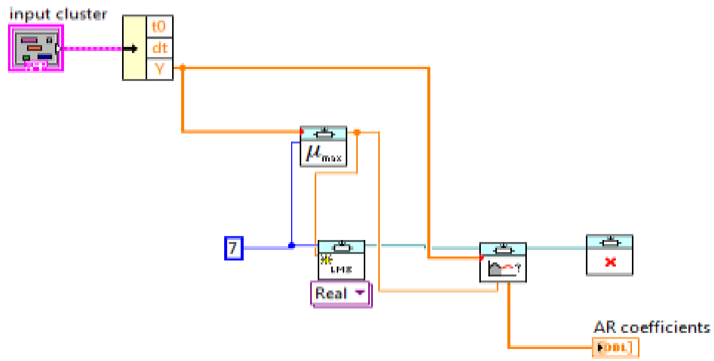


Figure 3-14 AR Coefficients Generation in LabVIEW

For the creation of "AR coefficients", first of all, the maximum step size for the "adaptive filter" was ascertained. The step size value affects the "convergence speed, steady state error, and stability" of the adaptive filter.

A little step size can be used to guarantee a small steady state error. However, a small step size also decreases the convergence speed of the resulting adaptive filter.

The step size can be increased to improve the convergence speed of the resulting adaptive filter. However, a large step size might cause the adaptive filter to become unstable.

This VI completes the following steps to estimate the maximum step size value for an adaptive filter.

"Obtains a series of filter input vectors from the input signal".

"Identifies the filter input vector that has the maximum signal power".

"Calculates the reciprocal of the maximum incoming signal power". The result is the maximum step size that you can use for the adaptive filter.

Thus a practical step size value was calculated for the filter length of 7. Then using the filter length of 7 and step size as calculated by the 1st block, adaptive filter was created using "least mean squares (LMS) algorithm".

Then "AFT Linear Prediction block" was used that performs "adaptive linear prediction by estimating the autoregressive (AR) model" of an input signal. It gave the AR coefficients of the input signal on the basis of which the signal is identified.

Chapter 4

INTEROPERABILITY METHODOLOGY / SIMULATION

4.1 Interoperability and Direct Mode Operation

Interoperability is the ability of different communication systems to exchange voice and/or data communications on demand and in real-time. It is the term that describes how radio communication systems should operate among agencies and jurisdictions that respond to common emergencies.

4.1.1 **Interoperability approaches**

There are many interoperability approaches some of them which were considered are discussed in following items.

4.1.1.1 **Using Various Antenna**

This approach towards interoperability insists on making a device which will have a separate physical antenna attached for each system i.e. one for TETRA, one for EDACS and so on. The device for every separate system will switch to the particular antenna for successful communication.

This approach towards interoperability had the limitation of a very huge size for a single device, as separate physical antennas would be installed on the device. Another limitation was that in order to energize all those antennas a large amount of power was to be required, if implemented.

4.1.1.2 Using a Bank of Filters

The approach towards interoperability was better than the previous one as it implies bank of filters to separate different frequency groups rather than to install separate antenna for each system. This will allow the device to identify whether a signal from a system is available or not and then tune its antenna to that frequency.

The above approach eliminated the drawback of huge size of device on the basis of physical antennae but still the size will remain huge enough to accommodate filters. Furthermore the device would be unable to distinguish between the different networks in the same frequency range. Another problem would be the large power required to energize the bank of filter.

4.1.1.2 Using modulation identification

For this approach there is no need of multiple antennas or bank of filters. Previously different systems were implemented using different frequency ranges but for interoperability using modulation identification we require them to use the same frequency range. However, we need to maintain original modulation schemes for the uniqueness of the systems.

4.2 System Identifier

For interoperability, the MS needs to identify which environment exists around it. If Suppose an EDACS MS is operating in the EDACS environment, it can easily communicate with the core network but if the environment is that of TETRA, it needs interoperability for communication. So a certain identification is required that can identify the environment in which the MS is operating. There are different techniques for the detection of the environment.

4.2.1 Modulation identifier based on EYE diagram

Since the P25 systems have distinct modulation schemes so this approach uses a modulation identifier based on the eye diagram. This identifier can be used to identify the modulation being used and henceforth can detect the system. Since all the processing is done in software so there is no power issue with this scheme

Each modulation has a distinct waveform and each waveform has distinct points of convergence that distinguish it from other waveforms. Calculating these points of convergence involves complex image processing that will cause a considerable time delay in the system which is unacceptable.

4.2.2 Modulation identifier based on Constellation diagram

Constellation diagram contains the amplitude and phase of each modulation waveform. It depicts the resultant of phase and amplitude in form of constellation points in each quadrant. This in turn helps in identifying the used modulation scheme on the basis of values of phase and amplitude.

It fails when filters with different parameters are applied; like in our case Gaussian filter with a BT of .25 caused GMSK constellation diagram to have more than 8 points, all randomly located, but within close proximity of the expected/theoretical locations, due to the pulses smearing/interference into each other. This made use of respective technique impossible as knowledge of exact location of the points is very important. Others limitations include, comparatively (compared to LPC) complex algorithms and difficulty of scaling the algorithm to include more than two schemes.

4.2.3 Modulation identifier based on Linear Predictive Coding

I have developed identifier on the basis of “LPC”. Each modulation scheme has a unique phase and amplitude value which is depicted in form of a waveform thus making that waveform a unique signature for that particular modulation scheme. Therefore by calculating the Auto “Regressive coefficients” of a modulated data stream we can differentiate different modulation schemes. This scheme has by far proved to be the best scheme with advantages including, easy recognition of all modulation schemes, ease of scaling and execution. “AR model” is a “random process that attempts to forecast the future value of a process based on its previous samples / values”. This process is represented by the equation,

$$x_t = \sum_{i=1}^{N} a_i \, x_{t-i} + \varepsilon_t$$

Such a process is called an "autoregressive process of order N". The present value of the process x_t is regressed on its past values: x (t-1),…, x(t-N). By this we can say that present value depends on the previous values of the process. The number of past values of the process that are involved in its formulation equals the order of the process N. Thus apart from for the term '$\mathcal{E}_t$' , the novelty process depicted by "white noise", the present values of the process equals a "linear combination of these past values". The coefficients a_i, that are used in this process are a linear combination and are called the "autoregressive (AR) coefficients" of the process.

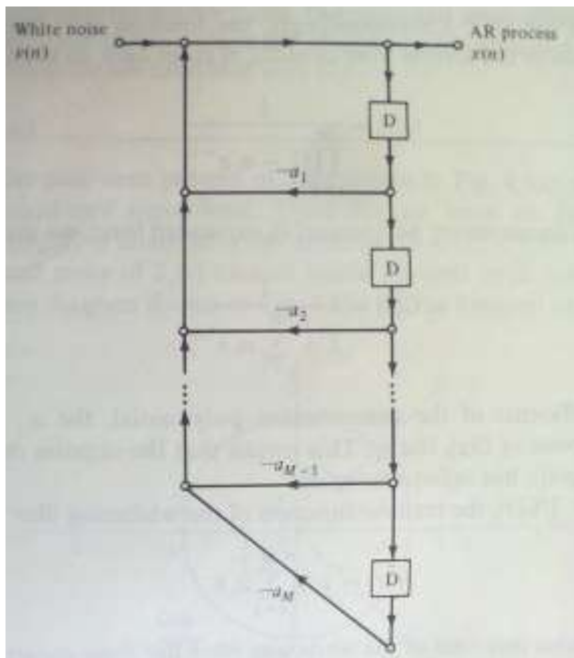


Figure 4-1 AR Model Implementation

4.3 EDACS MS in TETRA Environment

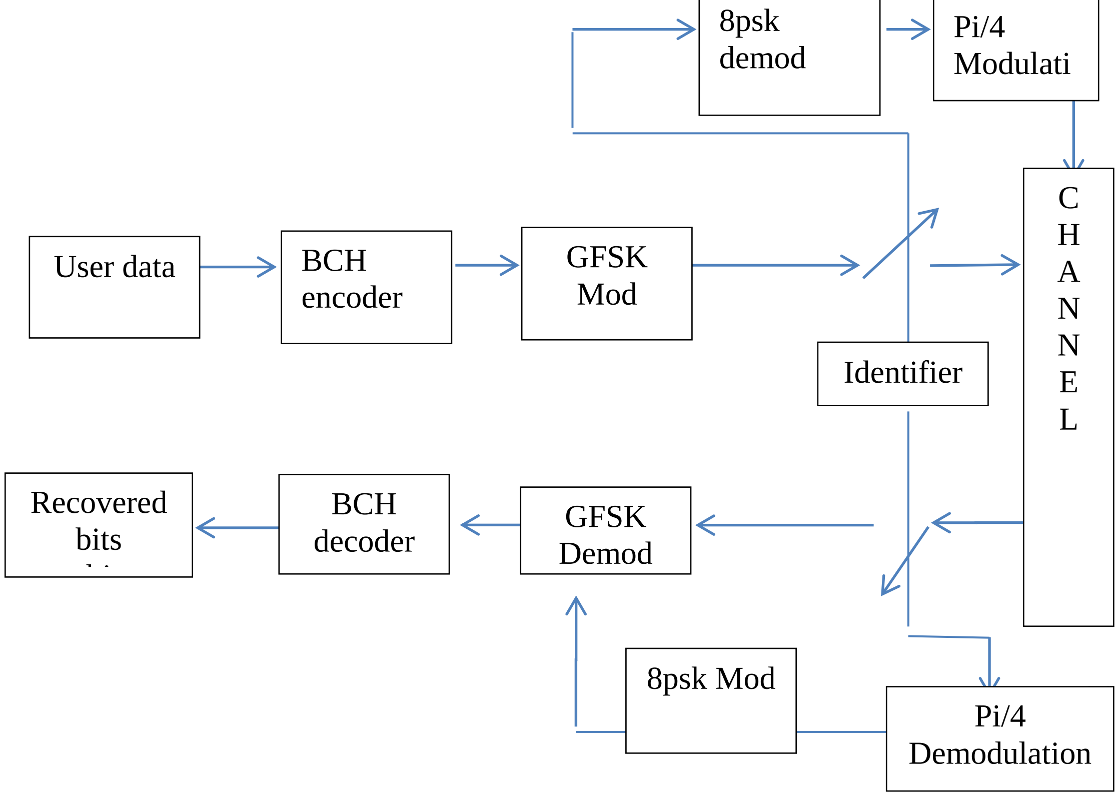
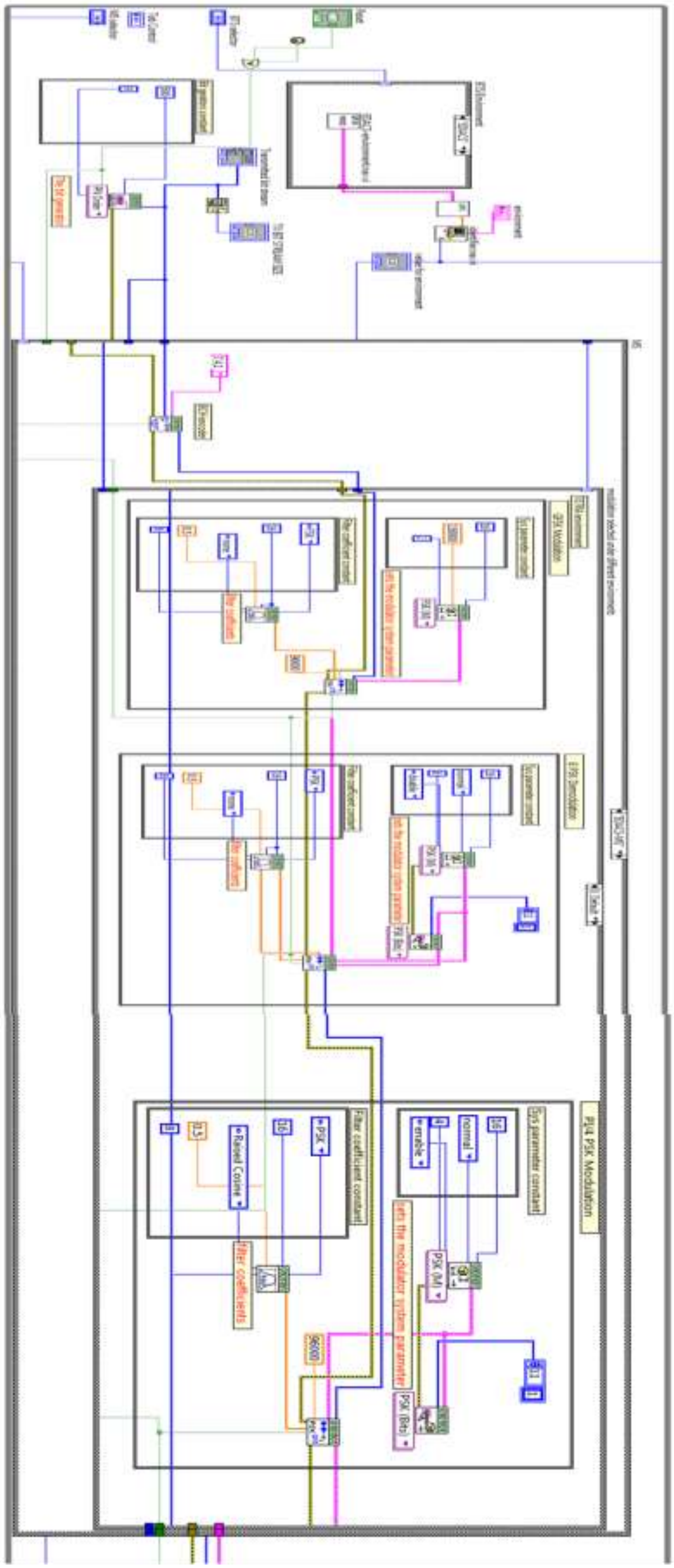


Figure 4-2 Flow Chart of EDACS MS in TETRA Environment

BTS function generates the environment of TETRA, for which the AR coefficients are calculated by the LPC sub-vi. These coefficients are sent to the identifier sub-vi which then identifies the environment. Then, based on the environment, the MS selects the appropriate circuitry for transmission of data.



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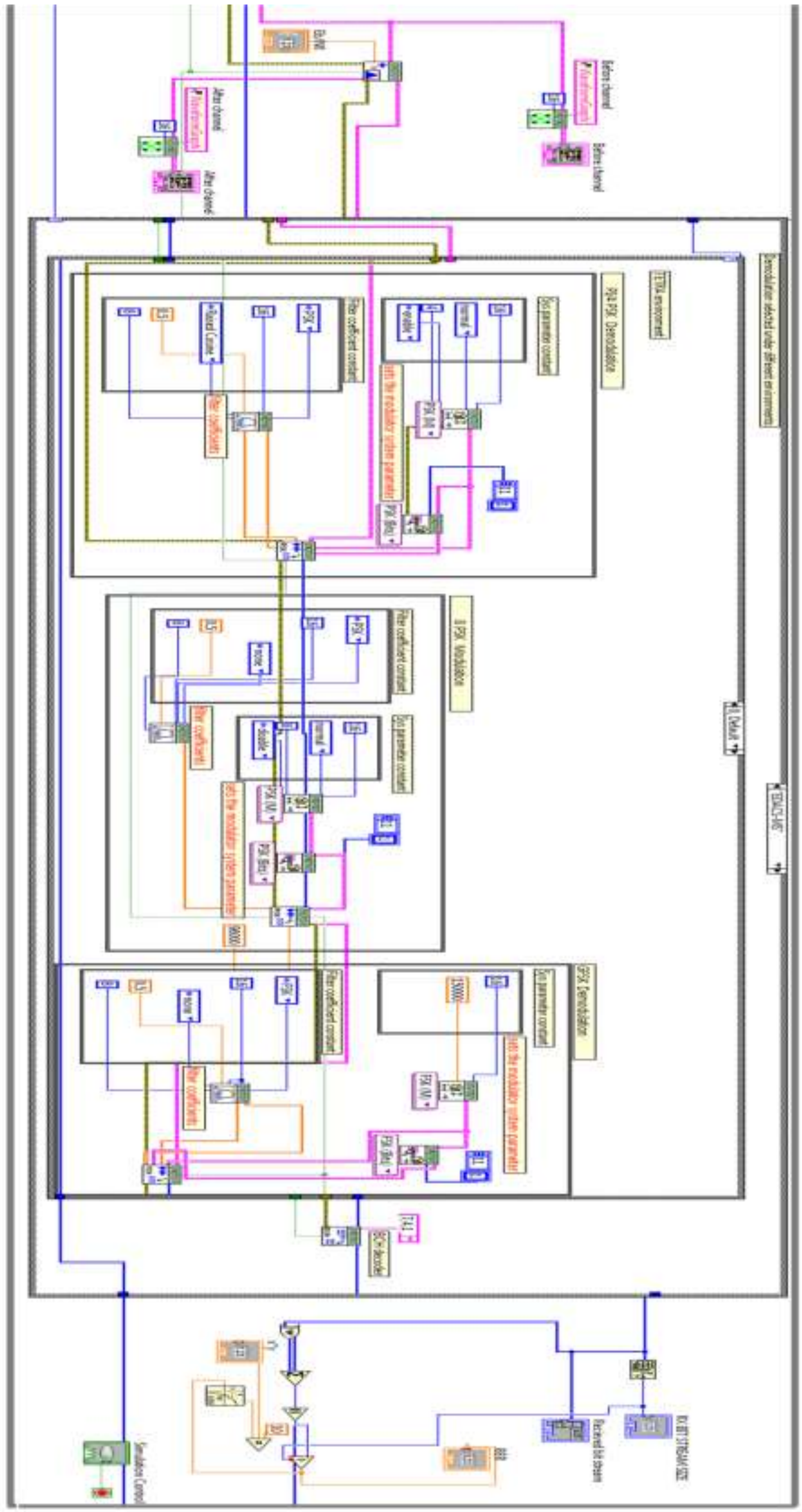


Figure 4-3 LabVIEW Simulation of EDACS MS in TETRA Environment

Bits generator generates the bits; these bits are then applied to the BCH channel encoder. The channel encoded bits are first modulated with GFSK, then demodulated with 8 PSK and last modulated with pi/4 PSK so that EDACS MS can communicate with the TETRA BTS. Since the systems are differentiated on the basis of their respective modulation schemes, therefore, GFSK is applied, which is the basic modulation scheme for EDACS, demodulation through 8 PSK has been applied to maintain the secrecy and integrity of the user's data, as the bits are completely randomized or in other words scrambled, and finally pi/4 PSK is applied so that the TETRA system may detect the signals, thereby enabling communication to be established.

4.4 TETRA MS in EDACS Environment

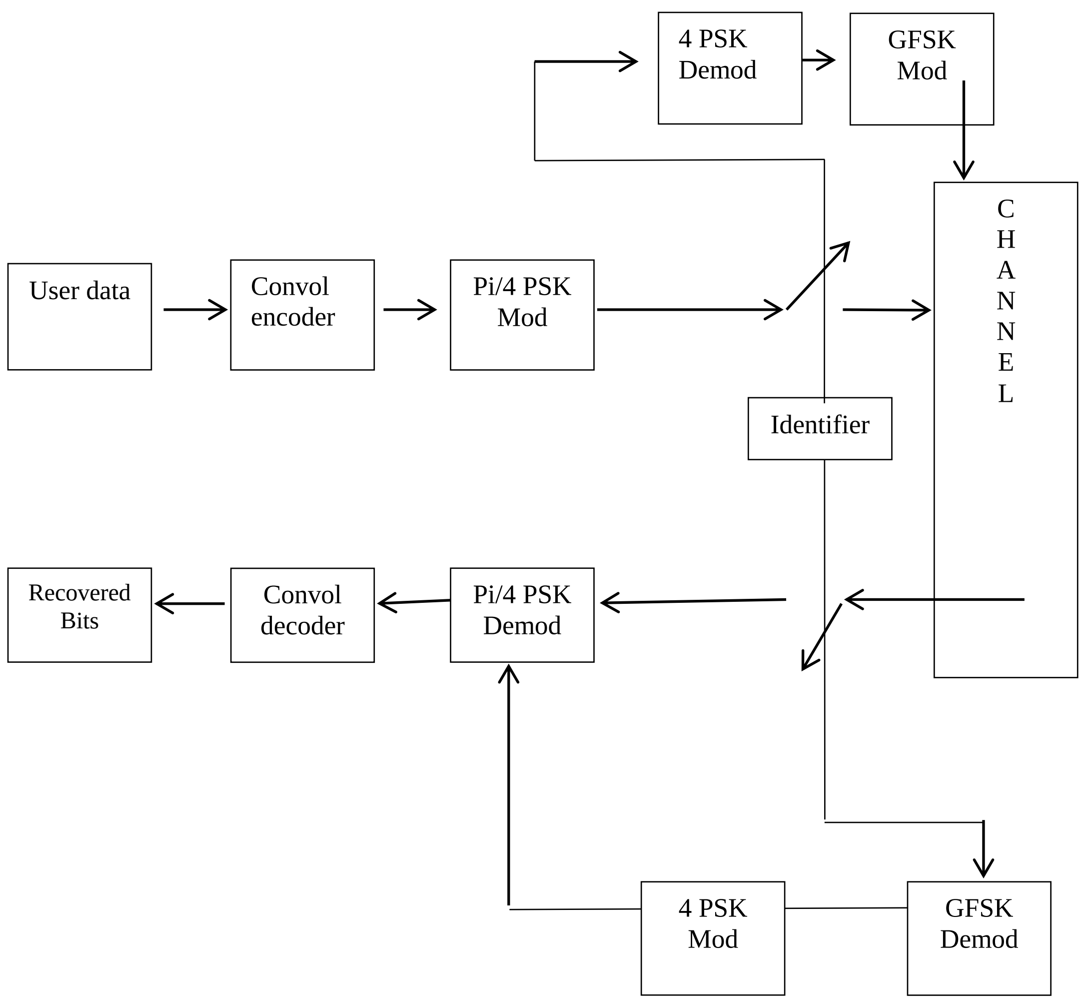
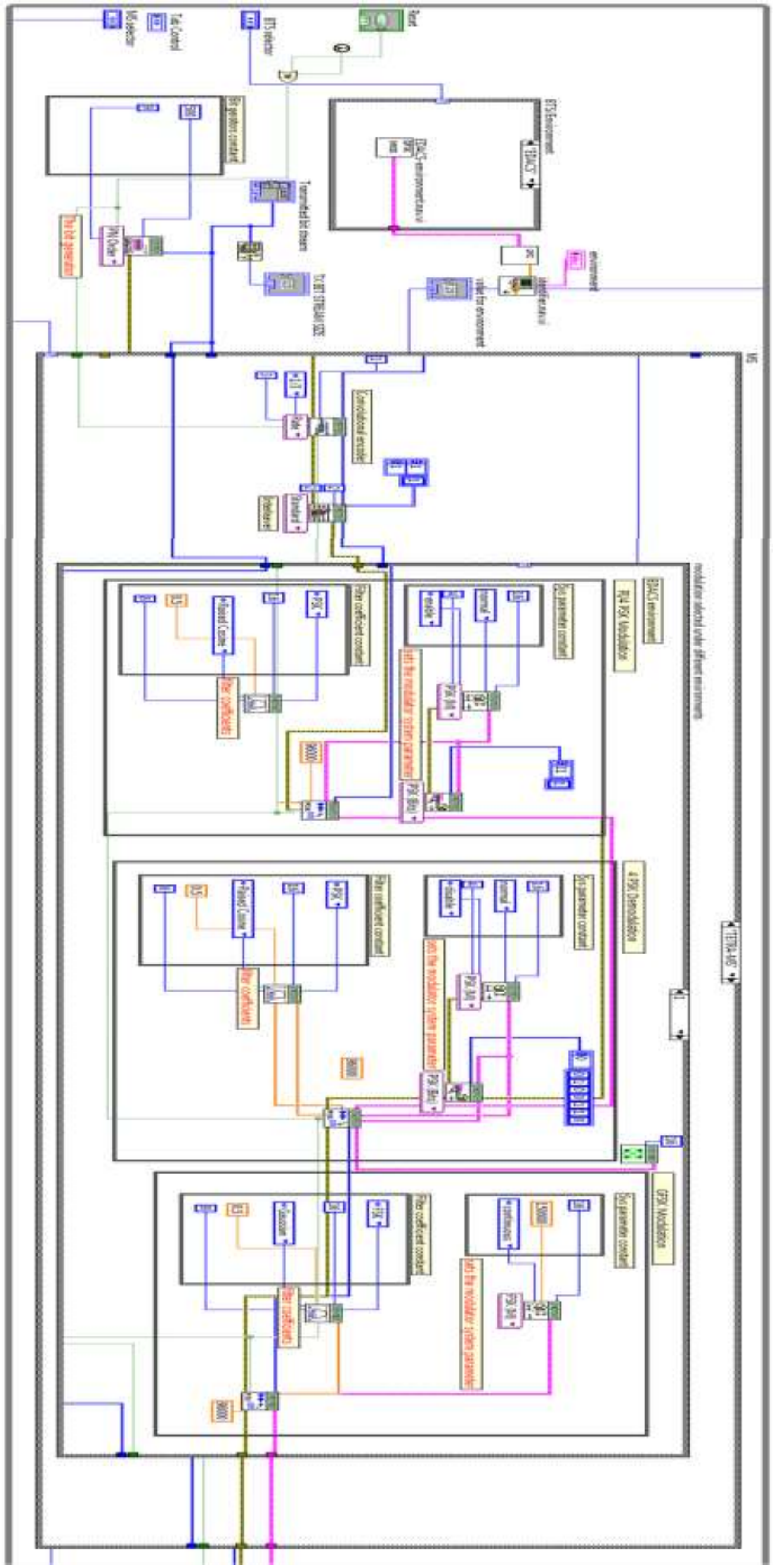


Figure 4-4 Flow Chart of TETRA MS in EDACS Environment



Cont....

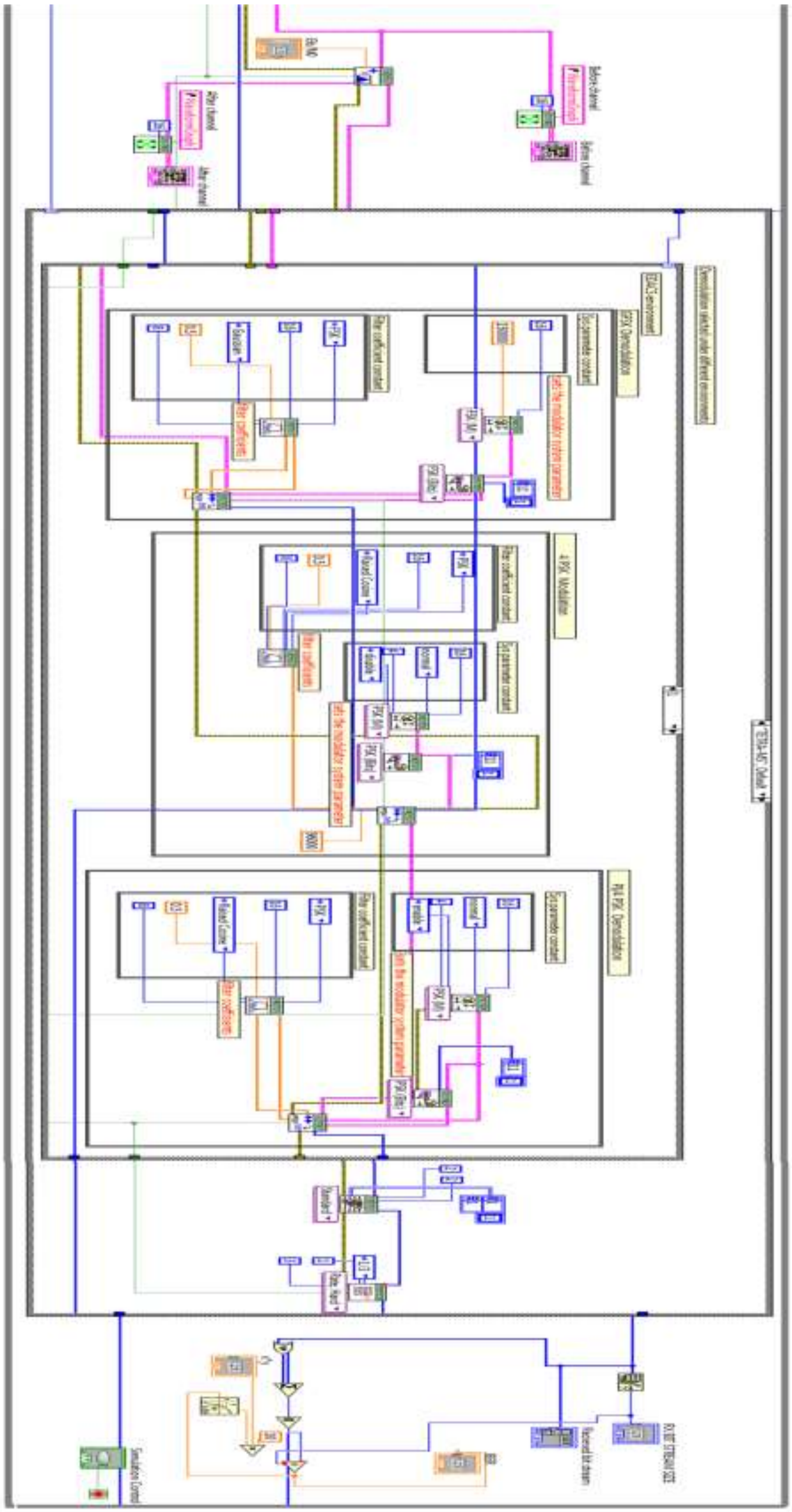


Figure 4-5 Lab view simulation of TETRA MS in EDACS

BTS function generates the environment of EDACS, for which the AR coefficients are calculated by the LPC sub-vi, in the MS function. These coefficients are sent to the identifier sub-vi which then identifies the environment. Then, based on the environment, the MS selects the appropriate circuitry for transmission of data. Bits generator generates the bits, convolution channel coding is applied before the bits are modulated with Pi/4 PSK, the Pi/4 PSK waveform is then demodulated with 4 PSK and then modulated with GFSK. Since the systems are differentiated on the basis of their respective modulation schemes, so Pi/4 PSK is applied, which is the scheme for TETRA, 4 PSK has been applied to maintain the secrecy and integrity of the user's data, as the bits are completely randomized or in other words scrambled, and finally GFSK is applied so that the EDACS system may detect the signals, thereby enabling communication to be established.

4.5 Simulation results for Interoperability

For EDACS MS in TETRA environment the following results were obtained

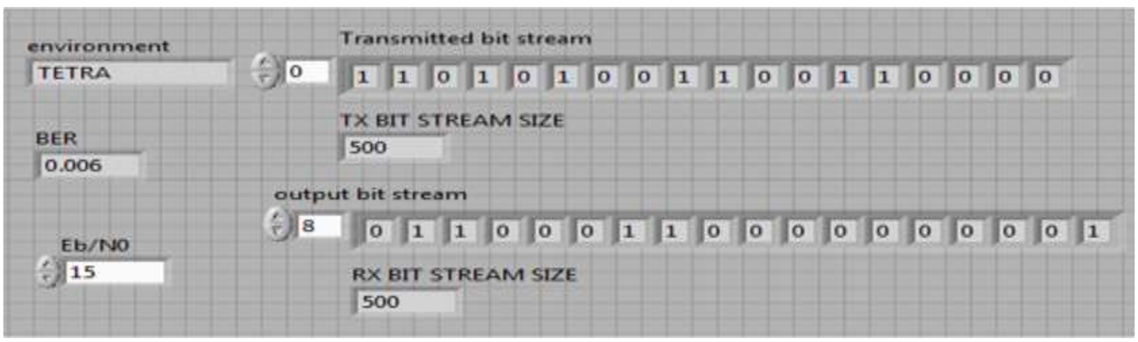


Figure 4-6 Transmission and reception of bit stream for EDACS MS in TETRA environment

Figure 4-5 shows the transmitted and received bit streams along with number of bits. It can be seen that the transmitted and recovered message is similar with BER of 0.0060 at E_b/N_o of 15 dB.

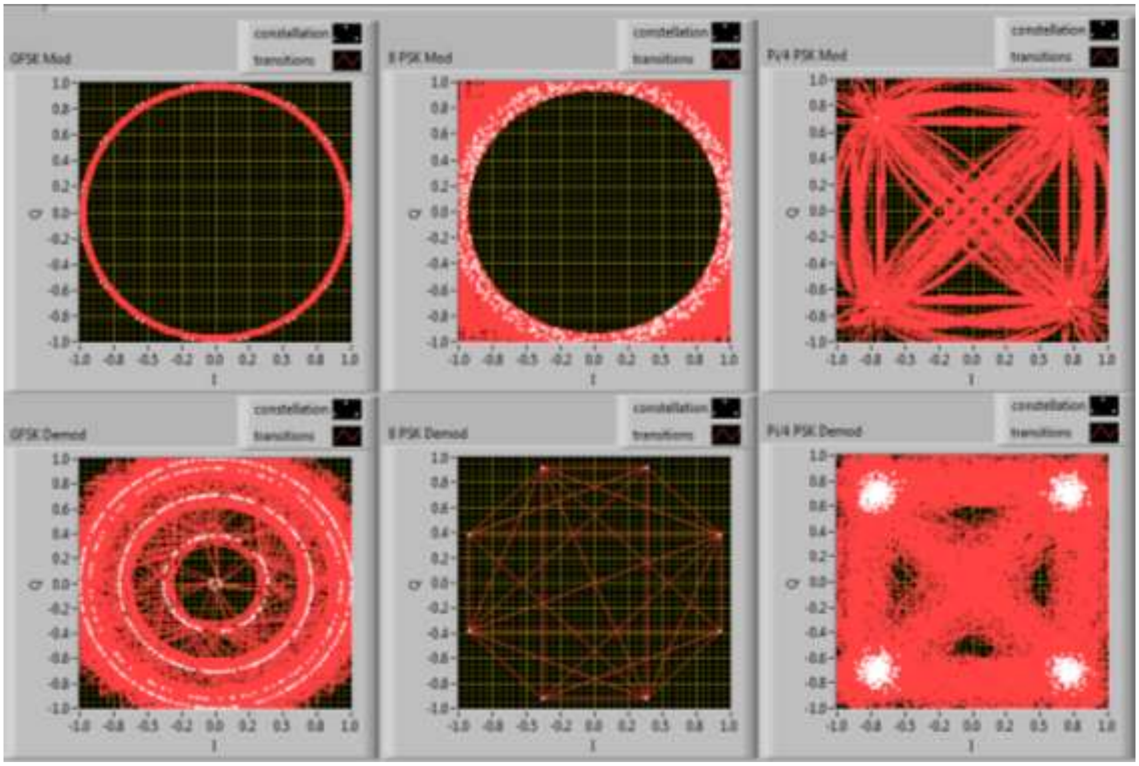


Figure 4-7 Constellation graphs for EDACS MS in TETRA environment

For EDACS MS first the GFSK modulated waveform was demodulated with 8-psk and then it was modulated with Pi/4 PSK to transmit the signal in TETRA environment. At the receiver end the Pi/4 PSK Demodulation was used to convert the bits stream. Then the bit stream was modulated with 8-PSK and finally the message was recovered using GFSK demodulation. The respective constellation diagrams at different instances are shown in figure 4-7.

For TETRA MS in EDACS Environment the following results were obtained

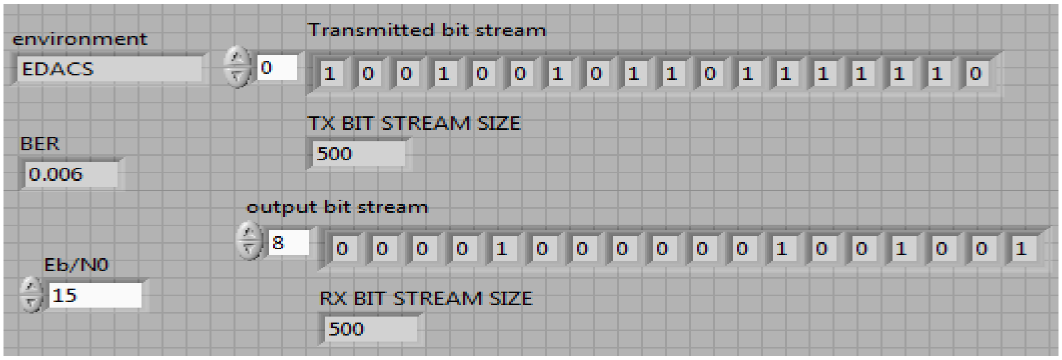


Figure 4-8 Transmission and reception of bit stream for TETRA MS in EDACS environment

Figure 4-8 shows the transmitted and received bit streams along with the number of bits. It can be seen that the transmitted and recovered message is similar with BER of 0.006 at E_b/N_o of 15dB.

For TETRA MS first the Pi/4 PSK modulated waveform was demodulated with 4 PSK and then it was modulated with GFSK to transmit the signal in EDACS environment. At the receiver end the GFSK Demodulation was used to convert the bits stream. Then the bit stream was modulated with 4 PSK and finally the message was recovered using Pi/4 PSK demodulation. The respective constellation diagrams at different instances are shown in figure 4-9.

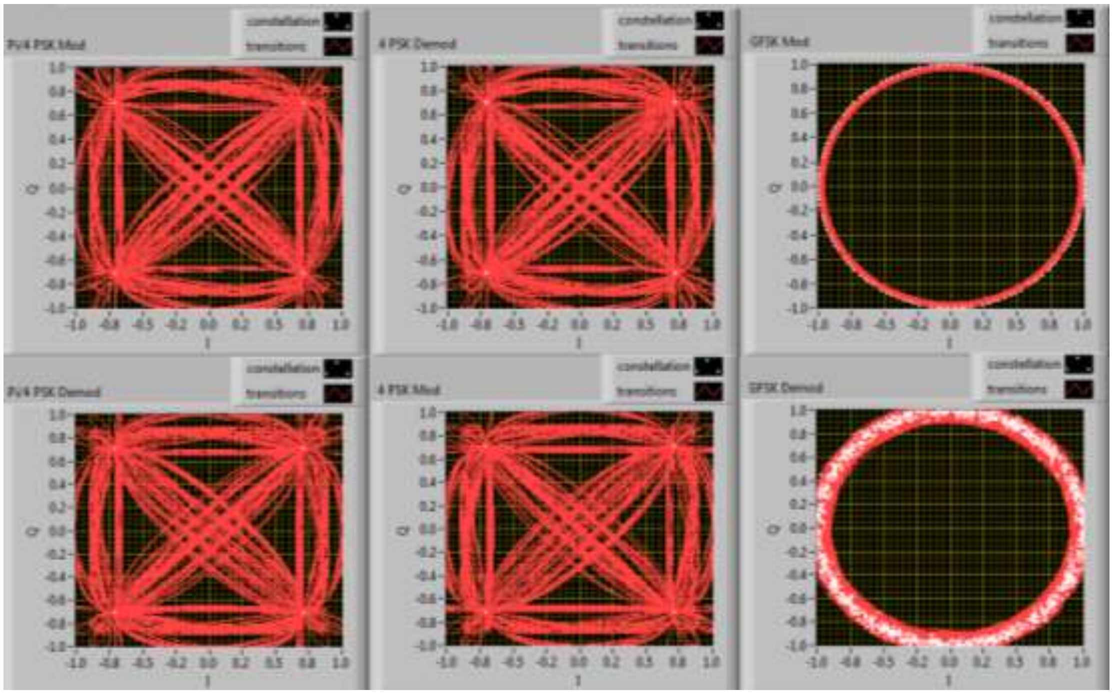


Figure 4-9 Constellation graphs for TETRA MS in EDACS environment

4.4 Direct mode

Direct mode operation is the connection between two mobile stations without any BTS involved. Whenever the receiver side is idle and direct mode is activated, a secure connection is setup for communication to take place.

4.4.1 Direct Mode of TETRA

In direct mode Pi/4 PSK was used for modulation and demodulation. The transmitting MS modulated the bit stream with Pi/4 PSK and transmits it over the air interface. The receiving MS demodulated the received signal and recovers the original message. The block diagram of direct mode is shown as figure 4-10.

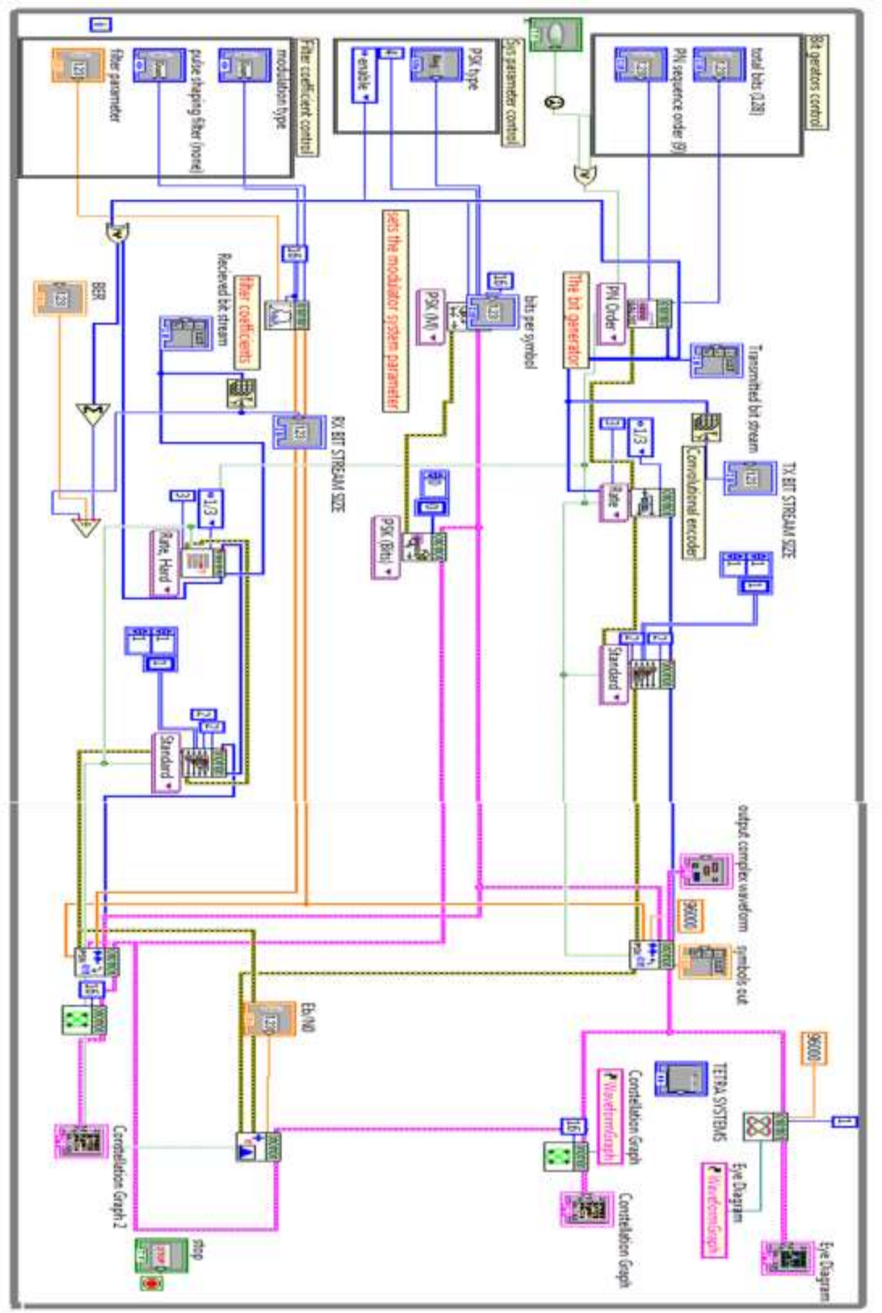


Figure 4-10 Block Diagram of Direct Mode of TETRA

Simulation Results of Direct Mode of TETRA

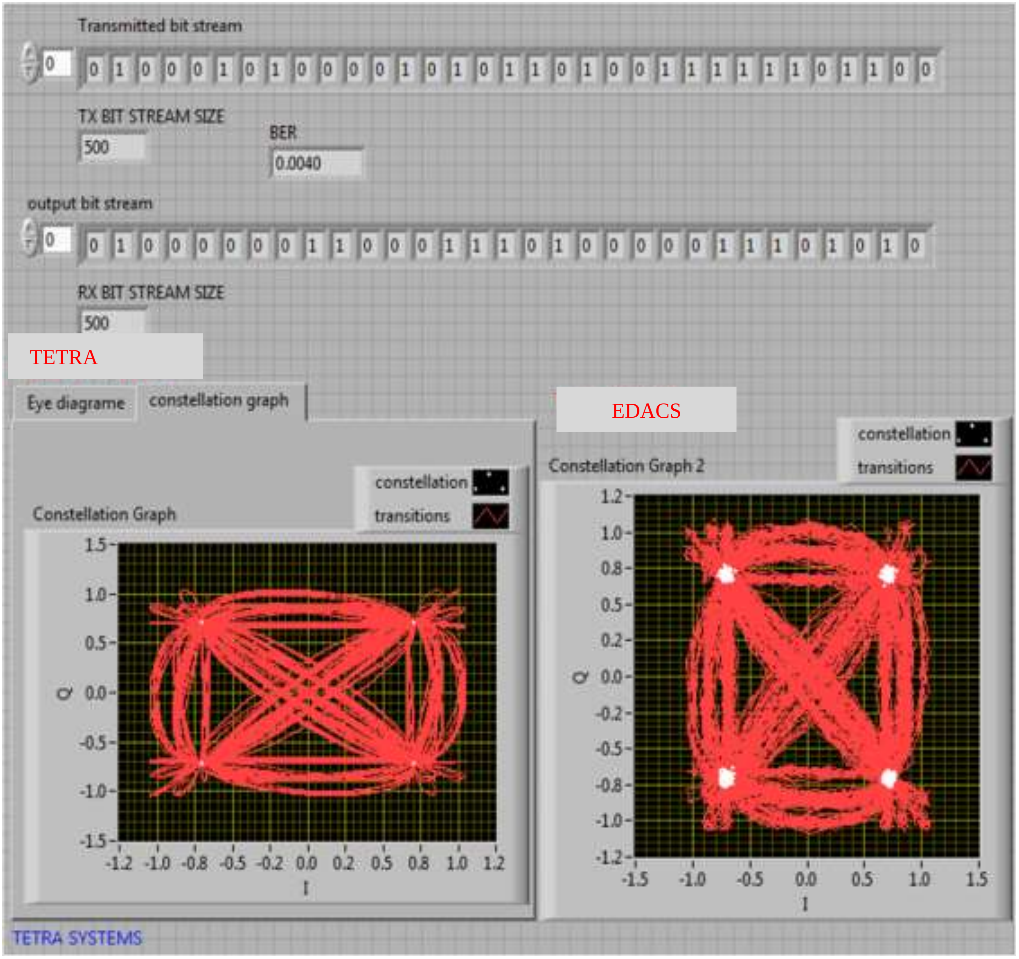


Figure 4-11 Simulation Result of Direct Mode of TETRA

Figure 4-11 shows the simulation result of direct mode of TETRA system. In this diagram, i/p bit stream, o/p bit stream as transmitted and received at the receiver end are shown. Constellation graph of Pi/4 PSK Modulator and the expected graph at the demodulator, BER, number of transmitted and received bits are shown. The analysis based on the constellation graph, comparison of transmitted and received bit streams and BER shows that the system is working perfectly fine.

4.4.2 Direct Mode of EDACS

Figure 4-12 shows the block diagram of direct mode in EDACS. It is very much similar to that of TETRA, it also uses mutually agreed upon modulation scheme of Pi/4 PSK for direct mode and emergency one to one transmission and reception, without involving the BTS upon enabling the direct mode; the procedure is the same as that of TETRA

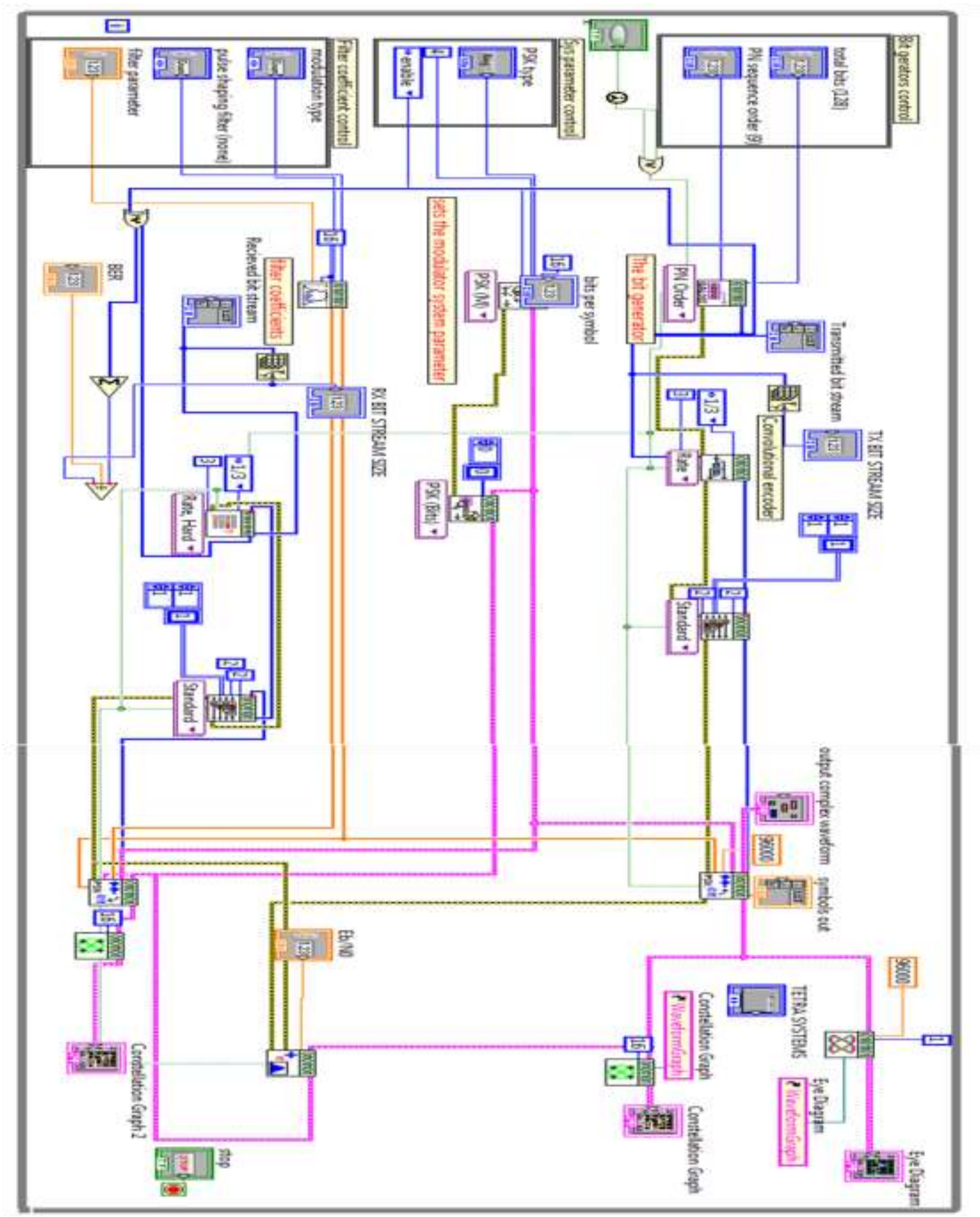


Figure 4-12 Block Diagram of Direct Mode of EDACS

Simulation results of Direct Mode of EDACS

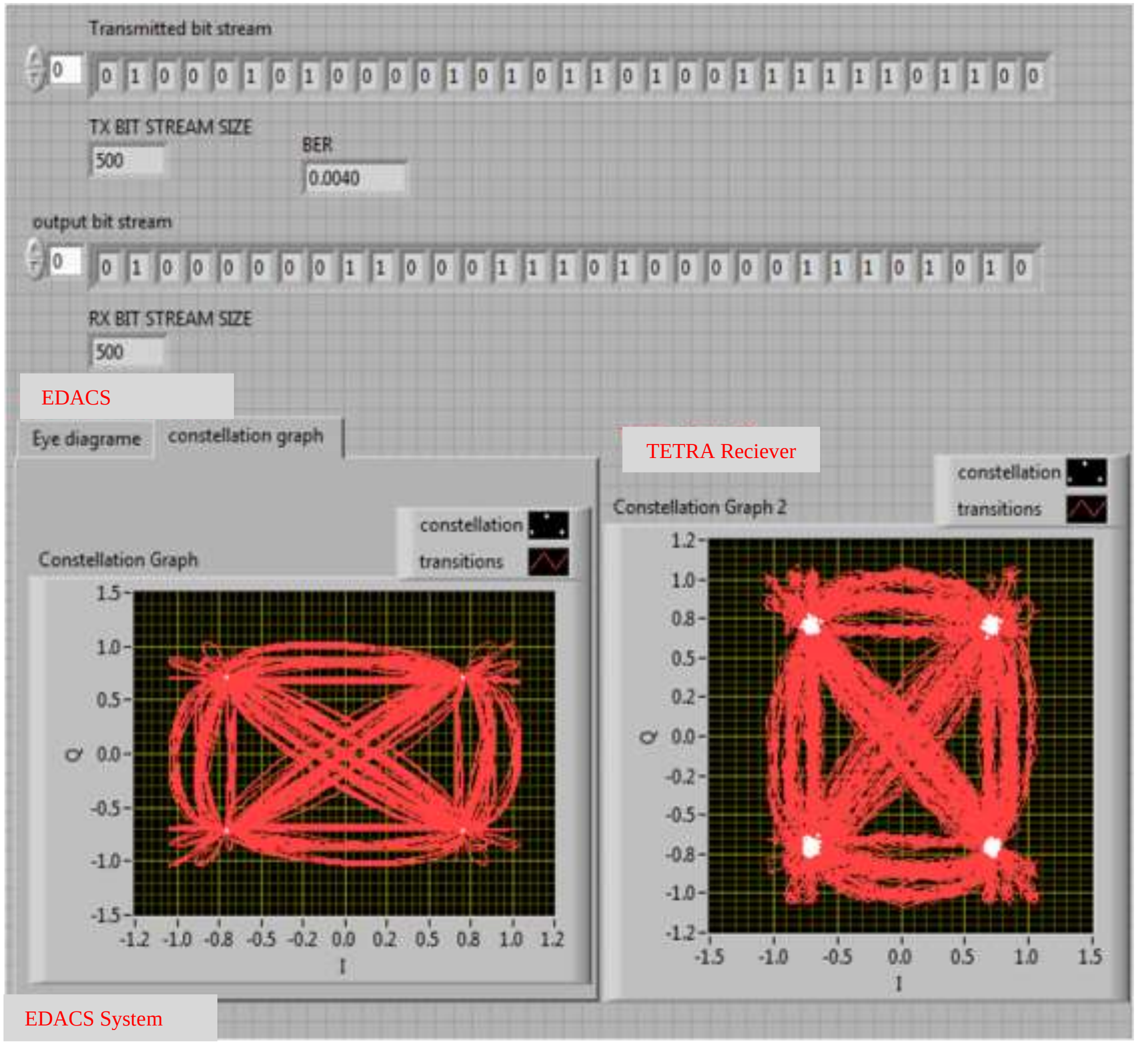


Figure 4-13 Simulation Result of Direct Mode of EDACS

The simulation results were similar to TETRA direct mode operation. The same constellation diagram was observed at transmitters and receivers at suitable SNR. The bits transmitted and received were similar with very less BER.

Chapter 5

RESULTS AND DISCUSSION

5.1 Introduction

The primary aim of the project is to highlight the performance of the Interoperability between EDACS and TETRA based on the Modulation Identification. The identification was carried out by calculating the AR coefficients using “linear predictive coding”. This was made possible due to the unique waveforms of the used modulation schemes in the considered systems. Both the systems were simulated and tested with their integral parameters followed by the identification testing at different noise levels and finally the interoperability was simulated and tested. The results are presented in the following paragraphs.

The interoperability between the systems would not only benefit the users by giving them open choice for selection of any network for communication but will also increase the wireless communication range.

5.2 TETRA System

In the figure 5-1, transmitted bits and the bits recovered at the receiver end, Constellation graph for modulator and demodulator, BER during the transmission and E_b/N_0 used for AWGN channel are shown. The results can be analyzed by considering the constellation graph, comparing the transmitted and received message bits, and also by checking the BER (bit error rate). 500 randomly generated bits were applied to the transmitter and were successfully retrieved at the receiver end, but as I went on increasing the no of input bits the processing time did increased but successful retrieval of still possible.

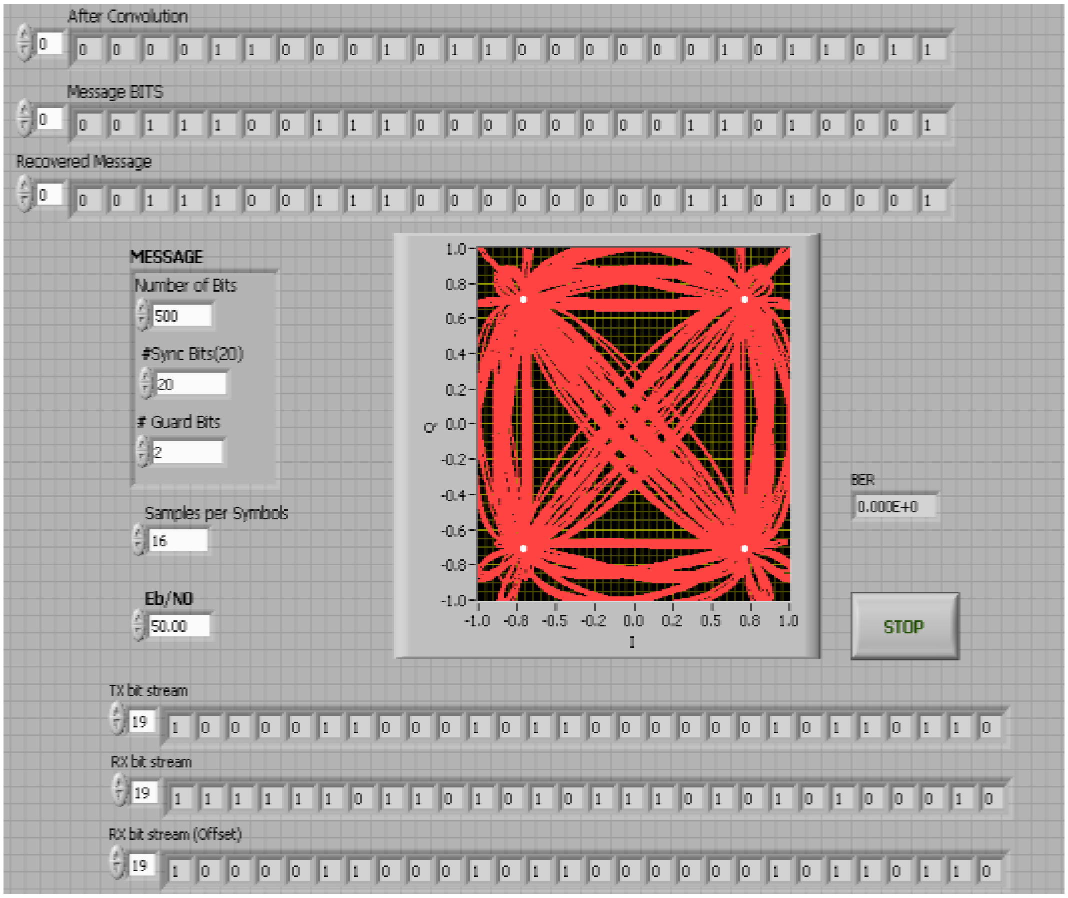


Figure 5-1 TETRA System

The transmission and reception was also tested in presence of AWGN channel with varying noise levels. The results are depicted in the form of a comparative graph between BER and E_b / N_o in figure 5-2. Results show satisfactory response of the transmission and reception in presence of noise.

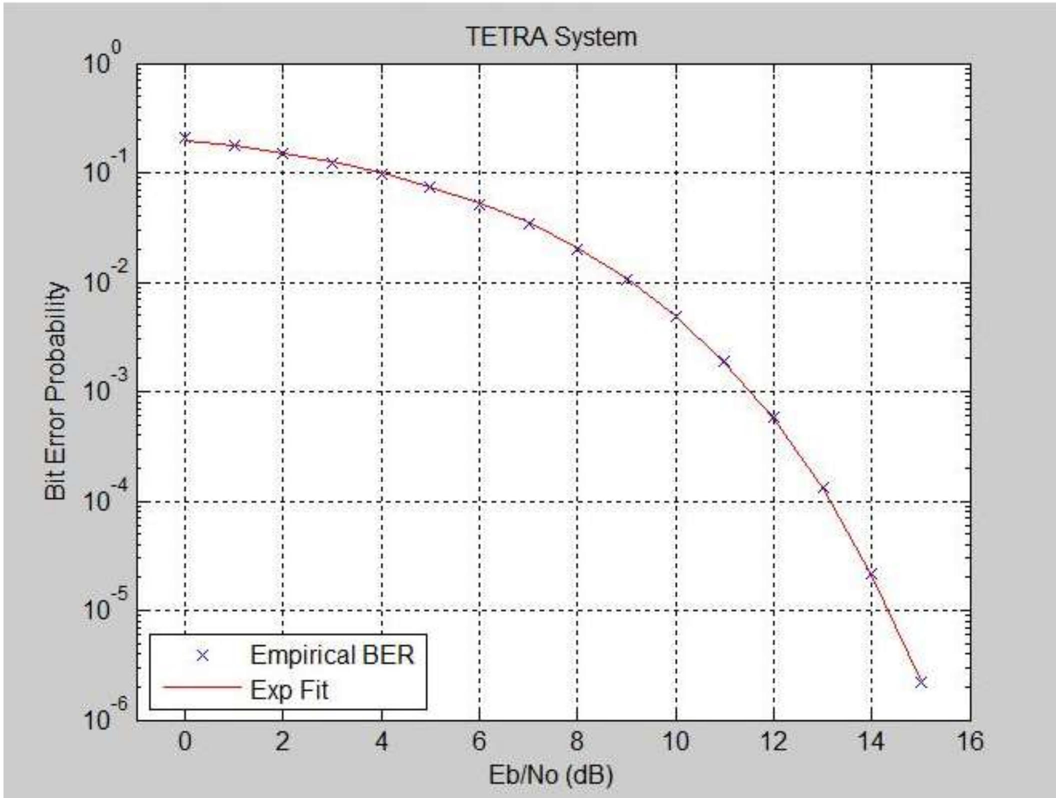


Figure 5-2 E_b / N_o verses BER - TETRA System

5.3 EDACS System

In the figure 5-3, transmitted bits, the bits recovered at the receiver end are displayed for EDACS system. Constellation graph for modulator and demodulator, BER during the transmission and E_b/N_0 used for AWGN channel are also displayed. The results can be analyzed by considering the constellation graph, comparing the transmitted and received message bits, and also by checking the BER (bit error rate). 500, 1000 and 1500 randomly generated bits were applied to the transmitter and were successfully retrieved at the receiver end, but as I went on increasing the no of input bits from 500, the processing time did increased but successful retrieval of still possible.

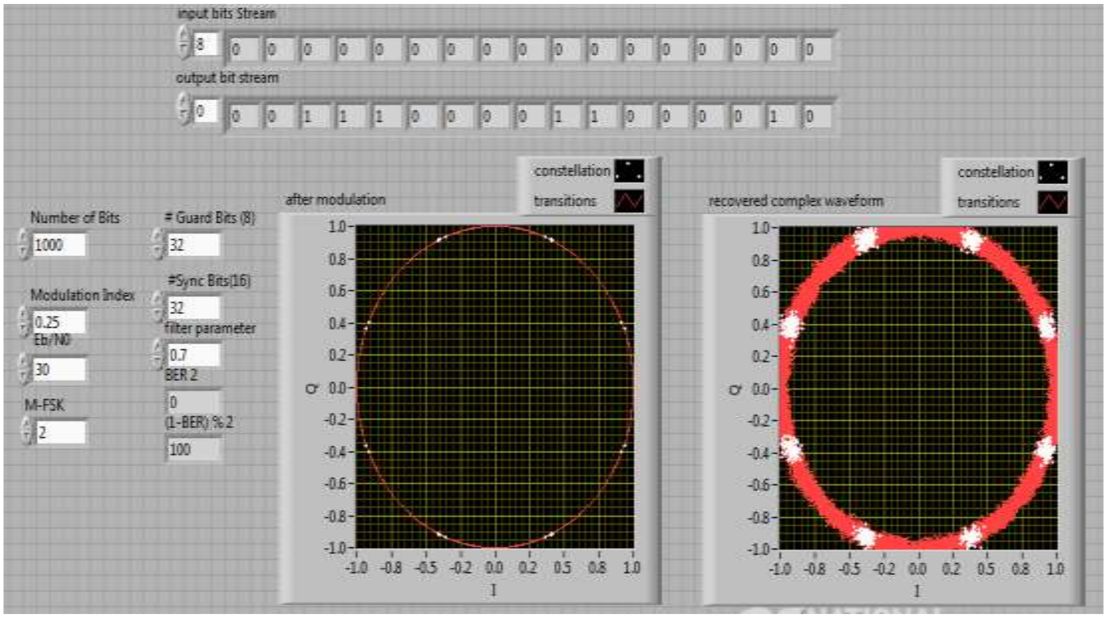


Figure 5-3 EDACS System

The transmission and reception was also tested in presence of AWGN channel with varying noise levels. The results are depicted in the form of a comparative graph between BER and E_b / N_o in figure 5-4. Results show satisfactory response of the transmission and reception in presence of noise.

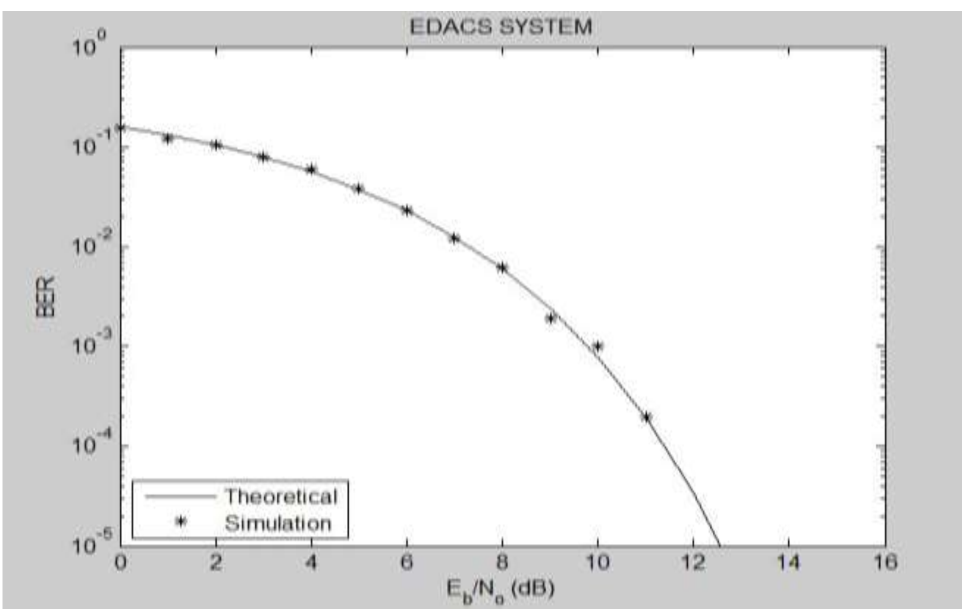


Figure 5-4 E_b / N_o verses BER - EDACS System

5.4 EDACS MS in TETRA Environment

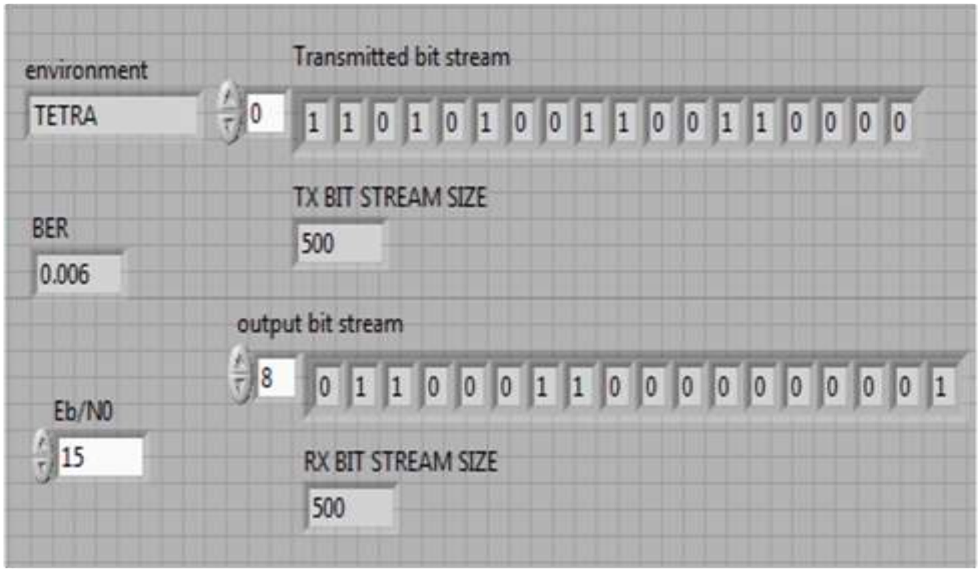


Figure 5-5 Transmission and reception, EDACS MS in TETRA environment

The figure 5-5 shows the transmitted and the received bits. It can be seen that the transmitted and recovered bits are similar with BER of 0.0060 at E_b/N_o of 15dB

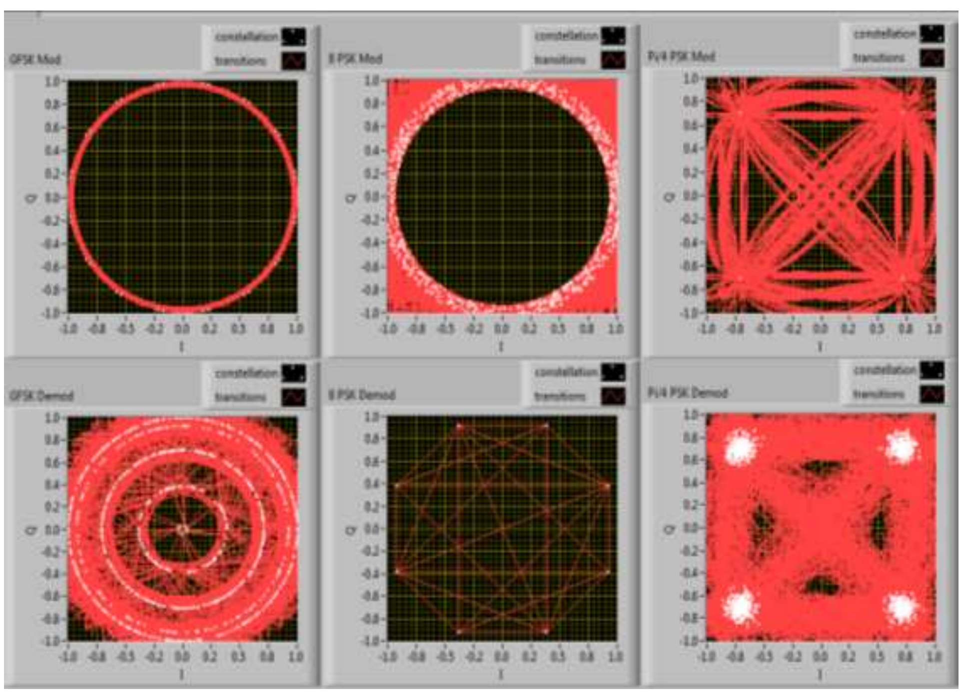


Figure 5-6 Constellation graphs for EDACS MS in TETRA environment

For EDACS MS first the GFSK modulated waveform was demodulated with 8-psk to maintain the system integrity and then it was modulated with Pi/4 PSK to transmit the signal in TETRA environment. At the receiver end the Pi/4 PSK Demodulation was used to convert the bits stream. Then the bit stream was modulated with 8-PSK and finally the message was recovered using GFSK demodulation. The respective constellation diagrams at an instance are shown in figure 5-6.

The transmission and reception was also tested in presence of AWGN channel with varying noise levels. The results are depicted in the form of a comparative graph between BER and E_b / N_o in figure 5-7. Results show satisfactory response of the transmission and reception in presence of noise.

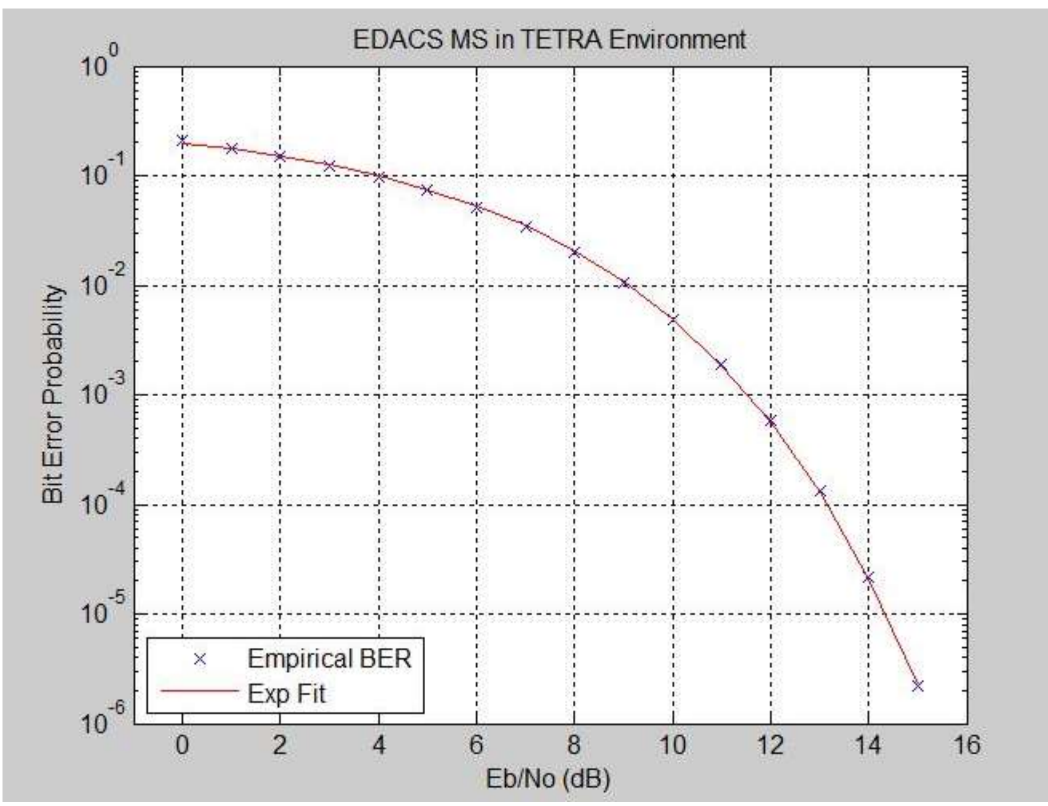


Figure 5-7 E_b / N_o verses BER - EDACS MS in TETRA Environment

Interoperability was successfully achieved and I was able to recover the transmitted message.

5.5 TETRA MS in EDACS Environment

Figure 5-8 shows the transmitted and received bit stream. It can be seen that the transmitted and recovered bits are similar with BER of 0.006 at E_b/N_o of 15dB.

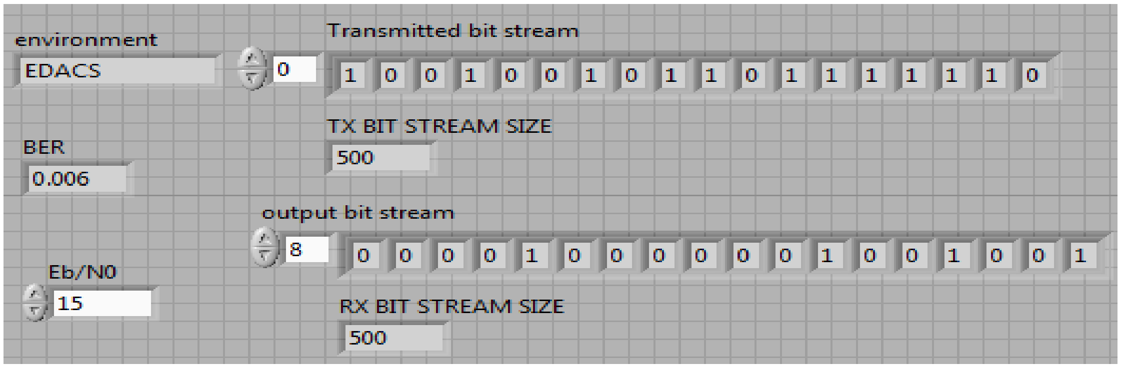


Figure 5-8 Transmission and reception -TETRA MS in EDACS environment

For TETRA MS first the Pi/4 PSK modulated waveform was demodulated with 4 PSK to maintain the system integrity and then it was modulated with GFSK to transmit the signal in EDACS environment. At the receiver end the GFSK Demodulation was used to convert the bits stream. Then the bit stream was modulated with 4 PSK and finally the message was recovered using Pi/4 PSK demodulation. The respective constellation diagrams at different instances are shown in figure 5-9.

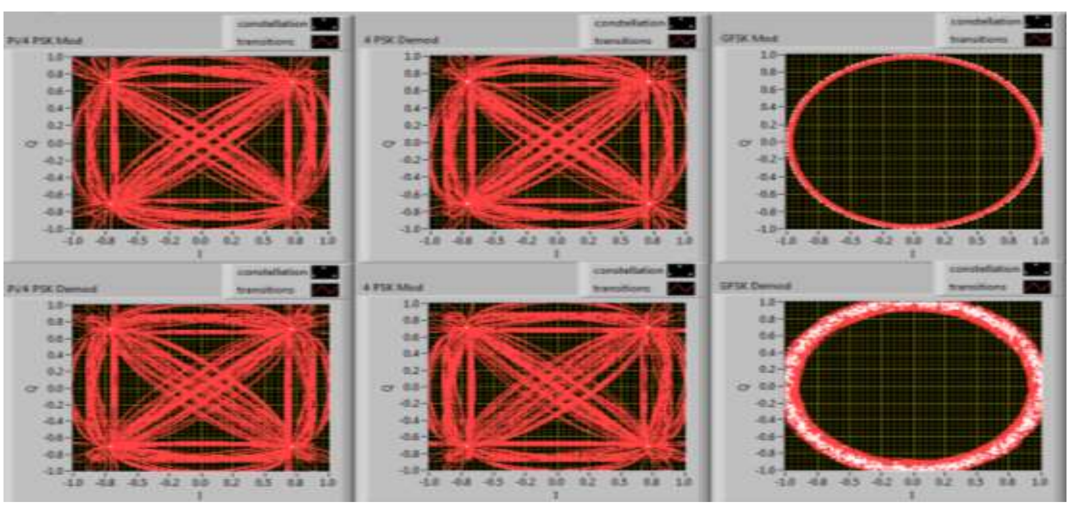


Figure 5-9 Constellation graphs for TETRA MS in EDACS environment

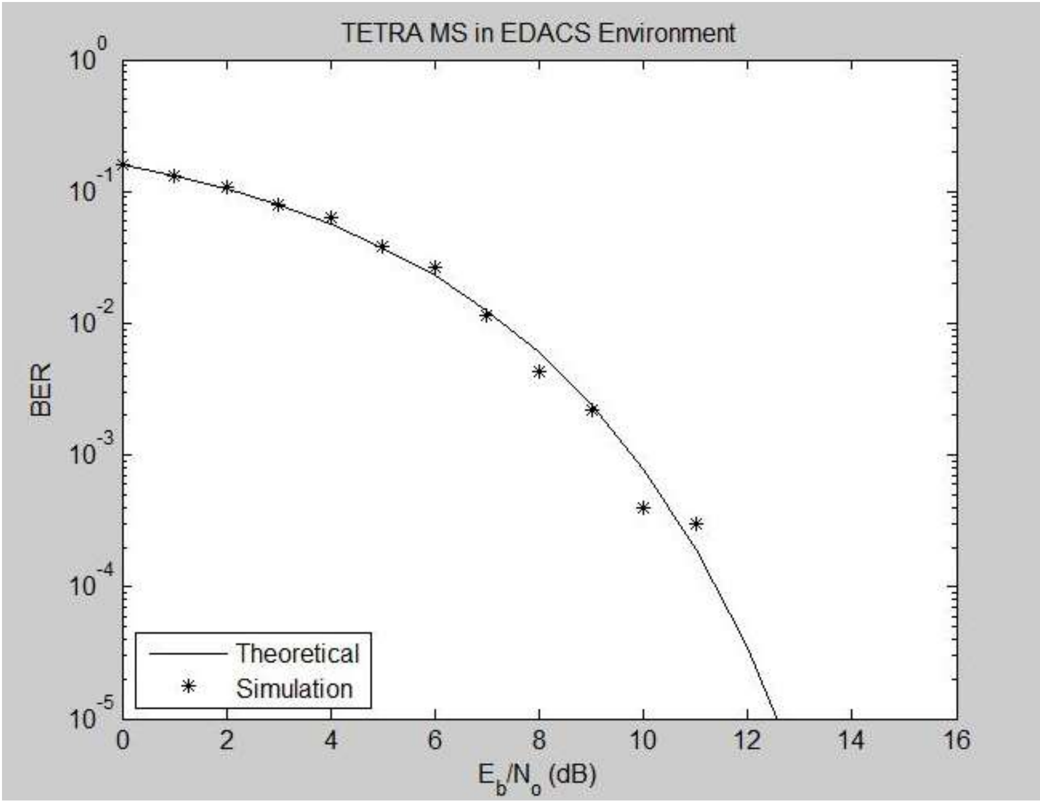


Figure 5-10 E_b / N_o verses BER - TETRA MS in EDACS Environment

The transmission and reception was also tested in presence of AWGN channel with varying noise levels. The results are depicted in the form of a comparative graph between BER and E_b / N_o in figure 5-10. Results show satisfactory response of the transmission and reception in presence of noise.

Interoperability was successfully achieved and the transmitted bits were recovered at the receiver.

5.6 Simulation Results of Direct Mode of TETRA

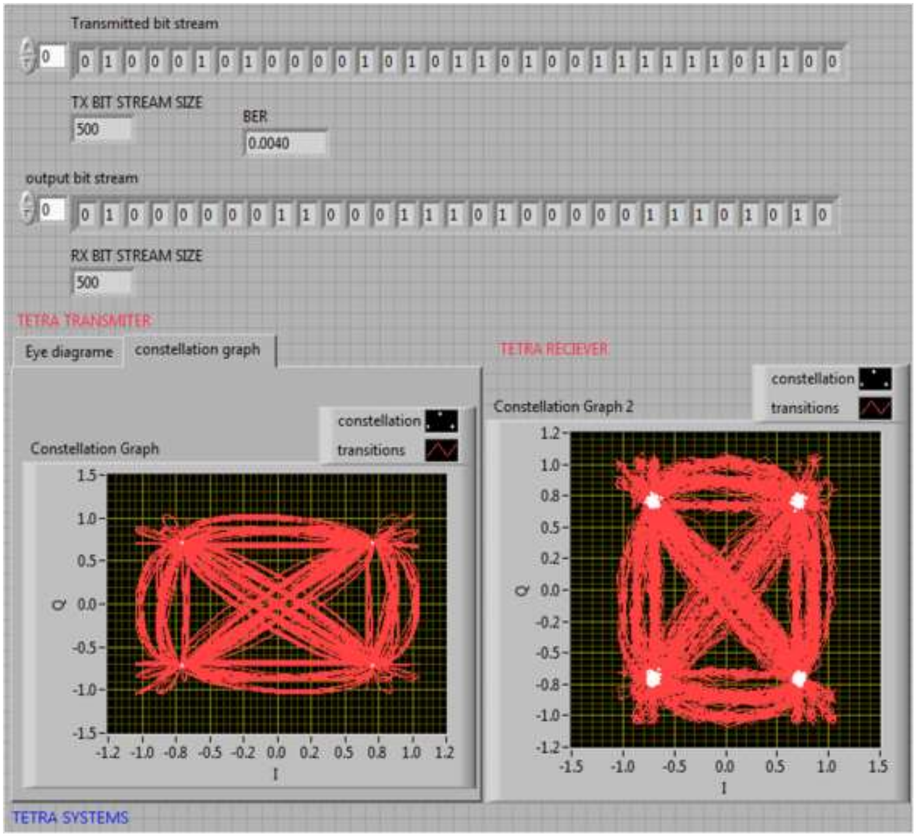


Figure 5-11 Simulation Result of Direct Mode of TETRA

In figure 5-11, i/p bit stream, o/p bit stream as transmitted and received at the receiver end are shown. Constellation graph of Pi/4 PSK Modulator and the expected graph at the demodulator, BER, Samples per symbol and E_b/N_0 also exist. I can analyse the result by considering the constellation graph, comparing the transmitted and received bits.

5.7 Simulation results of Direct Mode of EDACS

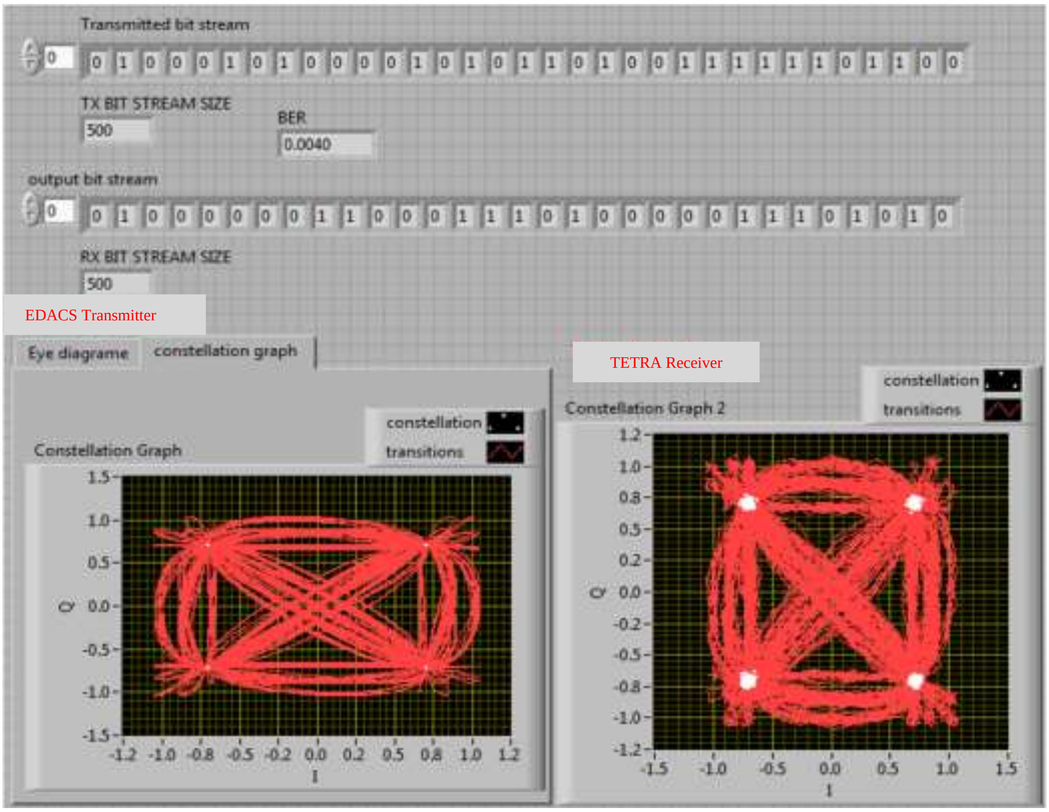


Figure 5-12 Simulation Result of Direct Mode of EDACS

The simulation results were similar to TETRA direct mode operation. The same constellation diagram was observed at transmitters and receivers at suitable SNR. The bits transmitted and received were similar with very less BER.

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Introduction

The primary aim of the thesis was to highlight the performance of the Interoperability between different networks. P25 is an open standard and manufacturers can easily license patented technologies. After the implementation of this project the users will have a good choice of selecting network operators and therefore ways will be open for healthy competition between service providers.

The interoperability between the different networks introduced in P25 standard would not only benefit the users by giving them open choice for selection of any network for communication but will also increase the wireless communication coverage area many folds. Because if even one of the component system of P25 standard is able to establish its communication in a far place, then other users will be able to access the network because of the interoperability between their network and the already installed network. After some time the interoperability introduced in this project is expected to extend to most of the popular commercially installed communication systems all over the world.

6.2 Recommendations and Future Work

This thesis is focused on interoperability and direct mode between the systems. Though these two methods have been covered with sufficient details there are still a few other parameters that are to be explored yet.

As discussed in chapter 2, there are six systems in Project 25 therefore an extension of our work would be to implement all the six system models with standard implementations.

Secondly, enhance the system capacity by adding 25 kHz, 12.5 kHz and 6.25 kHz operating channels. An incorporation of access techniques of the network would further improve the overall efficiency of the system.

Another dimension of future research is to develop complete interoperability between each pair of systems. After the establishment of interoperability between the six systems of P25, a centralized core network could be developed that would support all the six systems with a provision of handoff in between them without requiring any alteration in the user's hardware.

Research is an ongoing process and this work is by no means concluded, rather it is hoped that it will serve as a foundation for future endeavours in this important field.

6.3 Conclusion

In the present work a methodology for handover between TETRA and EDACS has been developed. For this purpose two systems TETRA and EDACS has been simulated in LABVIEW. Further an interoperability has been established between these two systems improving their performance in such a way that users can communicate even they are out of range from their own systems.

Along with interoperability, the provision of direct mode in the present work has further improved the system's performance. Direct mode channels are frequencies at which land mobile radios or other means of communication are able to communicate directly with each other without involving network. The proposed system has been designed for two conditions. In the first condition, under ordinary circumstances, the system will work in the conventional manner using π/4 PSK modulation scheme. But in case of emergency conditions (e.g. communicator is in an out of coverage area or in a disastrous area) the user may shift to direct mode and can enjoy a direct mode communication with the other user using the QPSK modulation scheme.