PAKISTAN ARMY RADIOFREQUENCY ANALYSIS AND MANAGEMENT SYSTEM (PARAMS)

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Submitted to Faculty of Electrical Engineering

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in partial fulfillment for the requirements of a B.E. Degree in

Telecommunication Engineering.

April 2006

Abstract

‘Frequency Spectrum’ is a scarce resource, demanding judicious use. The success of any communication plan requires an efficient frequency management system. Pakistan Army Signal Corps employs a number of radio sets in different frequency bands for provision of reliable communication. The current system of frequency allocation does not allow induction of new radio sets with different technical characteristics. A software based frequency analysis and management system has been developed. It analyses all factors of HF frequency communication theory. The emphasis is on an interference free distribution mechanism to the desired number of nets allowing usage of any type of radio equipment working on either fixed frequency (FF) or in frequency hopping (FH) mode. PARAMS has been designed to provide Pakistan Army with a dynamic and flexible HF frequency analysis and management system. An effort has been made to highlight the flaws in the system in vogue and the dire need of software envisaging new technologies.

Declaration

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

DEDICATION

Dedicated to our beloved Parents for their love, support and endless prayers that encouraged us to put in our best right through the span of this project.

ACKNOWLEDGEMENTS

The syndicate thank with complete humbleness to Allah Almighty for giving us the astuteness, ability and apparition to undertake this project and to put up our efforts under the umbrella of His myriad blessings. We extend our earnest gratitude to all those who helped us and prayed for our success in the accomplishment of this task successfully. There are many persons who have given their support in various capacities but some of the names demand their mention. They include Brig Ashraf and Col Mohsin Bokhari of Military College of Signals. Col Muzaffar Mustafa of Strategic Plans Division Chaklala. Maj Tariq and Sub Ghaffar of Signals Dte. Dr Badar, Mr Saleem and Mr Imran Iqbal of SUPARCO. Lt Col (Retd) Nazir of FAB. Above all we would like to thank our project supervisor Maj Imran Rashid whose experienced guidance stood as the epitome for us. His kind help, interest and support aligned our efforts in the right direction.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

List of Acronyms and Abbreviations

CCIR	Consultative Committee for International Radio Communication
CCITT	Consultative Committee for International Telephone and Telegraph
dB	Decibel
EHF	Extremely High Frequency
ELF	Extremely Low Frequency
EM	Electromagnetic
FAB	Frequency Allocation Board
FASC	Frequency Allocation Sub Committee
FSL	Free Space Loss
GHz	Giga Hertz
GUI	Graphic User Interface
HF	High Frequency
IFBR	International Frequency Registration Board
ITU	International Telecommunication Union
ITU-D	ITU-Development
ITU-R	ITU-Radio Communication
ITU-T	ITU- Standardization
KHz	Kilo Hertz
KM	Kilometer
LF	Low Frequency
LUF	Lowest Usable Frequency
MB	Mega Bit
MF	Medium Frequency
MHz	Mega Hertz
MUF	Maximum Usable Frequency
Na	Atmospheric Noise
NCC	National Control Centre
NFMMS	National Frequency Monitoring and Management System
Nm	Man Made Noise
PARAMS	Pakistan Army Radiofrequency Analysis and Management System
PRC	Portable Radio Communication
SHF	Super High Frequency
SLF	Super Low Frequency
SSN	Sun Spot Number
SUPARCO	Space and Upper Atmosphere Research Company
UG	Under Graduate
UHF	Ultra High Frequency
ULF	Ultra Low Frequency
UN	United Nation

VHF	Very High Frequency
VLF	Very Low Frequency
WWW	World Wide Web

Key to Mathematical Symbols

a	Radius of Earth
b_1	Bearing From Transmitter to Receiver
b_2	Bearing From Receiver to Transmitter
D	Distance in Km
dn	Angular Distance of Reflection Area
E	rms Field Strength in dB
e^-	Electron
f	Frequency
f_bEs	Blanking Frequency for E-Layer Storms
fH	Horizontal Component of Gyro frequency
f_ob	Frequency for Oblique Path
f_oE	Critical Frequency for E-Layer
f_oF1	Critical Frequency For F1 Layer
f_oF2	Critical Frequency for F2 Layer
F_v	Critical or Vertical Frequency
g_n	Geometrical Latitude of Reflection Area
G_r	Gain of Receiver
G_t	Gain of Transmitter
$h'E$	Virtual Height for E-Layer
$h'F2$	Minimum Virtual Height of F2 Layer
h_ob	Virtual Height of Oblique Path
$hpF2$	Virtual Height For F2 Layer Corresponding to Frequency = $0.83f_oF2$
L_g	Ground Reflection Loss
L_i	Ionospheric Loss
$M(3000)F2$	Conversion Factor of Critical Frequency to Oblique Frequency
N	Number of hops
O	Oxygen
P	Transmitter Power Output
R_{12}	12 month Average SSN
s_y	Sub solar Longitude
t_g	Universal Time
Φ	Angle Between Virtual Ray and Normal to Earth At h_ob
Δ	Take off Angle
θ_t	Angle Of Reflection
x_1	Geographical Latitude for Transmitter
x_2	Geographical Latitude for Receiver
x_n	Geographical Latitude of Reflection Area
y_1	Geographical Longitude for Transmitter
y_2	Geographical Longitude for Receiver

Yn Geographical Longitude of Reflection Area
$\mathbf{Y_p}$ Excess System Loss
ž Sun Zenith Angle

1. INTRODUCTION

The problem of frequency allocation and its usage has been haunting the global governing organizations since the inception of wireless communication. Its use has increased manifolds with the advent of modern technology. It is quite surprising that no purposeful endeavor in this field has been done in the past in Pakistan and particularly in Pakistan Army. However, Frequency Allocation Board (FAB) at Islamabad has recently acquired frequency management software. The limitation of that software is that despite efficiently assigning frequencies to different organizations of Pakistan, it is ill equipped to distribute and analyze individual frequencies for various nets within a frequency band. The requirement of frequency management in Pakistan Army is quite different and somehow complex than it is for commercial organizations.

The demand of frequency spectrum by Army depends upon the equipment that is to be used for a particular frequency band. Similarly the frequency distribution plan in High Frequency (HF) band within Army has been designed for radio set PK/PRC-786. This plan does not cater for induction of any new equipment with different technical characteristics. The issue becomes more complex with the fact that no continuous spectrum has been allocated for Pakistan Army, instead spot frequencies are available.

Pakistan Army Radiofrequency Analysis and Management System (PARAMS) offer a solution to these problems. It is a software based frequency analysis and management system that has a stored database of all required data of HF frequency communication. It analyzes each frequency and provides workable frequencies for both day and night operations suitable to geographical locations. It allows employment of multi-equipment operation for simultaneous fixed and hopping communication nets.

The complete HF frequency communication theory has been analyzed and prediction processes for frequencies have been explored and implemented. This report gives the concept, mechanism and implementation of PARAMS with a brief reference to the history of radio communication, frequency management and the role of global governing organizations.

2. BRIEF HISTORY OF RADIO COMMUNICATION

2.1 Introduction

Late 19th and 20th century saw the great technological evolution. Telecommunications alone has been a single source of bringing the world closer. It was deemed necessary to have a brief insight in history of wireless communications before the issue of frequency management is addressed. This chapter deals with the early days of radio communication. It also gives a brief account of the formation and development of International governing bodies.

2.2 Discovery of Radio Waves

In 1844, an American scientist named Samuel Morse sent his first public message over a telegraph line between Washington and Baltimore. The 'telecommunication' era had begun. However, it took a lot of hard work and many years by various scientists in different parts of the world to do wire-less communication.

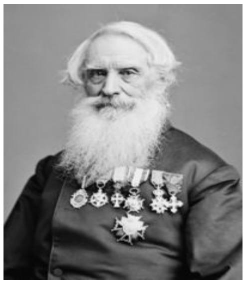

Figure-1: Samuel Finley Breese Morse [1]

In 1864, James Clark Maxwell, a Cambridge professor successfully forecast the laws, governing the propagation of radio waves. He calculated the speed of radio waves and compared it with the light waves. Maxwell showed how radio waves could be reflected, absorbed and focused like the beam from a torch and could change the very nature of the object on which they are focused.

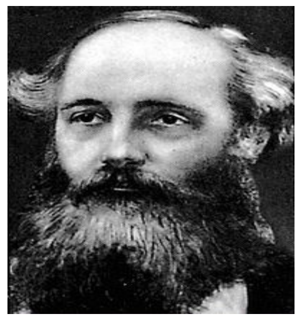

Figure-2: James Clark Maxwell [2]

In 1879, Professor David Hughes invented a device that caught the sound of radio waves.

In 1887, German scientist Heinrich Hertz carried out a famous set of experiments that proved Maxwell had been right in his theories.

Figure-3: Heinrich Hertz [3]

In 1894, British scientist Oliver Lodge succeeded in transmitting wireless signals over 150 yards.

‘Radio’ as a term was first used in United States of America. It was derived from radiation – the principle that governs radio waves. [4]

2.2.1 First Wireless Signal

In 1896, a 22-year old Italian physicist called Guglielmo Marconi demonstrated a new system of ‘telegraphy without wires’ at a distance of 300 yards.

Figure-4: Guglielmo Marconi [5]

2.2.2 First Transatlantic Radio Message

In 1901, Marconi sent a radio message across the Atlantic Ocean. He was successful and received signals from across the ocean – three dots representing the letter ‘S’. [6]

Alexander Popov, a Russian mathematician and physicist, invented a wireless communications system at about the same time as Marconi. Popov was trying to detect thunderstorms in advance by picking up static electrical signals, which led him to experiment with wireless. In May 1895 he transmitted a signal at a modest 600 yards, and within two years his wireless system was installed on Russian land stations and naval vessels. [7]

Figure-5: Alexander Popov [8]

2.3 Development at International Level

On 17th May 1865, first International Telegraph Convention was signed in Paris by the 20 founding members and the International Telegraph Union (ITU) was established to facilitate subsequent amendments to the initial agreement.

In order to study the question of international regulations for radio-telegraph communications, a preliminary radio conference was held in 1903. The first radio-telegraph convention was signed in Berlin in 1906. This convention was named as Radio Regulations.

2.3.1 Consultative Committee (CCIR)

In 1920, Marconi Company started its commercial sound broadcasting. In 1927, the International Radio Consultative Committee (CCIR) was established. The International Telephone Consultative Committee (CCIF) and the International Telegraph Consultative Committee (CCIT) were established in 1924 and 1925 respectively. CCIR was made responsible for coordinating the technical studies, tests and measurements being carried out in the various fields of telecommunications. It was also responsible for drawing up international standards.

2.3.1.1 Frequency Management

CCIR was also made responsible for allocation of frequency bands to various radio services of that time. Those included fixed, maritime and aeronautical mobile, broadcasting, amateur and experimental. This ensured greater efficiency of operation in view of the increase in the number of radio-communication services and technical peculiarities of each service.

2.3.2 International Telecommunication Union (ITU)

In 1932, the International Telecommunication Union (ITU) was formed. The name was given in 1934. It covered all types of wire-line and wireless communication. In 1992, ITU was remodeled in order to meet the new requirements with the advent of fresh technologies and increase in use of telecommunications. It aimed at giving greater flexibility to ITU to adapt to an increasingly complex, interactive and competitive environment.

2.4 Modern Approach

In 1947, after the Second World War, ITU held a conference in Atlantic City with the aim of developing and modernizing the organization. On 15th October 1947, it became a specialized agency of the newly created United Nations (UN). The headquarters was shifted to Geneva.

2.4.1 International Frequency Registration Board (IFRB)

After becoming the specialized agency of UN, ITU formed International Frequency Registration Board (IFRB). The task of IFRB was to coordinate the increasingly complicated task of managing the radio-frequency spectrum.

IFRB also deals with the international radio regulations as follows:-

- Working on non-interference basis.
- A registered frequency takes priority over an unregistered frequency.
- Where both frequencies are registered the older registered takes precedence.

2.4.2 International Telephone and Telegraph Consultative Committee (CCITT)

In 1956, CCIT and CCIR were merged to form the International Telephone and Telegraph Consultative Committee (CCITT). It was established in order to respond more effectively to the requirements generated by development and usage in the field of telecommunications.

2.4.3 Reorganization of ITU

In 1992, the Union was streamlined into three sectors each having a defined role. The new system also introduced a regular cycle of conferences to help the Union rapidly respond to new technological advances. The new sectors were:-

- Telecommunication Standardization (ITU-T)
- Radiocommunication (ITU-R)
- Telecommunication Development (ITU-D)[4]

2.5 Summary

The men credited with inventing wireless communications have been mentioned in this chapter. The need for an internationally accepted organization for coordination and management of telecommunications led to the formation of ITU and other related organizations. The development of these organizations has been given in this chapter in order to have an understanding in their functionality.

3. FREQUENCY MANAGEMENT

3.1 Introduction

Frequency spectrum is a scarce resource. The increase in the number of users and the inception of various types of radio equipment of same frequency band demands an efficient system of frequency allocation and its management. This chapter focuses on the issues related to 'frequency spectrum', its usage and international system of management. Moreover, the role of national organizations has been analyzed. The emphasis has been given to the frequency management within Pakistan Army.

3.2 The Electromagnetic (EM) Spectrum

The 'electromagnetic spectrum' is the range of all possible electromagnetic radiations. The electromagnetic spectrum extends from frequencies used in the electric power grid to gamma radiations covering wavelengths from thousands of kilometers down to fractions of the size of an atom. Following figure depicts the EM spectrum. [9]

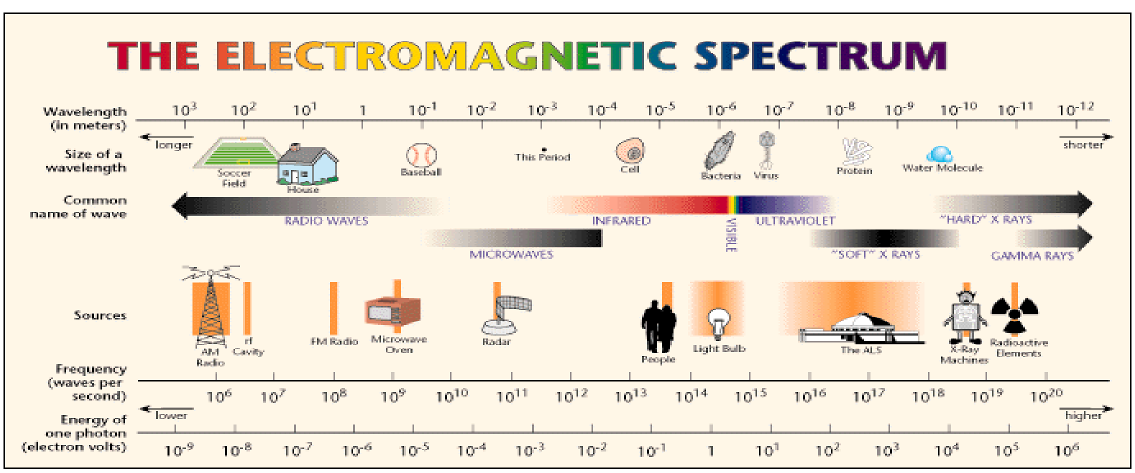

Figure-6: The Electromagnetic Spectrum [10]

Radio frequency comprises of those range of electromagnetic spectrum whose wavelength is suitable for radio communication. Frequency and wavelength are inversely proportional to each other. If the frequency increases, wavelength decreases. Short waves have relatively high frequencies; long waves have relatively low frequencies. Radio waves are identified by their frequencies, expressed in kilohertz (kHz), megahertz (MHz) or gigahertz (GHz) i.e thousands, millions and billions of cycles per second, respectively. A range or band of radio frequencies is controlled and assigned internationally by International Telecommunication Union (ITU). [11]

3.3 Radio Frequency Spectrum as covered by ITU Regulations

The total available resource as defined by ITU encompasses following:-

- The total available resource (f < 3000GHz) is limited by laws of physics.
- The technical available resource (300GHz < f < 3000GHz) is limited by present techniques.
- The technical exploitable resource (f < 60GHz) is limited by technical and economical constraints.

The radio frequency spectrum is shown in the following table.

Band Name	ITU Band	Frequency	Examples
Extremely Low Frequencies (ELF)	1	3-30 Hz	Communication with submarines
Super Low Frequencies (SLF)	2	30-300 Hz	Communication with submarines
Ultra Low Frequencies (ULF)	3	300-3000 Hz	Communication within mines
Very Low Frequencies (VLF)	4	3-30 kHz	Communication with submarines, avalanche beacons, wireless heart-rate monitors
Low Frequencies (LF)	5	30-300 kHz	Navigation, time signals, AM long wave broadcasting
Medium Frequencies (MF)	6	300-3000 kHz	AM medium wave broadcasting
High Frequencies (HF)	7	3-30 MHz	Short wave broadcasts and amateur radio
Very High Frequencies (VHF)	8	30-300 MHz	FM and Television broadcast
Ultra High Frequencies (UHF)	9	300-3000 MHz	Mobile phones, TV, wireless-LAN, ground-to-air and air-to-air communication
Super High Frequencies (SHF)	10	3-30 GHz	Microwave devices, radars,
Extremely High Frequencies (EHF)	11	30-300 GHZ	Radio astronomy, high-speed radio relay
		Above 300 GHz	Night Vision

Table-1: Radio Frequency Spectrum [12]

3.4 Levels of Management

The frequency spectrum, its allotment and usage, is managed at two levels world wide.

3.4.1 International Level

ITU is responsible for frequency management internationally. As per ITU regulations, frequency is allocated to all the member countries of UN. The frequencies are allocated band wise. The record of all assigned frequencies in each frequency band is maintained at the ‘Master International Frequency Register’. It is a data base which contains:-

- Record of frequency assignment.
- Records of geo-stationery satellite positions.

IFRB, a sub-committee of ITU, is responsible for registration of frequencies. No unregistered frequency can operate at any time throughout the world. It receives demands from different countries and makes a decision for acceptance or rejection on the basis of availability, interference etc.

The objectives set by ITU for management of frequency at international level are:-

- To optimize use of frequency spectrum.
- To prevent harmful interference between two countries.
- To decrease the number of administrative procedures and their recurrences.
- To facilitate new network deployment.

3.4.1.1 Frequency Allocation

World has been divided into three regions by ITU for the purpose of frequency allocation.

- Region-1: Europe, Africa, Russia and the Central Asian States.
- Region-2: North and South America.
- Region-3: Australia, Asia less Russia and Central Asian States.

3.4.1.2 Allocation Table

Allocation of frequencies is done at ITU through a table of allocation. This table of frequency allocation was first introduced in 1912 and has been declared mandatory.

3.4.2 National Level

Each country has the responsibility to manage and allocate the frequencies within the country. A national body defines and implements the national radio regulations in accordance with the instructions of ITU. National regulations generally include the following:-

- Distribution of bands between national users, ministries, army etc
- Coordination between national users for settlement of disputes.
- Coordination of the radio stations on the national territory.
- Preparation and participation in international conferences.
- Notification to ITU.
- Keeping the national 'Master Frequency Register.'
- Implementation of rules and regulations.
- Monitoring.

3.5 Frequency Management in Pakistan

Frequency Allocation Board (FAB) with its headquarters at Islamabad is the national body of Pakistan which deals all issues related to frequency allocation and its distribution. The major functions of FAB are:-

- To assign frequencies in Pakistan and in areas controlled by authorities in Pakistan.
- To coordinate assignment of frequencies with other boards when the frequencies are required for channels working to places outside Pakistan or where interference to channels operated by other authorities is likely to occur.
- To take such actions as is considered necessary to ensure the correct observation of the provisions of the international radio communication radio regulations with particular reference to tolerances, bandwidth of emissions.
- To advise government on any proposal to establish new wireless services and their operation.
- To maintain liaison with other boards and committees for the purpose of maintaining as complete record as possible of frequency assignments throughout the world.
- To coordinate the defense department and civil wireless system and advise on all matters of common interest with particular regard to the networks as they may affect one another.
- To prepare and keep constantly under review plans for the utilization of the defense department and civil wireless system in the disposal of urgent traffic during an emergency or breakdown of any line of telecommunication system.
- To control the sitting of all new fixed wireless stations in Pakistan.

- To scrutinize all applications for wireless transmitting licenses and advise the director general of posts and telegraphs thereon.[13]

3.5.1 Spectrum Management in Pakistan

In order to optimize the available spectrum, FAB has recently launched a system named National Frequency Management and Monitoring System (NFMMS). This system is aimed at integrated radio spectrum management and monitoring capabilities along with processing of licensing, regulations and tariff issues in post privatization era.

3.5.1.1 Monitoring

In order to monitor interferences among operators, number of fixed and mobile monitoring stations has been established as part of NFMMS. It has the capability to effectively monitor the frequency spectrum in various frequency bands ranging from 10 kHz to 22 GHz. All the monitoring stations have been equipped with the integrated, state of the art monitoring hardware and software to undertake the monitoring tasks.

3.5.1.2 Management

Establishment of National Control Center (NCC) along with the monitoring stations under NFMMS spread all over the country including mobile units. It has state of the art Spectrum Management Software tools for performing real time and swift analysis of the applications / proposals of applicants and optimizing the use of the available spectrum while securing the license conditions. [14]

3.6 Frequency Management in Pakistan Army

Signals Directorate under Chief of General Staff at General Headquarters, Rawalpindi, is responsible for management of frequency for different frequency bands within Pakistan Army. It initiates the demand for frequency allotment to FAB on the basis of communication equipment as soon as it is inducted for service. In case of HF frequency band, since the inception of Portable Radio Set PK /PRC – 786, FAB has allocated 2 – 12 MHz band for Pakistan Army. In addition 1686 different spots are available with Pakistan Army in HF frequency band. The different types of frequency distribution systems currently in practice are explained briefly in the preceding sections.

3.6.1 Existing Systems of Frequency Allocation in Pakistan Army

Pakistan Army employs two systems of frequency allocation for HF frequency band within the army. The aim of these systems is to reuse and share the limited registered frequencies in HF frequency band with least possible interference.

3.6.1.1 Regional System

This system is used where there is low concentration of troops over a large area. The theatre of war is divided into regions and blocks of frequencies are allocated. The main disadvantage of the system is that it does not allow for concentration of troops in one region at a short notice. The blocks are as follows:-

- Block ‘A’: General Headquarters, inter regional link and General headquarters theatre troops.
- Block ‘B’, ‘C’ and ‘D’: It contains blocks of frequencies for use with transmitters having power output of more than 100 watts. It is repeatable in every 4^{th} region.
- Block ‘E’: It contains blocks of frequencies for use with transmitters having power output of less than 100 watts. It is used in every region.

3.6.1.2 The List System

The list system of allocation of frequencies is being used currently. It has been formulated for use in main theatre of war. It consists of lists of frequencies having different power. These lists are repeated geographically at every 4^{th} or more formations or headquarters of the same type.

The number of frequency lists to various signal units and training institutions are allocated separately. This system works with large concentration of troops and can cope with indefinite number of formations. The disadvantage is that it gives little flexibility within formation owing to small number of frequencies which is further aggravated by power restrictions. The different types of lists are shown in the table below.

List Name	List Number	Power Rating
K	K1-K2	10 kiloWatts
M	M1-M50	500 Watts

N	N1-N27	100 Watts
P	P1-P34	25 Watts

Table-2: Lists of Frequencies used in the List System

3.6.2 Activation of Frequencies

Due to acute shortage of clear frequencies in the HF frequency band, there are many agencies that are always on the look out for finding frequencies for their use. In accordance with the international regulations on frequency registration, any frequency which remains inactivated for a continuous period of 60 days can be applied for registration by any prospective user. It is therefore essential that all of assigned frequencies are activated to avoid inactivation. Frequencies must be activated for a period of at least 24 hours either continuous or interrupted barring the frequencies pertaining to ‘P’ list.

As sufficient frequencies within appropriate power rating blocks may not be available. It is therefore permissible to use frequencies of higher power rating for sets having low power output provided frequency activation in the proper power is done according to the instructions given above. Frequencies meant for low power sets, however, cannot be used on sets with high power output.

3.6.3 Method of Registering Frequencies

The sequence of action adopted for the registration of frequencies by various agencies involved is as under:-

- General Headquarters: It compiles the requirement, prepares the notice and sends it to FASC (FAB).
- FASC: It scrutinizes the technical data, coordinates internally before forwarding the demand to IFRB (ITU).
- IFRB: It scrutinizes, monitors for a specified time, provisionally accepts it, confirms after specified period if no interference is reported and finally publishes it in the International Master Frequency Register.

3.6.4 Analysis of the Current System

The list system as explained in section 3.6.1.2 needs revision. After detailed analysis, following conclusions are drawn:-

- The lists are rated on the basis of power. These lists are distributed amongst all Corps of Pakistan Army on monthly basis.
- Headquarters Signals of each Corps retains the required frequencies to be used for radio nets of Corps Headquarters. Corps Operation Signal Battalion then forwards the frequencies to the under command formations of the Corps.
- Radio Company of a Division Signal Battalion manages the frequency at formation level.
- There is no differentiation for day or night frequencies in these lists.
- The feasibility of frequencies is not checked at any stage.

- As communication in HF frequency band incorporates the use of ionosphere for sky wave propagation, no consideration is given to any of the factors involved in this phenomenon. The factors namely are the sunspot numbers, concentration of charges and all the predicates pertaining to ionosphere in a particular geographical location.
- The frequencies suitable for sky wave communication at one geographical location, may not work in other geographical location. As a result a number of frequencies remain unused owing to their unsuitability.
- The allotted frequencies are checked in the formation by radio company using raw methods. For instance, the operators would make an attempt to establish communication on the allotted frequencies from the list. Frequencies are then marked suitable for communication.

3.7 Summary

The frequency spectrum is managed at both the international and national level. These management processes have streamlined the method of registering frequencies. The detailed arrangement of frequency management in Pakistan has been presented. The analysis of the existing system of frequency management within Pakistan Army is particularly important to grasp the essence of PARAMS.

4. THEORY OF HF FREQUENCY COMMUNICATION

4.1 Introduction

The HF frequency band ranges from 3-30 MHz. It is necessary to understand the mechanism of HF frequency communication before it is employed in a management system. This chapter emphasizes on various aspects of HF frequency band communication theory. It employs two main types of wave propagation; the ground waves and the sky waves. The sky wave propagation has been discussed in some detail as it incorporates a number of factors for successful communication. The literature available on ionosphere and its role in HF sky-wave radio communication is quite extensive. Theories concerning ionospheric propagation are not repeated here in detail, but some background material is given for an understanding of the prediction processes and those necessary to comprehend the philosophy of PARAMS.

4.2 Background

Scientists carried out many experiments to study the variations in communication ranges while working on high frequency. It was after 1930 that a link between these variations in communication ranges and ionosphere was established. It was only then that an investigation was carried out to determine the ionospheric parameters and their effects on radio wave propagation.

HF frequency communication employs two main types of radio waves. Firstly those waves which travel with the surface of earth known as ground waves, and secondly those waves which go up in the sky and fall back after reflection from ionosphere known as sky waves.

4.3 Classification of Radio Waves

Radio waves are classified in two ways:-

- According to the frequency or wavelength.
- According to the path followed between transmitter and receiver.

Radio waves always travel at the speed of light i.e., 3×10^8 meters per second. Classification of radio waves with respect to their path is shown in the following table.

Band	Radio Wave
VLF	Myriametric
LF	Kilometric
MF	Hectometric
HF	Decametric
VHF	Metric
UHF	Decimetric
SHF	Centimetric
EHF	Millimetric

Table-3: Classification of Radio Waves according to the path

4.4 Ionosphere

The atmosphere of the earth comprises of various layers. These layers vary in density and composition as the altitude increases above the surface. Figure-7 shows these layers. The lowest part of the atmosphere is called the 'troposphere' and it extends from the surface up to about 10 kilometers (6 miles). The gases in this layer are predominantly molecular Oxygen (O_2) and molecular Nitrogen (N_2). All weather is confined to this lower layer and it contains 90% of the earth's atmosphere and 99% of the water vapors. The highest mountains are still within the troposphere and all of our normal day-to-day activities occur here. The high altitude jet stream is found near the 'tropopause', at the upper end of this layer.

The atmosphere above 10 kilometers is called the 'stratosphere'. The gas is still dense enough that hot air balloons can ascend to altitudes of 15 - 20 kilometers and Helium balloons to nearly 35 kilometers, but the air thins rapidly and the gas composition changes slightly as the altitude increases. Within the stratosphere, incoming solar radiation at wavelengths below 240 nm is able to break up or dissociate molecular Oxygen (O_2) into individual Oxygen atoms, each of which, in turn, may combine with an Oxygen molecule (O_2), to form Ozone, a molecule of Oxygen consisting of three Oxygen atoms (O_3). This gas reaches a peak density of a few parts per million at an altitude of about 25 kilometer (16 miles).

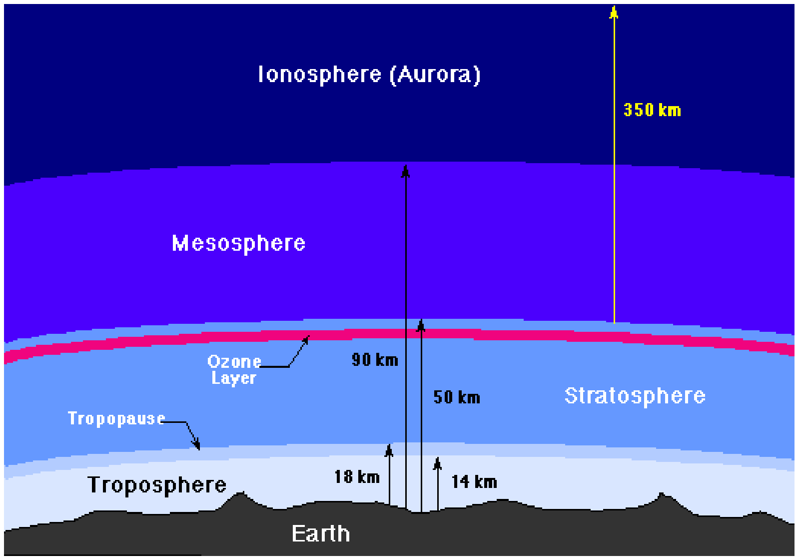

Figure-7: Diagrammatic Representation of Earth's Atmosphere [15]

The gas becomes increasingly rarefied at higher altitudes. At heights of 80 kilometers (50 miles), the gas is so thin that free electrons can exist for short periods of time before they are captured by nearby positive ion. The existence of charged particles at this altitude and above, signals the beginning of **ionosphere**, a layer having the properties of a gas and of plasma. [16]

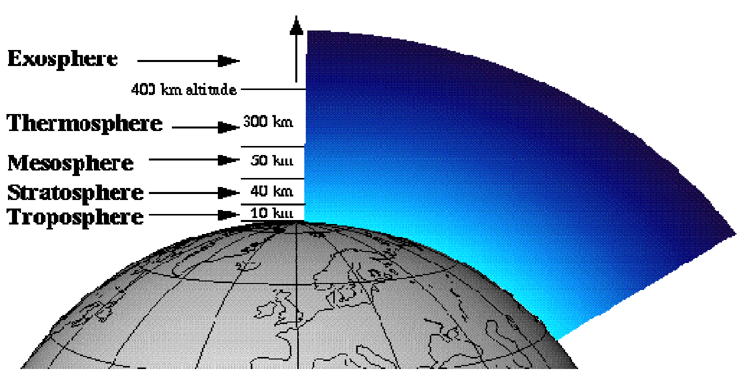

Figure-7: Layers in Atmosphere above Earth's Surface [17]

4.4.1 History of Ionosphere

The connection between electricity and magnetism was first realized by Oersted in as early as 1819. The theory of EM and the prediction of radio waves were put forward by Maxwell in 1864. The work of Hertz and Marconi in 1887 and 1899 respectively, showed the presence of ionosphere in earth's upper atmosphere. [18]

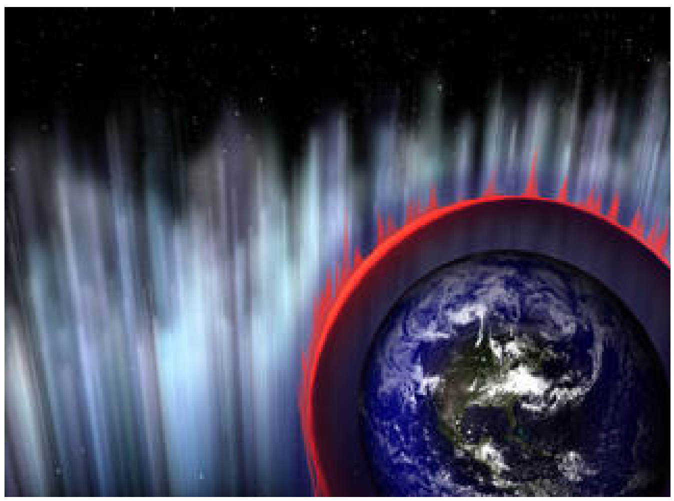

Figure-8: The Ionosphere [19]

In 1899, Nikola Tesla researched ways to utilize the ionosphere to transmit energy wirelessly over long distances. He transmitted extremely low frequencies through the earth and portions of the ionosphere in his experiments. Tesla made mathematical calculations and computations based on his experiments and discovered that the resonant frequency of this area was approximately 8Hz. In 1902, Oliver Heaviside proposed the existence of

‘Kenelly-Heaviside Layer’ of the ionosphere which bears his name. Heaviside’s proposal included means by which radio signals are transmitted around the earth’s curvature. Also in 1902, Arthur Edwin Kennelly discovered some of the ionosphere’s radio-electrical properties. The ionosphere was confirmed in 1923. **Edward V Appleton** was awarded a Nobel Prize for demonstrating the existence of the ionosphere. Lloyd Berkner first measured the height and density of the ionosphere. [20]

Figure-9: Edward V Appleton [21]

4.4.2 Theory of Ionization

Sky wave communication is only possible because of the existence of ionized layers in the earth’s upper atmosphere. These layers, under certain conditions have the power of bending back towards the earth wireless waves which strikes them. The formation of the ionized layers in the atmosphere is due to the phenomenon of ionization of gases by radiation.

When any gas at low pressure and density is subjected to sufficiently intense radiation, electrons are detached from the gas molecules, which are then left as positive ions, see figure- below. Owing to the presence of ‘free’ electrons and ions, the gas then becomes partial conductor of electricity and is said to be ionized. Ionization continues as long as the gas is subjected to radiation.

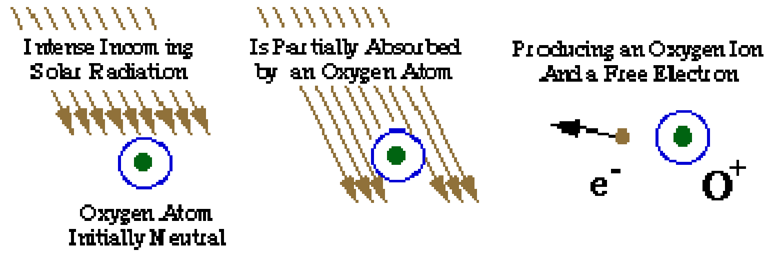

Figure-10: Detachment of Free Electrons of Oxygen Molecule due to Solar Radiation [16]

The degree of ionization depends of the following:-

- Intensity of radiation.
- The length of time for which the gas has been subjected to radiation.
- The density of gas.
- The characteristics of the particular gas (es) concerned.

Since electrons are negative and ions are electrically positive, they will necessarily tend to recombine. The rate of recombination depends upon the density of gas. The lower the density of gas, the farther apart will be the gas molecules resulting in the slower rate of recombination.

When the radiation is withdrawn from an ionized gas, the degree of ionization at any subsequent time will clearly depend on the degree of ionization at the time radiation stopped and on the rate of recombination and hence on gas density.

4.5 Ionospheric Layers

At heights from 50-450/500 kilometers from the earth's surface, under suitable conditions, ionization layers called ionosphere exists. As ionization results from radiation, sun is its source in the atmosphere. There will be considerable ionized layers at these heights during day time. At night when the sun's radiation is no more, ionization will tend to disappear owing to recombination. This happens particularly at lower levels of atmosphere where the gas density is higher and radiation is less intense. At higher levels, ionization persists for a little longer.

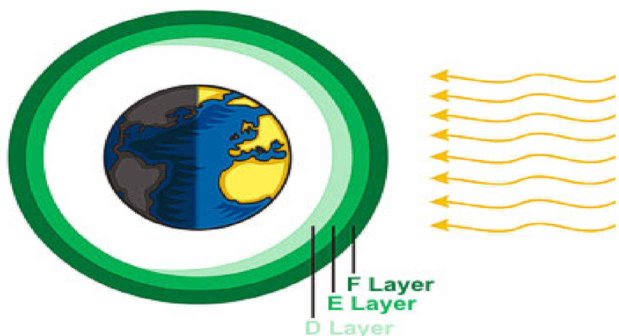

Figure-11: Ionospheric Layers [22]

4.5.1 'D' Layer

The D layer lies between the approximate limits of 60 and 90 kilometers above the earth's surface. The electron density is relatively small compared with the other layers. It is present only at day time because ionization is produced by the ultraviolet solar radiation. However, the wave loses energy due to the collisions between the molecules of atmosphere and the free electrons accelerated by the electromagnetic wave. This loss of energy is referred to absorption. The degree of absorption is expressed by the absorption factor.

This factor is directly proportional to the product of the collision frequency and electron density and is inversely proportional to the square of the wave frequency.

D layer absorption is important at all frequencies. The absorption in D layer is called non-deviative absorption. This type of absorption occurs below the level of reflection and predominates when little or no bending of the ray path takes place. It happens because of the low electron density in this layer. This is the reason that D layer does not reflect useful transmissions in the frequency range above 1 MHz.

Ionization decreases rapidly after sunset and as a result non-deviative absorption becomes negligible within 2 to 3 hours after sunset. Non-deviative D layer absorption is the principal cause of the attenuation of HF sky waves, particularly at the lower frequencies during daylight hours. [23]

4.5.2 'E' Layer

The approximate true height range of the regular E layer is 90 to 130 kilometers and it is assumed that the maximum electron density occurs at 110 kilometers and the semi-thickness is 20 kilometers. The ratio of the height to the semi-thickness is assumed to be 5.5. It is also a low ionized layer but has greater electron density in comparison with D layer. The most important characteristic feature of E layer is its critical frequency from communication perspective. Initially the E layer critical frequency was used to be determined by a semi-empirical equation involving the sunspot number and the zenith angle of the sun. In recent times sufficient ionospheric data (ionograms) has been collected and most features of E layer have become known. The minimum virtual height of the E layer and the variation of maximum electron density within this layer as a function of time and geographic location are easily accessible from the ionograms.

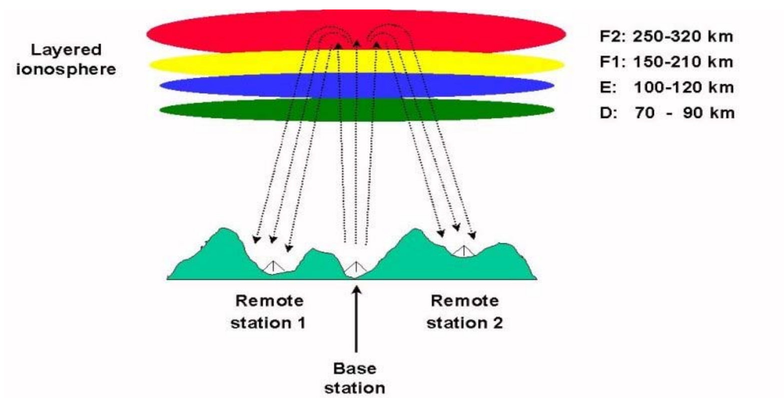

Figure-12: Reflection of Radio Waves from Ionospheric Layers [24]

4.5.2.1 Characteristics of 'E' Layer

The E-layer characteristics have been systematically analyzed and they include:-

- f_0E; The critical frequency of the ordinary component of the E layer. It is that frequency at which the signal from transmitter just penetrates the E layer.
- h'E; The minimum virtual height of E layer measured at the point where the trace becomes horizontal.
- f_0Es; The highest observed frequency of the ordinary component of sporadic E (Es).

- h'Es; The minimum virtual height of the sporadic E layer measured at the point where the trace becomes horizontal.
- fbEs; The blanketing frequency i.e., the lowest ordinary wave frequency at which the Es layer begins to become transparent, usually determined from the minimum frequency at which ordinary wave reflections of the first order are observed from a higher layer.

4.5.2.2 Predictions

The regular E layer is predicted using three parameters:-

- The monthly median value of critical frequency (f_0E).
- Height of maximum ionization of the layer (hmE).
- The ratio of hmE to semi-thickness (ymE).

Numerical coefficients of monthly median f_0E are available for computer applications in terms of geographic latitude, longitude and universal time. The numerical coefficients representing f_0E has been derived from measurements taken in the years which cover high and low phases of sunspot cycle. Interpolation has been used between the data to determine high and low values of the sunspot periods to obtain f_0E estimates. Little information is available concerning the statistical distribution of the monthly median f_0E. In daytime, the E layer is sufficiently regular that the distribution spread of the monthly median f_0E may be considered negligible. Therefore the E layer characteristics most important for communication purposes are adequately represented by the available f_0 E monthly median numerical coefficients. [23]

4.5.3 'F' Layer

F layer is the most important part of the ionosphere for HF frequency communication. It consists of two layers F1 and F2. The main peak of the layer is identified by F2 layer, while F1 layer appears at certain times at the lower level in F layer. The F1 layer has not been well defined as compared to F2 layer in terms of its predictable characteristic features. The F1 layer is only important to communication in the daylight hours or during ionospheric storms.

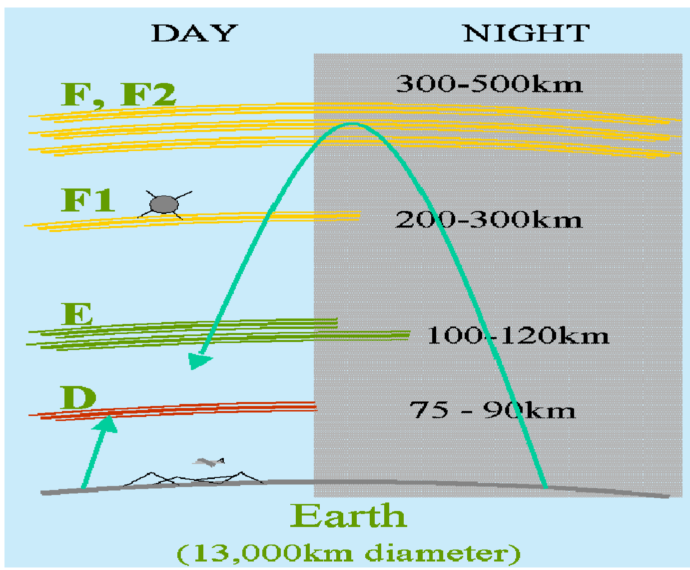

Figure-13: Approximate Heights of Ionospheric Layers [24]

This layer lies at heights from 200-250 kilometers from the earth's surface. It undergoes both seasonal and solar cycle variations which are more pronounced during summer and in high sun-spot periods.

4.5.3.1 Characteristics of 'F' Layer

The F-layer characteristics have been systematically analyzed and they include:-

- f_0F2: The critical frequency of the ordinary component of the F2 layer, i.e., that frequency at which the signal just penetrates the F2 layer.
- M (3000) F2: The factor for converting vertical-incidence critical frequencies to oblique incidence for a distance of 3000 kilometers via the F2 layer.
- f_0F1: The critical frequency of the ordinary component of the F1 layer; i.e., that frequency at which the signal just penetrates the F1 layer.
- h'F2: The minimum virtual height of the F layer; i.e., the minimum virtual height of the night F layer and the day F1 layer. It is measured at the point where the F trace becomes horizontal.
- hpF2: The virtual height of the F2 layer corresponding to a frequency f, where $f=0.834f_0F2$. This is based on the assumption of a parabolic ionization distribution, which is usually considered justified as an approximation to the height of maximum ionization of the F2 layer.

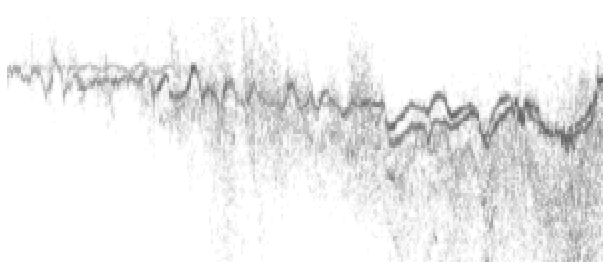

Figure-14: Wave Propagation at 3.5 MHZ in F layer. In this Spectrogram Vertical Axis show Frequency while the Horizontal Axis shows the Time. [25]

4.5.3.2 Predictions

The F2 layer is described by three parameters as follows:-

- The monthly median value of the critical frequency (f_0F2).
- The height of maximum ionization (hmF2).
- The ratio of hmF2 to the semi thickness (ymF2).

Monthly median values of f_0F2 and the M (3000) F2 for two solar activity levels are available as numerical coefficients in terms of a modified magnetic-dip angle and longitude, and universal time.

The recent model of F2 layer is based on a combination of observed and theoretical data. The theoretical data provides stability in large layers where no observed data existed, such as ocean area and non-industrialized areas. This F2 layer model shows minor improvements in populated layers and significant improvements over sea area and unpopulated layers when compared to observed ionosonde and satellite measurements. The model divides the F2 layer into four distinct zones as follows:-

- Normal low-latitude and mid-latitude ionosphere as described by the numerical coefficients.
- The trough.
- The zone of aurorally enhanced f_0F2.
- The polar cap.

4.6 Electron Density Profile Model

For the generation of the electron density profile a single set of critical frequencies and associated parameters are chosen. Depending on the path length, a process of elimination is used to reduce upto 5 control points to 1 to 3 control points that best represent the ionosphere for that particular communications circuit. The ionospheric parameters are then used to build an electron density profile.

4.6.1 Control Point Selection

As per CCIR 252-2, up to five geographic points are calculated along the circuit path. From these geographic locations, upto 3 control points are selected with ionospheric parameters assigned to each. When the ionospheric profile is generated, the layer parameters are selected from the values at three control points.

- Distance ≤ 2000 km - 1 Control point
    - f_oF2; from path midpoint
    - f_oF1; from path midpoint
    - f_oE ; from path midpoint

- 2000 km < Distance ≤ 4000 km – 2 Control points
    - Control point 1
        - f_oF2; from path midpoint
        - f_oF1; 1000 km from transmitter
        - f_oE; 1000 km from transmitter

- Control point 2
  - f_oF2; from path midpoint
  - f_oF1; 1000 km from receiver
  - f_oE; 1000 km from receiver

- 4000 < Distance ≤ 8000 km – 3 Control points
  - Control point 1
    - f_oF2; 2000 km from transmitter
    - f_oF1; 1000 km from transmitter
    - f_oE; 1000 km from transmitter
  - Control point 2
    - f_oF2; from path midpoint
    - f_oF1; from path midpoint
    - f_oE; from path midpoint
  - Control point 3
    - f_oF2; 2000 km from receiver
    - f_oF1; 1000 km from receiver
    - f_oF2; 1000 km from receiver

When circuit parameters that describe characteristics of the path are calculated, the profile is made up of the most pessimistic layer values, minimum f_oF2 or minimum f_oE when the f_oF2 values are approximately equal.

4.7 Calculation of Circuit Parameters from Path Geometry

To determine the operational parameters of an HF ionospheric radio communication circuit, it is necessary to calculate several parameters that are based on the geometry of the path.

4.7.1 Path Length and Bearings

The first parameter to be calculated, given the geographic latitude and longitude of the transmitting and receiving locations, is path length, which is taken to be the shorter of the great-circle distances between the two points, and which is computed as follows:-

$$\cos d = \sin x1 \sin x2 + \cos x1 \cos x2 \cos (y1-y2) \qquad (4.1)$$

where

x1 = geographic latitude of the transmitter,

y1 = geographic longitude of the transmitter,

x2 = geographic latitude of receiver,

y2 = geographic longitude of receiver,

d = path length in radians.

Having obtained the path length, we calculate the bearing of transmitter to receiver and receiver to transmitter along the great circle path:-

$$\cos b1 = (\sin x2 - \sin x1 \cos d)/(\cos x1 \sin d) \qquad (4.2)$$

$$\cos b2 = (\sin x1 - \sin x2 \cos d)/(\cos x2 \sin d) \qquad (4.3)$$

where

b1 = bearing transmitter to receiver in radians,

b2 = bearing receiver to transmitter in radians.

4.7.2 Reflection Area Coordinates

In the development of a profile of electron density along the path, the ionospheric parameters at from one to five reflection are along the path are evaluated depending on the path length. These five areas are as follows:-

- The mid-point of the path.
- The E-layer reflection area nearest the transmitter for the estimated least possible number of hops.
- The E-layer reflection area nearest the receiver for the same number of hops.
- The F-layer reflection area nearest the transmitter for the estimated least possible number of hops.
- The F-layer reflection area near the receiver for the same number of hops.

The estimated least possible number of E-layer and F-layer hops is determined from the following relationship to path length:-

- 1E, 1F – 0000 km < path length < 2000 km.
- 2E, 1F – 2000 km < path length < 4000 km.
- 4E, 2F – 4000 km < path length < 8000 km.
- 6E, 3F – 8000 km < path length < 12000 km.

For paths less than 2000 km, only the midpoint is considered. This establishes the reflection areas for determining the ionospheric characteristics for the entire path.

To evaluate the ionospheric parameters of these five reflection areas, their geographic coordinates and geomagnetic latitude have to be computed as follows:-

$$x_n = 90^o - \text{arc cos } (\cos d_n \sin x1 + \sin d_n \cos x1 \cos b1) \qquad (4.4)$$

$$y_n = y1 - \text{arc cos } ((\cos d_n - \sin x_n \sin x1)/(\cos x_n \cos x1)) \qquad (4.5)$$

$$g_n = 90^o - \text{arc cos } (\sin 78.5^o \sin x_n + \cos 78.5^o \cos x_n \cos (y_n - 69.0^o)) \qquad (4.6)$$

where

d_n = angular distance of reflection area from transmitter,

x_n = geographic latitude of the reflection area,

y_n = geographic longitude of reflection area,

g_n = geometric latitude of reflection area.

4.7.3 Sun's Zenith Angle

For the first three reflection areas, the zenith angle of the sun is needed for each hour of the day, to be used later in calculating the absorption factor, and is computed from the following equation:-

$$\cos \check{z} = \sin x_n \sin s_x + \cos x_n \cos s_x \cos (s_y - y_n) \qquad (4.7)$$

where

$s_y = 15\ t_g - 180$ = subsolar longitude,

t_g = universal time,

s_x= subsolar latitude for the middle of the month,

$\check{z}$ = sun's zenith angle

4.8 Sky Wave Propagation

Sky wave propagation paths may be described by a set of parameters known as ray sets. For most HF communication applications, this consists of operating frequency, take-off angle, virtual height of reflection, true height of reflection and ground distance. The basic inputs are true and virtual heights as a function of critical-incidence frequency.

The ray paths are calculated using the following simplifying assumptions:-

- Horizontal and azimuthal variations in the ionospheric electron density profiles are negligible for each hop.
- The magnetic field may be ignored.
- The ionosphere is spherically symmetrical to the earth.

With these simplifications the equivalence between a given frequency on an oblique path (f_{ob}) and a vertical incidence frequency (f_v) with same vertical height specified by Snell's law is

$$f_{ob} = f_v \sec \theta_t \qquad (4.8)$$

where

θ_t = angle between the apparent ray path and the normal to the earth at the true height of reflection

By simple geometry, the virtual height of the oblique path is related to the take-off angle Δ as follows:-

$$a \cos \Delta = (a + h'_{ob}) \sin \Phi \qquad (4.9)$$

where

Δ = take-off angle of the ray,

a = earth's radius,

h'_{ob} = virtual height of the oblique path,

Φ = angle between the virtual ray and the normal to the earth at $h'_{ob.}$

4.9 Noise Parameters

The probability of successful transmission depends on the probability that the available signal to noise ratio at the receiving location is the one required for a specified grade of service in the presence of noise, but in the absence of any other unwanted signals. The three major types of external noise with which the HF signal must compete are galactic, atmospheric and man-made noises. In general, these noise sources have spectral energy distributions that very more or less uniformly over the entire high frequency range. All values of noise are considered representative of those that would be expected with a short vertical lossless receiving antenna. No allowance is made in the program to account for the directional and polarization properties of other types of receiving antennas that could alter the available signal to noise ratio.

4.9.1 Atmospheric Noise

In the HF band, the atmospheric noise (N_a) is the most erratic of the three major types of noise. It is generally characterized by short pulses with random recurrence superimposed upon a background of random noise. Averaging these short pulses of noise power over several minutes yields average values that are nearly constant during a given hour. The variations seldom exceed ± 2 dB, except during sunrise or sunset periods and when local thunderstorms are present. World-wide maps published in CCIR Report 322-3, representing the median of hourly medians of atmospheric noise at 1 MHz within 4 hour time blocks for the four (3-month) seasons of the year, are used as the basis for estimating this noise at any given receiving locations. Levels of atmospheric noise for other frequencies and its associated distribution about the median are available for each time block and season.

4.9.2 Man-Made Noise

At certain receiving locations, un-intended man-made radio noise may be the predominant external noise with which the communication system must compete. It may arise from a number of sources, such as power lines, industrial machinery, ignition system etc., and thus have wide geographic and short term variations. Information for deriving specific man-made noise levels as a function of geographic location and time is insufficient, but from the limited observations available, it is possible to express typical levels of unintended radiation.

Four models are used to designate the median level of man-made noise, all based on the following equation:-

$$N_m = c + d \log_{10}(f) - 204 \text{ dBW} \quad (4.10)$$

where

N_m = man-made noise power in decibels below 1 W in a 1 Hz bandwidth.

f = frequency in MHz.

c, d = constants derived from measurements and given below.

Serial	Environmental Category	c	d
1.	Business	76.8	27.7
2.	Residential	72.5	27.7
3.	Rural	67.2	27.7
4.	Quiet Rural	53.6	28.6
5.	Galactic Noise	52.0	23.0

Table-4: Values of Constants for Man-Made Noises [23]

Urban location is defined as one within the industrial-business area of large cities, residential is one near a large city or within a small town and rural location is one well removed from all populated areas and chosen to be as free as possible of man-made noise. The upper and lower decile values of N_m are 9.7 dB and 7.0 dB respectively. Estimates of the uncertainty in predicting the median and deciles are 5.4 dB and 1.5 dB respectively.

4.9.3 Combination of Noises

The two basic noise sources man-made and atmospheric noise are independent of each other and must be combined by a statistically accurate method in order to represent the overall noise level at the site of interest. The current noise distributions are considered log normal and the method used to combine them is to determine the log normal distributions that best approximate the true distribution of the sum. The method used is a rather complex mathematical process.

4.10 Ionospheric Loss Model

Losses calculated here are for HF sky wave communication for a single-hop mode. Lower decile, median and upper decile values of field strength can be determined by the methods described in this section. These equations are based on the CCIR 252-2 loss equation using a philosophy that modifications are made only when measured values demand a change.

In addition to the D-layer losses due to absorption, there may be losses at the area of reflection if the ionization of the layer is insufficient to reflect all the radio energy. This loss increases as frequency increases, starts to be significant as the frequency nears the maximum useful frequency (MUF) and increases rapidly above the MUF. Since this loss is closely related with the MUF, the day-to-day variation of the MUF within the month can be used to estimate the variations.

4.10.1 Free Space Basic Transmission Loss

Free space loss result from the geometrical spreading of energy as the radio wave progresses away from the transmitter. In ionospheric propagation, the incremental cross-section of the ray bundle at the receiver depends upon the physical properties of the ionosphere and the geometry of the propagation path. Simplifying assumptions are made in the program so that transmission losses can be calculated in a particular manner.

In the simplest model of sky wave propagation, it is assumed that the earth and the ionosphere are both flat and that the reflection is specular (mirror-type). For this type of propagation, the energy density diminishes as the inverse square of the ray-path distance. This means that for an isotropic transmitting antenna radiating p watts of power, the power flux density at a slant range distance D is $p / (4 \pi D^2)$. The total area of an isotropic receiving antenna in free space is $\lambda^2 / (4 \pi)$, where λ is the wavelength of the radio wave. Therefore, the total power received by the antenna is $p \lambda^2 / (4 \pi D)^2$. The basic free-space transmission loss is the ratio between the power radiated and the power received by a loss-free receiving antenna, and is given by:-

$$FSL = 32.44 + 20 \log_{10} D + 20 \log_{10} f \quad (4.11)$$

where

FSL= free space loss in dB

D= distance in kilometers

f= frequency in MHz

4.10.2 Ionospheric Loss

Absorption of energy is usually the second major loss in radio-wave propagation via the ionosphere. The local wave attenuation depends on the product of electron density and effective collision number, divided by the local refractive index for the wave. This loss is calculated by using the equation given by Lucas and Haydon, 1966 as follows:-

$$L_i = [\{ 677.2 (\sec\theta) \} / \{ (f + f_H) 1.98 + 10.2\}] \Sigma I_j \qquad (4.12)$$

where

n= number of hops

θ= angle of refletion

f= operating frequency in MHz

fH= frequency at 100 km

$I_j = \{ (1 + 0.0037 R_{12}) (\cos 0.881\Psi_j) 1.3 \}$

where

R_{12}= 12-month average running sun spot number

Ψ_j= Zenith angle of the sun

4.10.3 System Loss

The system loss of a radio circuit is defined as the signal power available at the receiving antenna terminals relative to the available power at the transmitting antenna terminals in decibels. This excludes any transmitting or receiving antenna transmission line losses, since such losses are considered readily measurable. The system loss does include all the losses in the transmitting and receiving antenna circuits not only the transmission loss caused by the radiation from the transmitting antenna and reradiation from the receiving antenna, but also any ground losses, dielectric losses, antenna loading coil losses, terminating resistor losses in rhombic antenna etc.

The system loss is summarized as:-

$$L_s = L_{bf} + L_i + L_g + Y_p - (G_t + G_r) \quad (4.13)$$

where

L_{bf} = The basic free-space transmission loss expected between ideal, loss-free, isotropic, transmitting and receiving antenna in free space.

L_i = losses caused by ionospheric absorption,

L_g = losses caused by ground reflection,

Y_p = excess system loss,

G_t = transmitting antenna power gain relative to an isotropic antenna in free space,

G_r = receiving antenna power gain relative to an isotropic antenna in free space.

In this report, G_t and G_r are in the direction of the propagation path and include all antenna losses, so that $G_t + G_r$ is an approximation of the gain G_p. The values G_t and G_r are required for any elevation angle, azimuth, direction and frequency.

The sky wave field strength is directly related to the transmission loss, $L_{b.}$ This is the loss that would be observed if the actual antennas were replaced by ideal, loss-free, isotropic transmitting and receiving antennas. The field strength is

$$E = 107.2 + 20 \log_{10} f_{ob} + G_t + P - L_b \qquad (4.14)$$

where

E = rms field strength in dB referred to one microvolt per meter,

G_t = Transmitting antenna gain in the direction of the ray path used to determine L_s

P = Transmitter power delivered to the transmitter antenna in decibels referred to 1 watt,

f_{ob} = Operating frequency in megahertz.

4.11 Summary

The estimation and prediction processes related to sky wave communication have been explained in this chapter. Although the theoretical aspects available on HF frequency communication have not been given in totality, yet the fundamentals used in the software implementation have been highlighted. The techniques explained are universally used for software development; however we have incorporated Pakistan-specific data in the pertinent equations and mathematical functions. This theory forms part of frequency analysis portion of PARAMS.

5. PARAMS – THE CONCEPT

5.1 Introduction

This chapter is vital in understanding the core of PARAMS. It contains all details starting from the basic idea till its implementation. The process of conceiving the basic skeleton of the software is given. It elaborates the importance of such like software for Pakistan Army. The programming parameters and the cumbersome phase of data collection have been highlighted. The basic working of the software is also presented in an understandable manner.

5.2 Background

PARAMS has finally come up after a lot of research, data collection and deliberation. Initially the project focused on computerization of frequency distribution for various frequency bands in Pakistan Army. The start was taken with HF frequency band. Software can easily be developed for the purpose of distribution of frequencies only. It was not until the whole mechanism of HF frequency band communication understood and the system in vogue and the known practical communication problems critically analyzed that a comprehensive analysis and management system was conceived. Even at this stage, the software is not in its final shape and this will be emphasized in the section covering the room for future work. This software has changed its shape all along the course of our work. As more research on the subject was carried out, more changes and improvements resulted in the program.

5.3 Factors Necessitating Development of Software

The basic considerations for development of this software are same as described in section 3.4.4 under the analyses of the current system. However, following factors advocate the dire need of comprehensive software.

5.3.1 Flaws in Current System

The List system of frequency management has many identifiable shortcomings. The theoretical drawbacks are magnified during the practical application. The few notable flaws are highlighted below:-

- In the current system more focus is on management of frequencies ignoring the analysis altogether. As a result many frequencies remain unused due to various reasons.
- Although the lists are power-specific, yet other technical considerations like particular features of the equipment in use or geographical repercussions have not been catered for.
- The Corps Headquarters are situated all over the country; they fall in different geographic locations having particular ionospheric characteristics. Owing to the dependence of HF frequency communication on ionosphere, a particular frequency might not work at different geographic locations. Currently, the lists of frequencies are distributed randomly amongst all Corps on monthly basis. It is obvious that those frequencies unsuitable for communication in a particular region will remain unused.

- At the time of frequency allotment, day and night frequencies have not been defined.
- The feasibility of frequency is never checked.
- The current system is inflexible as it is difficult to allocate frequencies to a new equipment of different characteristics or to have means to avoid interference in the event of a formation moving in the area of responsibility of another formation.

5.3.2 Technical Aspects

The technical aspects of communication equipment and media are of prime importance in any management system. These technical specifications are:-

- Operating frequency.
- Channel spacing / bandwidth.
- Power output of the transmitter.
- Receiver sensitivity and selectivity.
- Antenna gain.
- Transmission losses including free space loss, ionospheric loss, ground reflection loss etc.
- All types of noises.

Software is better equipped to calculate and analyze these considerations as compared to any method performed by humans. It can intelligently cover all technical aspects within the tactical employment of communication equipment.

5.3.3 Dynamic Approach

Software can provide a dynamic approach for frequency analysis and management. Comprehensive software incorporating all technical and practical modalities will always give the best output. User can enter the data of his own choice or as per requirements, like the number and types of nets, type of equipment and region of operation, and can get the workable frequencies as the output of the program. Although any manual method can do the same job, but that would be time consuming and has greater probability of inducing errors.

5.3.4 Facilitation in Planning

Planning is the most important phase of any peace-time or operational assignment. The hindrances pose the threat of prolonging this vital phase. Frequency analysis and management software will definitely act as a helpful tool for both commanders and staff officers alike. A lot of displacements of formations occur during an operational situation as seen in the recent escalation in 2001-2. In addition a similar situation could be faced for an internal security assignment like Wana Operation or in aid of civil power as a natural disaster like the earthquake in October 2005. These scenarios also require the move of formations in the area of operation of another formation. Apart from other tactical and technical considerations, situations like these demands an error free communication plan.

5.3.5 Enhancing the Efficiency

The present system is old and requires revision. It is an ideal option to replace the existing system with an effective, efficient and flexible software based system encompassing all considerations relative to the latest technical advancements.

5.4 Programming Parameters

It is imperative to define the programming parameters before designing any software. These parameters provide the frame-work for programming. The significance of this project demanded carefully laid out parameters. After a number of brain storming sessions, following parameters were laid out before programming started.

5.4.1 Judicious Utilization of Resource

The primary parameter is to utilize the resource to its fullest. As the number of users has considerably increased in recent times, the HF frequency band has become a scarce resource. In pure military terms, it is not a problem till the time single equipment is operating in a specific frequency band. In the event of operation of more than one communication equipment with different channel spacing in a frequency band, resource becomes scarce. In order to use the workable frequencies, an efficient system is required for extraction of frequencies. Furthermore, it is equally important to utilize all the extracted frequencies from the allotted band.

5.4.2 Feasibility of Individual Frequency

Checking the feasibility of individual frequency is the focal point of PARAMS. It means that each frequency undergoes certain scientific mechanism, before it is declared suitable for operation in a particular geographical region. Besides numerous other factors, each frequency is tested with respect to following while checking its feasibility:-

- Length of the path between transmitter and receiver along with the bearings.
- Electron density profile of the region of operation.
- Ionospheric parameters.
- Sun's zenith angle.
- Noise parameters.
- All possible transmission losses.

5.4.3 Distribution Mechanism

Any frequency system cannot be termed as efficient, until the distribution mechanism employed caters for all types of nets or equipments to be used. The program is aimed to provide frequencies for a multi-equipment operation. This parameter was defined for situations in which a hopping radio set is also employed alongside the fixed frequency operation. The available frequencies after checking the feasibility of each frequency is distributed in a way that it fulfils the following criteria:-

- Avoidance of mutual interference.

- Providing frequencies to different nets for operation by equipments with distinctive channel spacing.
- By abiding the above two criterion; utilizing all frequencies including the reserve frequencies, consequentially resulting in no or minimum wastage of frequencies.

5.4.4 Mutual Interference

The primary aim of frequency management is to avoid mutual interference, and hence this parameter had to be included. The program employs numerous checks to ensure that the allotted frequencies do not interfere. The program selects following two thresholds for this purpose:-

- An upper threshold; the communication set with the highest channel spacing is selected.
- Lower threshold is set with the communication equipment with the worst technical characteristics.

5.4.5 Power Considerations

The power consideration is incorporated to calculate the Lowest Useable Frequency (LUF). All the communication equipment to be used will have its own transmitter power output. The signal strength of the propagating signal and the communication range is varied with the power output of the transmitter. It is therefore an important consideration while assigning frequencies to various nets.

5.4.6 Dynamic

The program is aimed to be dynamic in all respects. User can freely customize nets of fixed and hopping frequencies for different types of radio sets in any number of formations. The algorithm makes allowances for all types of radio sets working in HF frequency band.

5.5 The First Step

The importance of the first step in any field is undisputed. It not only requires appropriate visualization of the whole program, it also acts as a foundation for the rest. It is always easy to improve upon anything which is tangible. The extensive research, collection of data, visits to pertinent organizations and detailed analysis perked up our comprehension on the subject. Initially the project focused on developing a computerized frequency management system; alternatively, the research dictated the scope rather than the scope dictating the research. As the new depths in HF frequency communication theory was explored, new avenues made their way in the program.

The first step thus was to 'understand the requirement'. It might seem quite simple to identify the requirement; but understanding it in totality for executable implementation definitely requires vision and persona. The task assigned was to develop frequency management software for Pakistan Army. This requirement presented many definitions like:-

- Develop software that bears the database comprising all the power differentiated frequency lists allotted and provide means to distribute them amongst all Corps and other static installations of Pakistan Army on monthly basis. (existing system)
- Develop software that also caters for a specific radio set in addition to other attributes as mentioned above.
- Develop software that analyses the propagation characteristics of radio waves from transmitter to receiver.
- Develop software that carries database of available frequencies in HF band, details of required ionospheric parameters, details of standard radio nets working in HF band and complete details of present order of battle of all offensive and defensive Corps of Pakistan Army. It also has the complete database of ionospheric parameters of Pakistan which include LUF, critical frequencies for all three ionization regions etc. It checks the feasibility of each frequency using the ionospheric parameters data relative to geographical regions. It employs a distribution mechanism which caters for employment of multi-equipment operation within the same or distinctive nets. It is also capable of assigning frequencies for hopping as well as fixed nets. It is dynamic in nature and user can create a net(s) pertaining to specific requirements and geographical locations and can extract the workable frequencies.

The syndicate understood the problem as explained in the last paragraph. The subsequent chapters elaborate the programming preferences/mechanics, function of each module, user interface and limitations of PARAMS.

5.6 Collection of Data

The data collection is a lengthy phase. As part of research the data was collected from various sources. It continued simultaneously with programming and as new requirements arose, new data was required to be collected. The data was collected for the following:-

- HF frequency band allocated to Pakistan Army.
- International and national criteria for allocation of frequencies.
- Role of FAB in frequency management in Pakistan.
- The present system of frequency allocation in Pakistan Army.
- Radio wave propagation.
- HF frequency band communication theory.
- Role of ionosphere in sky wave propagation.
- Transmission losses and noise parameters affecting HF frequency communication.
- Capabilities and features of equipment(s) employed in Pakistan Army for communication in HF frequency band.
- Role of Signals Directorate, Headquarters Signals of a Corps, Corps Operation Signal Battalion, Formation Signals unit in frequency allocation and employment of radio sets.

- Practical problems faced at different levels in HF frequency radio operation alongside the requirements of frequencies in both operational and peace-time commitments.
- Theory and organization of all radio nets of Pakistan Army.
- Programming language and other software tools suitable to our requirement.

The data was collected from various sources. It required a lot of effort including visits to organizations located as far as Karachi. The sources of collected data were:-

- The World Wide Web (WWW).
- General Staff Publications related to training, role, organization and employment of Signal units.
- CCIR / ITU publications and newsletters on the subject.
- Work done previously on the subject available in the form books/literature in libraries.
- Numerous visits to FAB at Islamabad, Signals Directorate, General Headquarters at Rawalpindi, Strategic Plans Division, Joint Staff Headquarters at Chaklala, Space and Upper Atmosphere Research Company (SUPARCO) at Rawat and also at Karachi. In addition, several visits were carried out to Headquarters Signals 10 Corps at Chaklala, 12 Signal Battalion at Westridge and a Radio Company of a Divisional Signal Battalion.

The collection of data was never easy and a number of problems were faced, particularly during the visits. It was a great hindrance and many a times seriously affected the progress of our project. Some of the problems are presented here with a view that a system may be devised, such that the Under Graduate (UG) courses can easily approach/access any organization in order to obtain data required for final year project.

- The civil and army organizations have separate problems. As regards to the civil organizations like FAB and SUPARCO, the major problems were:-
    - Finding and locating the right person.
    - Arrangement of appointments with the concerned officials linked to his/her availability and willingness.
    - Making him/her understand the purpose of visit including the complete background of the project and the exact information required from that particular individual.
    - If the individual understood the problem, the data can only be made available after a lot of consultations with his higher official resulting in total denial. Consequentially making of liaisons and acquisition of data required several important days.
- Army organizations had their own problems like:-
    - Accessing the right person e.g any staff officer at Signals Directorate.

- Meeting the individual, making him understand and convincing him the importance of our project required at least two to three visits.
- Accessing the data was highly dependent upon the cooperation of the individual concerned.

- Unfortunately, the biggest problem was that no one was aware of the current system of frequency management. More is left upon the clerks and the method once devised half a century ago is being followed blindly. Not even a single person in the whole process was willing to help right away.

5.7 PARAMS – The Functionality

Although the detailed implementation of the program is explained in the next chapter, however it was felt necessary to give out the basic functionality of the software at this point. The flow chart of the Broad Operational Overview is given in Appendix-'A'.

5.7.1 The Input by User

The user is required to input the month and year of operation and the relevant sun spot number. The feature of reserve frequencies is also available. However the user friendly nature of the program helps in filling up of the required fields. Importantly user has to ensure the updation of database. This point has been explained in detail in the next chapter. It is in the database that the user will specify the type of equipment, number and types of nets and other related details based on his suitability.

5.7.2 Internal Database

The internal database is accessed in various stages of processing. The input by user is one such stage and at this point the ionospheric data for that particular time of the year is accessed.

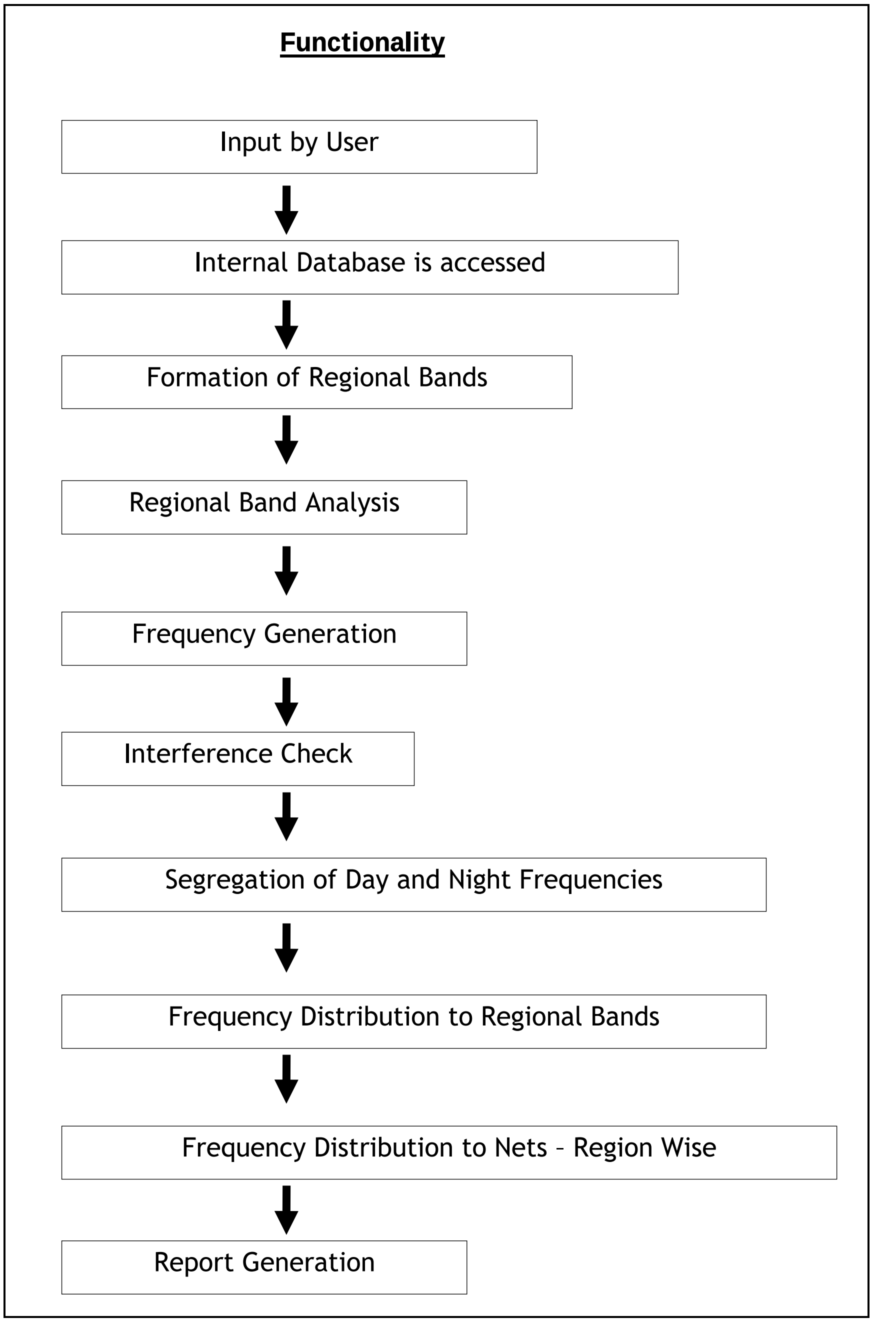

Figure-15: Basic Functionality of PARAMS

5.7.3 Formation of Regional Bands

The ionospheric data leads to the formation of three distinct regional bands of Pakistan each having peculiar ionospheric characteristics. These regions have been shown in figure-16. The useable frequency limits for each of the three bands is calculated here.

Figure-16: Regions of Pakistan as per Ionospheric Parameters [26]

5.7.4 Region Band Analysis

Once the regional bands are formed, they are analyzed and these inferences are used during the frequency distribution stage. The common band, mutual common band between any two regions and the independent region band are critically analyzed here.

5.7.5 Frequency Computation

The frequencies in the available band are then generated. The mutual and second channel interference is checked here. Day and night frequencies are also segregated at this stage.

5.7.6 Distribution

The final stage is the frequency distribution. First the workable frequencies are distributed to regions followed by distribution to the nets within a particular region.

5.8 Summary

This chapter is vital in understanding the background and concept of PARAMS. It encompasses all important stages of a software development. The research activity and the data collection process have been given. The basic functionality of the software has been explained.

6 PARAMS – THE RENDITION

6.1 Introduction

This chapter focuses on the practical aspects of programming. The prime considerations for implementation of the flow chart, given in chapter 5, have been discussed. The modular design of the software is explained in a systematic order for better understanding. Although the program envisages all the required aspects using a number of modules, however, the key modules driving the program has been explained linking numerous smaller modules. Comments on programming have also been included in order to give an insight into the minds of the programmers.

6.2 Programming Technique

The programming can be sub-divided into four main parts. They include programming for both 'front end' and 'back end' as follows:-

- Nets and Formations Database
- Ionospheric Parameters Database
- Frequency Commander
- Reports Generation

The program heavily depends on the many types of databases as required in different stages of the software. It is important to constantly upgrade the database in order to get the correct result. The detail account of the database has been given in section 7.4.

6.3 Operation of Modules – The Description

The programming has been done by making a number of modules and procedures. As a number of mathematical equations were required to be implemented, a number of functions aiming at desired operations have been created. The description has been given in a manner that it will facilitate the reader in understanding the mechanics of the software.

6.3.1 User Data Input

The user is initially required to enter the following:-

- Year (Optional)
- Month (Optional)
- Sun Spot Number (Optional)
- Reserve (Customizable)

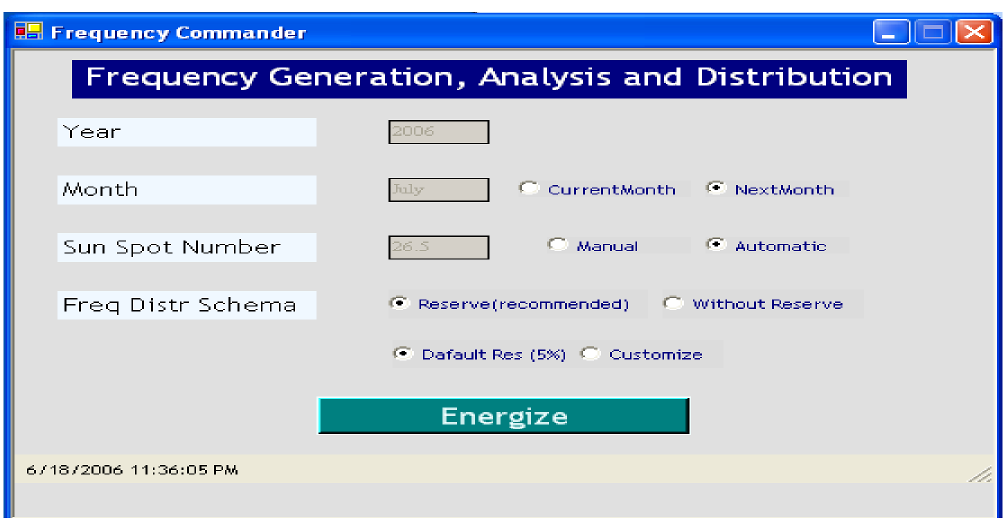

Figure-17: The GUI for User Input

The ionospheric data in the database has been classified according to the sun spot number. When the user will enter the data and click ‘yes’ on the form, the first module start its function. It is named ‘*GetIonoData*’ that refers to the ionospheric data. The flowchart and code for ‘*GetIonoData*’ are given in Appendix ‘B-1’The sequence of actions occurring in the background after the user clicks ‘yes’ is enlisted below:-

- As soon as the user enters the data, a procedure ‘*Get_data*’ in the module ‘*GetIonoData*’ checks whether the ionospheric parameters related to the sun spot number as entered by the user exists in the database or not. It is checked using the function ‘*isSSN_aval*’. The value returned by this function will tell whether the required data pertaining to the sun spot number is available or not.
- If the data is found, it is picked up and stored in temporary variables using a complex array. This data transference involves use of the ‘Data Adapter’ function of ADO.net in VisualBasic.net.
- If the required data is not present in the database, then the module ‘*Get_data*’ will pick all the data for 20 sun spot numbers. The selection will be such that it will pick data of ‘+10’ and ‘-10’ sunspot numbers with reference as the desired sun spot number. The function ‘*getSSN*’ have been used for this purpose.
- After this data is picked, the module will interpolate it, first using 3/8 Simpson and then using linear interpolation. The result of this

interpolation would be the data pertinent to the entered sun spot number by user.

6.3.2 Computation and Allocation of Frequencies

MUF and LUF are calculated for both day and night for all three ionospheric regions. The module ‘*RBand*’ performs all these functions. Its working is explained in detail in the following sections. The complete procedure from this module onwards is repeated twice for ‘fixed frequency’ and ‘frequency hopping’ operations.

6.3.2.1 Calculating MUF and LUF

The sequence of the functions performed by this module is given below:-

- The first function is to calculate the critical frequencies for ‘E’ and ‘F’ regions. As E-region is only present in the day its value can be calculated for day and is obtained from the ionospheric data. Similarly the critical frequency for F-region is also calculated by taking the minimum value from the ionospheric database. This is performed by the module ‘*criticalfreq*’. It stores the required values in actual variables from the temporary ones, which were stored during the operation of ‘*Get_data*’.
- Average heights of the ionospheric regions for both day and night are then calculated. It is done using ‘*avg_height*’. The critical frequency

calculated above and average height is used in determining the angle of reflection.

MUF for each region is also calculated in '*RegionBand*'. The module '*freqMUF*' calculates MUF using function '*freq_muf*'. This function has been developed using equation 4.8.

In order to get the value of angle of reflection, '*freq_muf*' calls a function '*reflection_angle*'. This function calculates the angle of reflection.The above procedure yields the result for day if the day values of critical frequency and other variables are inserted and vice-versa.

- The fourth and last function of '*RegionBand*' is to calculate LUF. It makes use of equation 4.14.

This module makes use of functions '*freespace_loss*' and '*ModIono_losses*' to calculate the losses. The mathematical expression for free space loss is given by equation 4.11, whereas the ionospheric loss is given by equation 4.12. This procedure is repeated twice with both day and night values.

6.3.3 Total Frequency Generation/Computation

This portion describes the mechanics of frequency generation, segregation of frequencies as per ionospheric regions of Pakistan and extraction of workable frequencies for fixed frequency operation. The procedure as preformed by various modules is systematically explained below.

6.3.3.1 Frequency Generation Day/Night

This function is performed by module '*FreqGeneration*'. It inputs the initial and final value of the frequency range and the required channel spacing to generate the frequencies. This is done by using the inbuilt function '*Random*'. We have defined this function as an object. Whenever this function is called it returns one value. Once the minimum and maximum range is given, it employs equi-probable function to giva a value from within the specified range. The number of times this function is called has been determined by using simple division formula as under:-

Range / Channel Spacing = Number of times frequency is generated

The limit for both day and night frequencies is fed to get different sets of day and night frequencies.

6.3.3.2 Combining Day and Night Frequencies

There are two main purposes to combine day and night frequencies. Firstly it is necessary to combine them to check the second channel interference, and secondly some frequencies of day and night might overlap. The module for this operation is '*arrayOp*'. It calls a procedure named '*Add2Arrays*'. It combines the two arrays of day and night frequencies.

6.3.3.3 Removal of Duplication

This is also done by module '*arrayOp*'. It calls procedure named '*RemoveDuplication*'. As the frequencies have been randomly generated, some frequencies might duplicate or even triplicate or even more. Therefore, repetition is being removed here. A '*for*' loop is employed which runs in the range from highest frequency to the lowest frequency. The condition statement '*if*' checks for equality and deletes any entry which satisfies the condition.

6.3.3.4 Discarding Un-authorized Bands

The module '*DiscardUnAuthBand*' employing a procedure named '*Discard_UnAuthBand*' performs this function. A difference of one channel spacing is kept at both ends, high and low, of un-authorized frequency band and then all entries falling in this range are deleted using a '*for*' loop.

6.3.3.5 Frequencies of Authorized Band

The module '*AuthBandFreq*' employing a procedure named '*Freq_AuthBand*' has been defined for this operation. The mechanism employed is such that a difference of channel spacing is kept at end limits as follows:-

Lower limit + channel spacing, and

Upper limit – channel spacing.

The frequencies are then picked by a difference of one channel spacing from the obtained frequency range for authorized band. Remember that 'authorized band' refers to the available frequency band clear of all un-authorized frequencies.

6.3.3.6 Sorting of Frequencies

It means arranging of all available frequencies in both ascending and descending order for night and day frequencies respectively. This step is a pre-requisite for subsequent employment of interference-checking mechanism. This is also done in module '*arrayOp*'. Ascending order is obtained using procedure '*Sort*' and descending order is obtained by using procedure named '*SortDsc*'. The ascending or descending depends upon the number of day or night frequencies. If night frequencies are more then they are sorted in ascending order, whereas if day frequencies are more then they are sorted in descending order.

6.3.3.7 Checking of Interference

In order to make our program efficient, a comprehensive yet complex interference-check mechanism has been employed. Multiple checks are performed in order to cover all possible cases of mutual and second channel interference. The name of module for this purpose is '*InterferenceCheck*'. It calls a procedure named '*Interference_check*'. The various functions performed by this procedure are explained as follows:-

- **Procedure '*IntCheckBetweenRGFandUsedFreq*';** the term 'used freq' refers to the frequencies already in use by other organizations or agencies. As mentioned in the table of acronyms, RGF stands for 'Randomly Generated Frequencies'. This procedure checks interference between the randomly generated frequencies and the used frequencies. The interfered frequencies as found are deleted.
- **Procedure '*IntCheckBetweenRGFand1stHarUsedFreq*';** this procedure checks the interference between RGF and the 1st harmonics of the used frequencies.
- **Procedure '*IntCheckBetweenRGF1stHarandUsedFreq*';** this procedure checks mutual interference between the 1st harmonic of RGF and the used frequencies.
- **Procedure '*IntCheckWithinRGF*';** the mutual interference between the generated frequencies is checked here.
- **Procedure '*InterCheckBetweenRGFand1stHar*';** the interference between the generated frequencies and the first harmonics of these frequencies is checked by this procedure.

6.3.3.8 Segregation into Day and Night Frequencies

After checking interference, the day and night frequencies are again separated. The overlapping or repetition of frequencies is again checked here. If there is no overlapping, procedure '*SegArrayInto2*' in the module '*arrayOp*' is used. In the event of overlapping, procedure '*SegOverLapCombArray*' is employed. The overlapping frequencies are stored in another array. The nonoverlapping frequencies are segregated into day and night frequencies. The duplication is removed and the frequencies are then distributed.

6.3.4 Region Band Analysis

The term 'region' refers to the different geographical regions of Pakistan demarcated on the basis of ionospheric characteristics. The preceding functions are also performed by the module '*RBand*'. After the workable frequencies for day and night are extracted, they are required to be distributed for use in different geographical regions, thus forming the region band of frequencies. Pakistan can be divided into three regions as per the ionospheric characteristics namely Northern Region (Islamabad), Central Region (Sargodha) and the Southern Region (Karachi). The frequencies are allotted to these regions in the module '*BandAnalysis*'. After allocation of frequencies, it is necessary to carry out analysis so that no discrepancy of any kind is left. The analysis is performed by the procedure named '*band_analysis*'.

6.3.4.1 Union

It is used to obtain the maximum and minimum value of frequency found in all three bands. The following diagrammatic explanation will be helpful in understanding the function of '*union*' procedure.

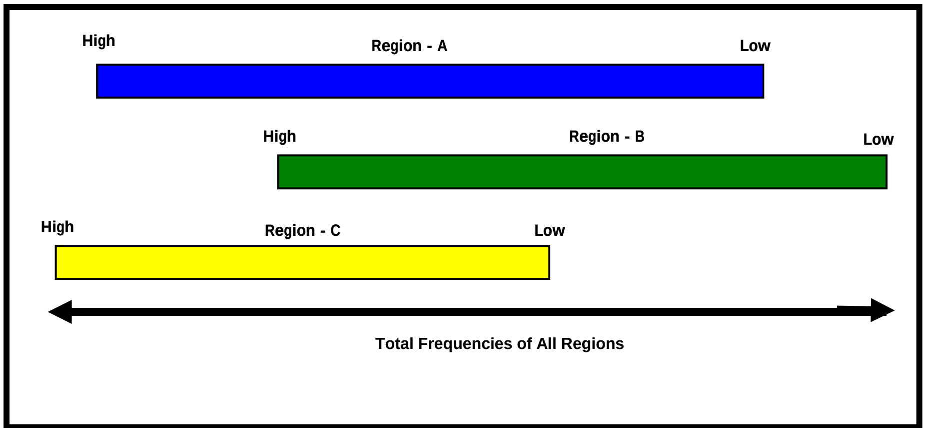

Figure-18: The Regional Bands

6.3.4.2 Common Band

The common band comprises of those frequency ranges which are present in all three regions. It is diagrammatically explained below.

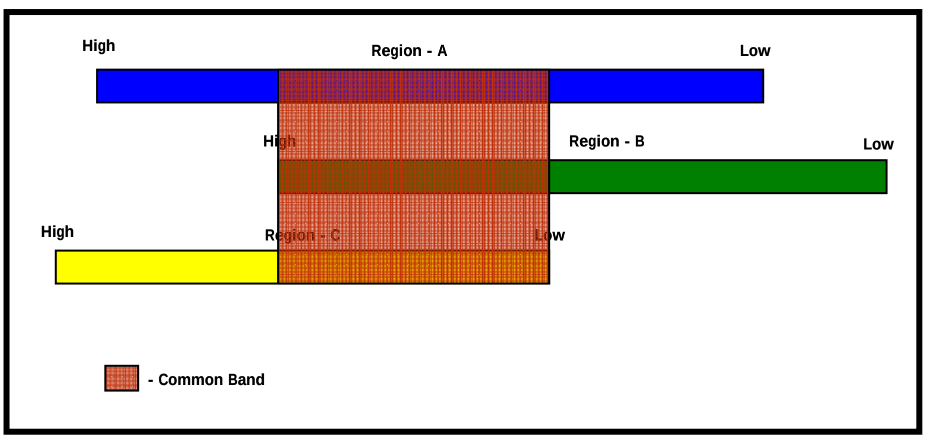

Figure-19: The Common Band

6.3.4.3 Mutually Common Band

There could be some portions of individual region bands that is common between any two region other than the common band. This band has been determined using procedure '*cRegionBand*'. It is shown below.

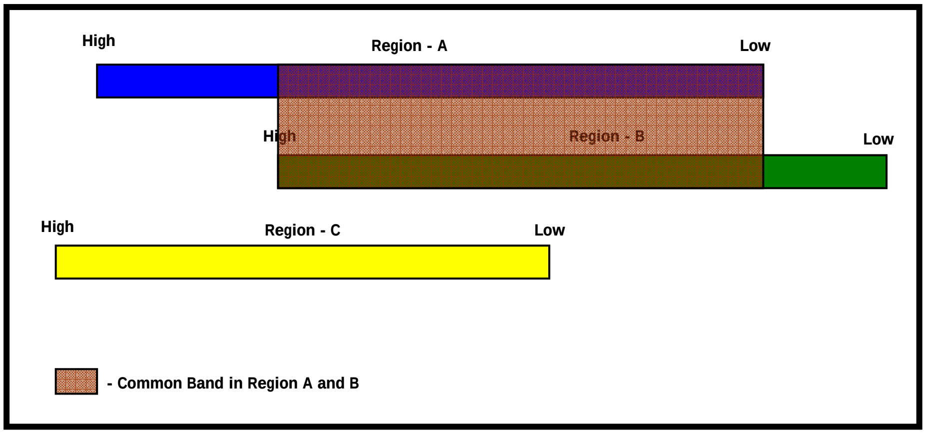

Figure-20: The Mutually Common Band

6.3.4.4 Independent Region Band

It refers to that portion of region bands that are independent of other region bands. This is calculated using procedure named '*iRegionBand*'.

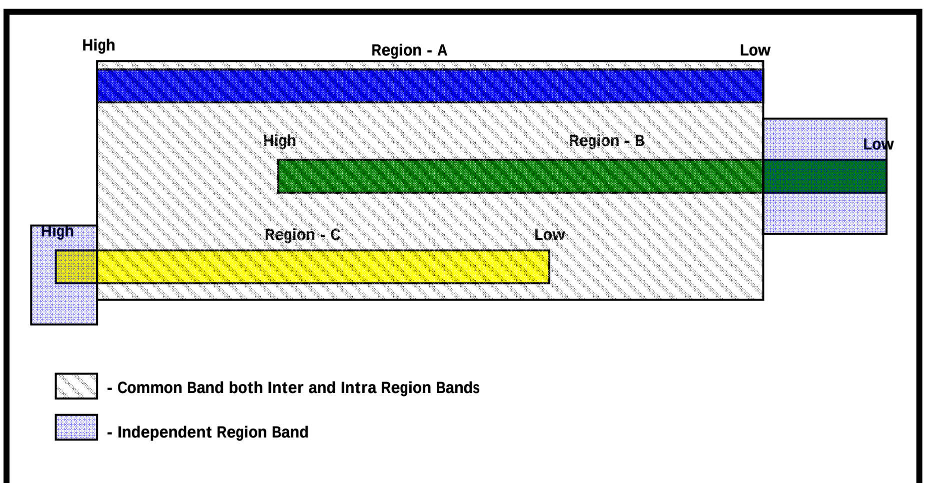

Figure-21: Independent Region Band

6.3.4.5 Independent of Mutually Common Region Band

It is the band other than the collectively common band in any two regions. It is computed using procedure '*indepCommonRegionBand*'.

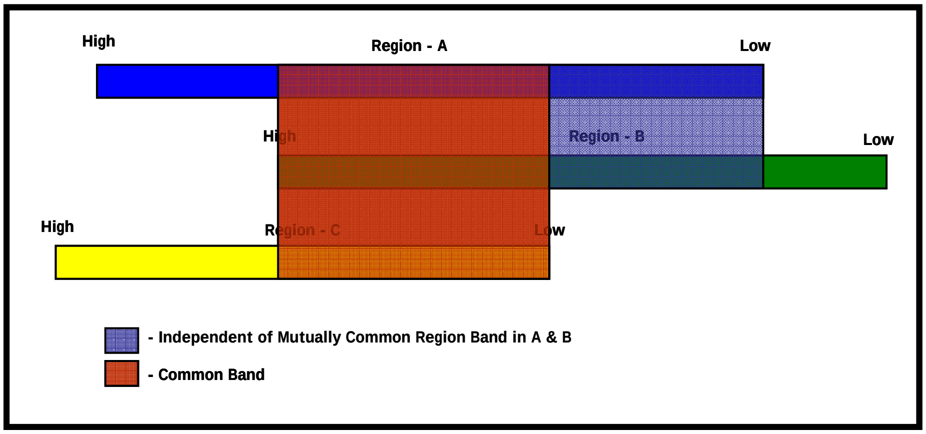

Figure-22: Independent of Mutually Common Region Band

6.3.5 Assignment of Frequencies to Regions

The frequencies are first assigned to nets working on fixed frequencies followed by assignment to frequency hopping nets. The module performing this function is '*RFreqs*'.

6.3.5.1 Procedure '*R_Freq*'

This is the first procedure called by '*RFreqs*'. There can be two options for user, distribution with or without reserves. If the user decides to allot frequencies without reserves, then the frequencies will be assigned to nets on the basis of total workable frequencies. A simple division process will determine the number of frequencies which will be allotted to each net. If the available frequencies are more than three frequencies per net, then two frequencies per net will be allotted. If the available frequencies are more than two frequencies per net then 1.5 frequencies per net will be assigned. '1.5/net' means that each net will be assigned one frequency and 50% nets will be allotted two frequencies. The minimum threshold is one frequency per net. If in the worst scenario, number of nets exceeds the number of frequencies, program will generate an error message. This allocation is for both day and night frequencies. Thereby, two frequencies per net means that actually four frequencies per net are being issued; two each for day and night operation respectively. This distribution is done by procedure named '*DistrWithoutRes*'.

The user does have the option of defining the reserve frequencies in terms of percentage. This is performed by the procedure named '*DistrWithRes*'. The mechanism can be understood by an example. Let us suppose that the total number of nets is 100 and the number of available frequencies is 150. Now, irrespective of the percentage specified for the reserve frequencies, one frequency per net will be issued. Therefore, 80 frequencies can be issued to 80 out of 100 nets (making 2 frequencies for 80 nets and 1 frequency for 100 nets). At this moment the percentage will be employed. If user had specified 5% reserve, then 5% of 80 frequencies will be kept as reserve and remaining frequencies shall be distributed among the nets with all nets having an equal probability of receiving an extra frequency.

The module '*RegionFreqDistr*' assigns the frequencies to the regions. The formations are then distributed the frequencies by the module '*FmnFreqDistr*'.

6.4 Summary

This chapter explained the implementation of the program. The function of each module has been given in detail. The software design can be understood after studying the renditions. The complex nature of the mechanisms employed by the software demanded usage of multiple procedures and modules. An effort has been made to explain these modules in a simple manner.

7. USER MANUAL

7.1 Introduction

This chapter encompasses all details necessary for installation and operation of PARAMS. The system requirements, installation procedure and the operating instructions have been given in detail. It also explains the database in totality whose constant updation is imperative for successful operation of the software. The different features and database have also been highlighted.

7.2 System Requirements

The system features required to support the software are:-

- **Processor:** Intel Pentium-III onwards. Pentium-IV recommended.
- **Operating System:** Windows XP-SP2
- **RAM:** 128 MB (minimum), 256 MB (Recemmended)
- **Space Required:** Approximately 100MB(Database dependent).
- **Screen Resolution:** 1024 x 768 pixels (Recommended)

7.3 Installation Procedure

The installation process require following three steps by the user to successfully install the software:-

- At this screen click the ‘next’ button to start the installation.

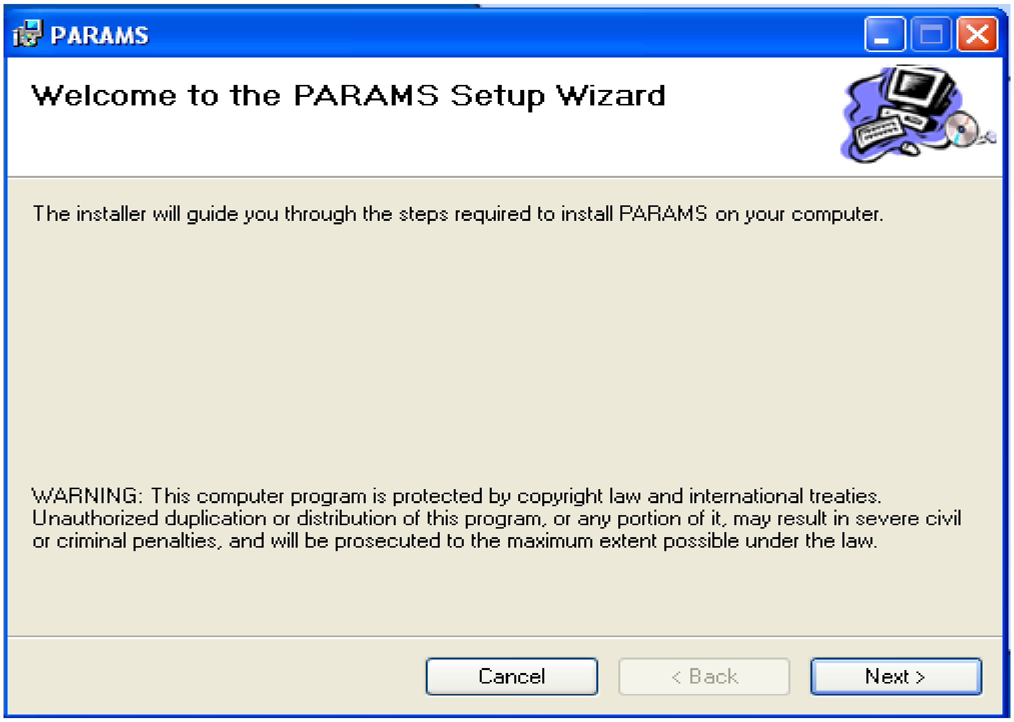

Figure-23: 1st Screen of Installation Process

- On the second screen give the path "c:\ PARAMS" for installation and

  click

  next.

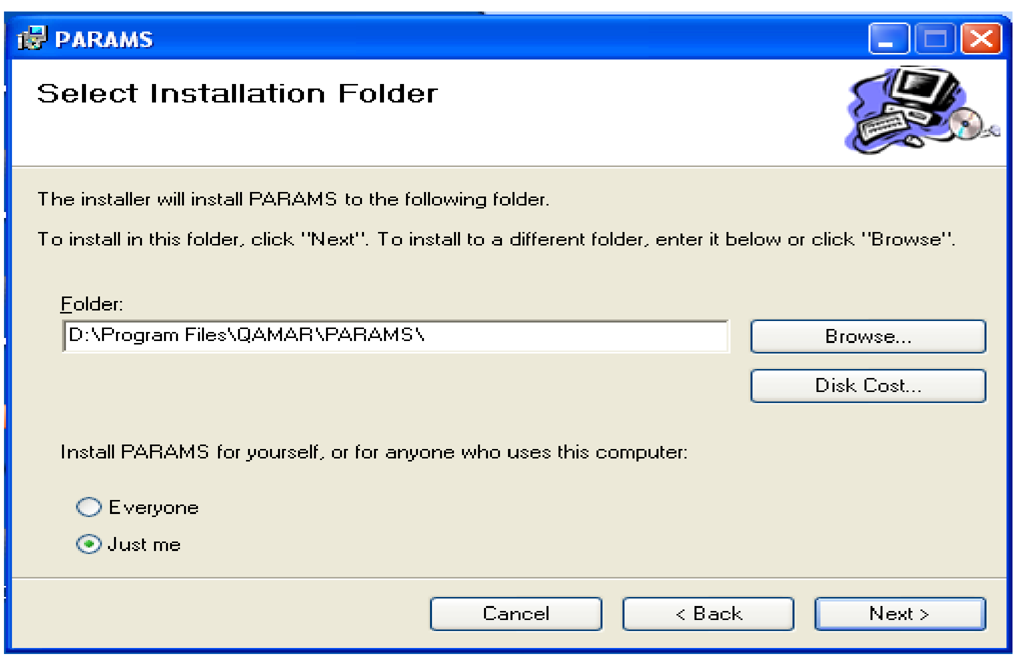

Figure-24: 2nd Screen of Installation Process

- On the next screen confirm the installation and click next.

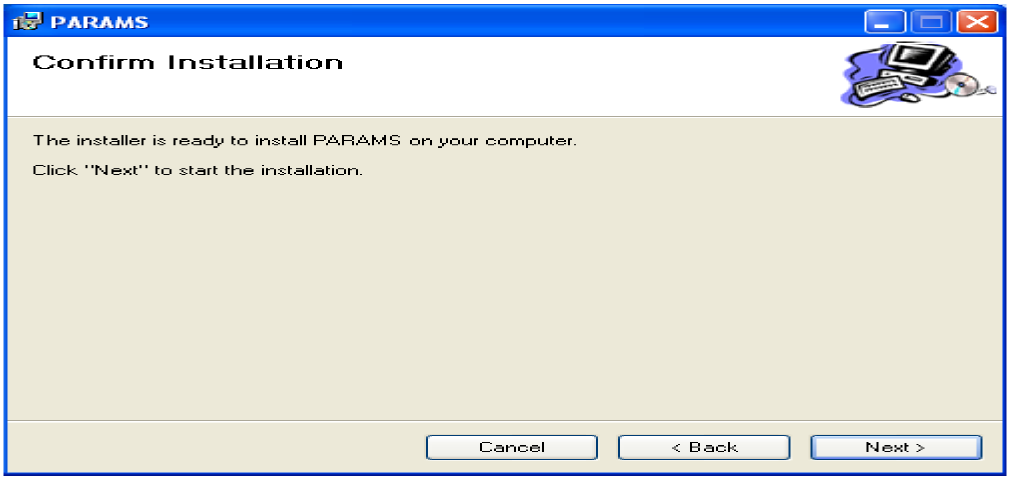

Figure-25: 3rd Screen of Installation Process

7.4 Operating Instructions

7.4.1 General

PARAMS is a frequency management software which deals with HF frequency sky-wave communication. A robust database has been designed and is stored in the program. The required data is accessed from the database as required by the software. A number of processes take place before reports are generated. It is dynamic in nature, designed for any tiered organization like Pakistan Army. It can calculate workable frequencies for different types of equipment working in numerous nets in either fixed or hopping mode.

7.4.2 Features

PARAMS has been designed and implemented after a comprehensive study of HF frequency communication theory. It entails a number of features which have been designed keeping in view the practical problems that have emerged over the years. PARAMS has following features:-

- **<u>Employment of Equipment</u>**. PARAMS allows employment of any kind of equipment working in HF frequency range. Frequency distribution and management heavily depends upon the type of equipment that is being used. The various technical characteristics of the radio set employed are of prime importance. For instance, channel spacing of a set governs the frequency distribution criteria while other characteristics are used in the calculation of LUF and MUF and so on. The program picks up the data of the desired radio set as selected by the user and picks up its data from the database. If a new set whose characteristics are not present in the database is entered it asks the user to give the required technical characteristics of that set. Another major facilitation provided to user by PARAMS with regards to employment of equipment is that it can manage/distribute frequencies for sets working on both fixed frequency and also on frequency hopping mode.
- **<u>Supports Multi-Equipment Operation</u>**. PARAMS has the flexibility to generate and extract workable frequencies for more than one set at a time with different technical distinctiveness. It is important to understand that radio frequency spectrum is a scarce resource. The frequencies are distributed in terms of the channel spacing of the set

being used. Therefore if more than one set is being used then it necessary to employ a judicious distribution mechanism. As an example, radio set PK/PRC-786 has the channel spacing of 1 KHz, whereas it is only 100 Hz for HARRIS set (5800 series). Now it is evident that a larger frequency spectrum will be utilized by the set having greater channel spacing. The mechanism employed in PARAMS gives the user this facility to carry out a multi-equipment operation.

- **Ionospheric Considerations Incorporated**. HF frequency sky-wave communication is dependent upon the ionospheric characteristics of the geographical area in which it is employed. There might be a frequency which is workable at one geographical region successfully communicates at another. There are a number of ionospheric parameters involved in sky-wave communication. These include the sun spot number, sun's zenith angle, average height of ionospheric layers, charge concentration and critical frequencies of each of ionospheric layers etc. The comprehensive ionospheric data incorporated in the software has been acquired by SUPARCO. The ionospheric behavior divides Pakistan into three regions namely Northern (Islamabad), Central (Multan) and Southern (Karachi). The useable range for operation in each region is calculated followed by checking of feasibility of each individual frequency.
- **Interference Check**. The interference of frequency is thoroughly checked soon after their generation. A total of five interference check

mechanisms filter out the best workable and interference free frequencies. Apart from mutual interference, second channel interference as well as adjacent channel interference is also checked.

- **Judicious Distribution Mechanism**. A judicious distribution mechanism has been employed. It aims at minimum wastage of workable frequencies. As highlighted earlier, Pakistan has been divided into three regions. First the distribution of frequencies into regional bands is carried out followed by the distribution to the nets in a particular region. Mechanism is such that the software allocates the frequencies on the basis of number of nets in a region. If one particular region has more nets than the second region, it first distributes the frequencies from the independent region band and then utilizes the mutual common band between any two regions or the collectively common band of all three regions.
- **Provision of Reserve Frequencies**. The software allows the user to pre-define the percentage of reserves, if desired by the user. A default of 5% of the available frequencies can be designated as reserve frequencies. However, reserves are customizable.
- **User Friendly**. The GUI of the software has been developed in a manner that facilitates the user. A number of options are available to the user for filling up of different fields. The reports are comprehensive and they give out all necessary details in a systematic and an understandable manner.

7.4.3 Operation

The primary requirement before the operation is to fill in the database (Consult Section 7.4 if not already filled). The first form that opens after user runs the program is the 'Frequency Commander'. It is shown in figure-4. The user is initially required to enter the following:-

- Year (Optional)
- Month (Optional)
- Sun Spot Number (Optional)
- Reserve (Customizable)

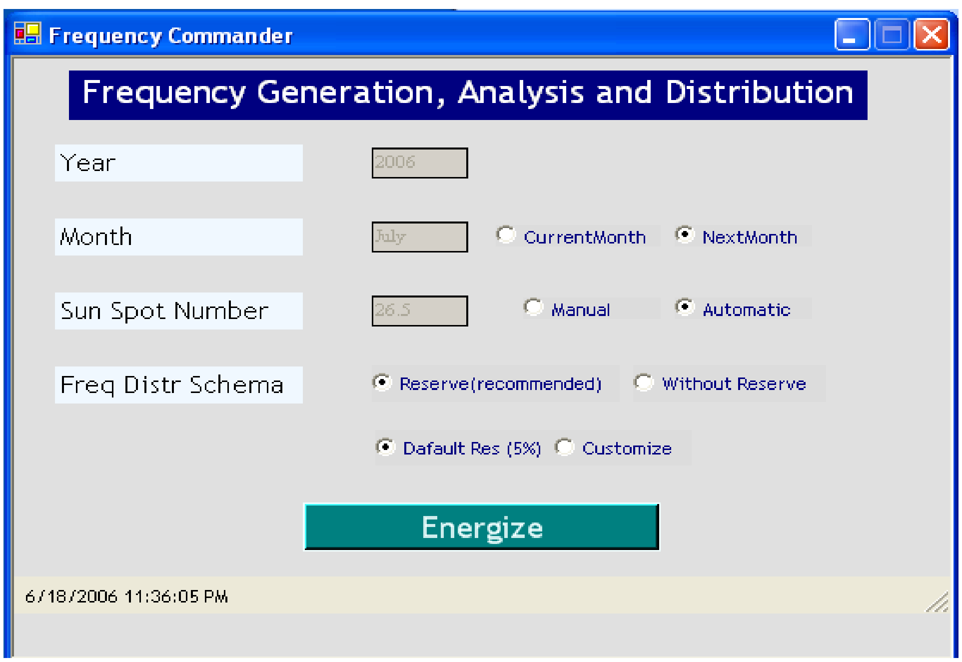

Figure-26: Form of 'Frequency Commander'

7.4.4 The Database Management

The software relies on a backend database designed in MS Access. The databases are broadly categorized into ionospheric database (**HourlyMedianValues**) and database pertaining to Formational Nets (**Nets**). Both of these softwares have numerous tables, queries and views that have been designed for customized access through any Client Program used for Data Access.

7.4.4.1 Nets

This Database pertains to **4** major aspects:

- Organizational tiers of the Formations.
- Details of Communication equipment held by the organization.
- Number of HF nets used by the organization.
- Details of frequencies allotted to each tier for a particular month.

One of the Four Applications installed as part of PARAMS is **Nets & Formations.** This is the Client Program that gives access to the Nets Database through Robust yet User Friendly Forms. These Forms enable the user to Add, View, Edit and Delete Records into the Nets Database in a Guided Manner. Let's see these Data Entry forms in detail for better comprehension:-

- **Hierarchical Formation Addition**. User can enter data for all tiers of the organization in an hierarchical manner. The display is shown in figure-27 below. Anyone who has basic knowledge of MS Word or any software of MS Office can very easily manipulate the entries and browse to the desired form.

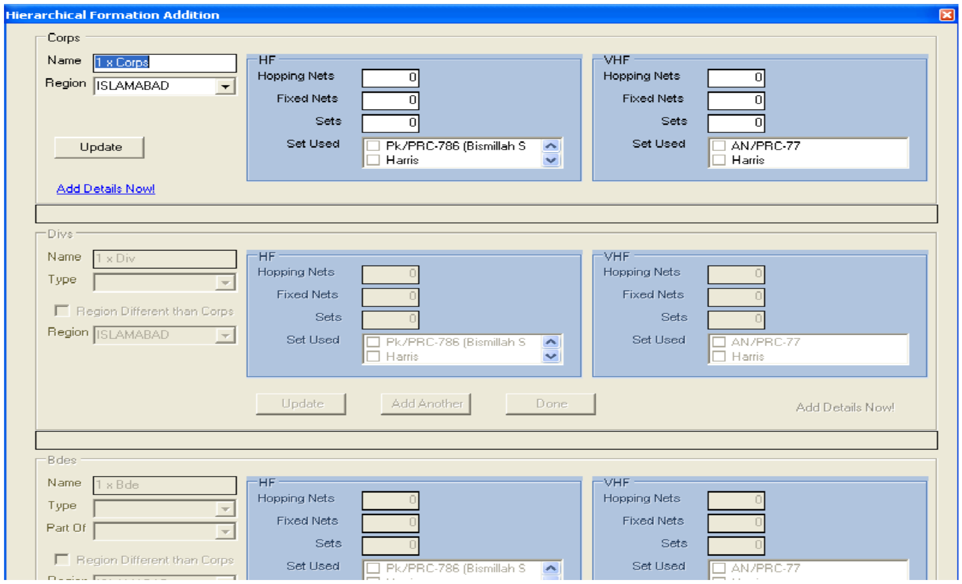

Figure-27: Form of 'Hierarchical Formation Addition'

- **<u>Add a Corps</u>**. 'Corps' here means the topmost tier of any organization. As evident from the name and depicted in figure-28, any desired addition is possible in this database.

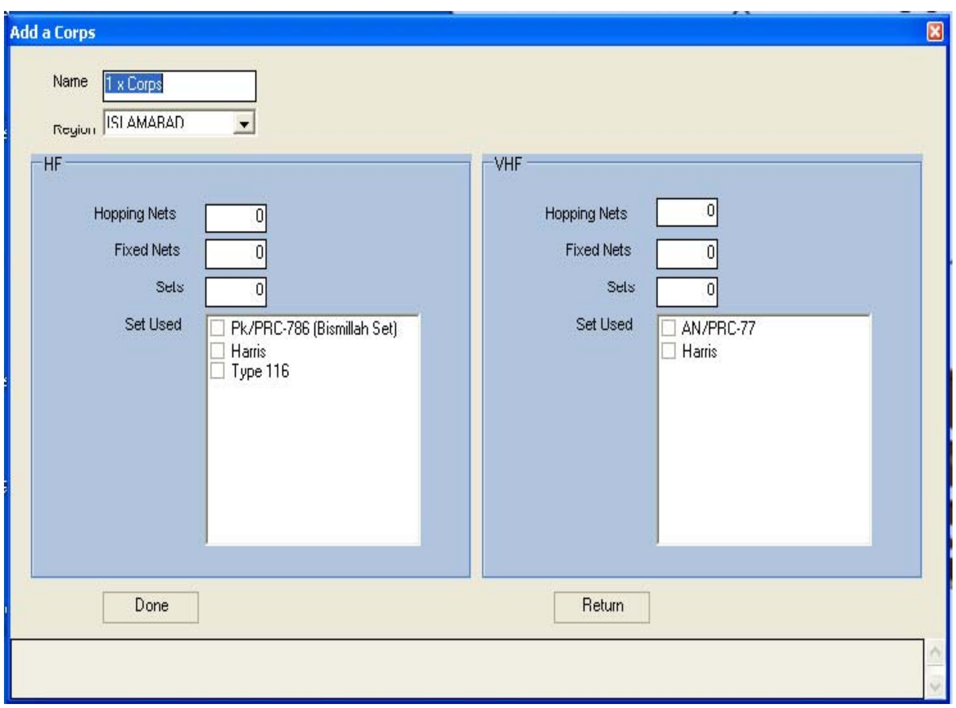

Figure-28: Form of 'Add a Coprs'

- **<u>'Add a Div' and 'Add a Bde'</u>**. These forms are for the subsequent tiers of any organization. Figures-29,30 show the window of the form:-

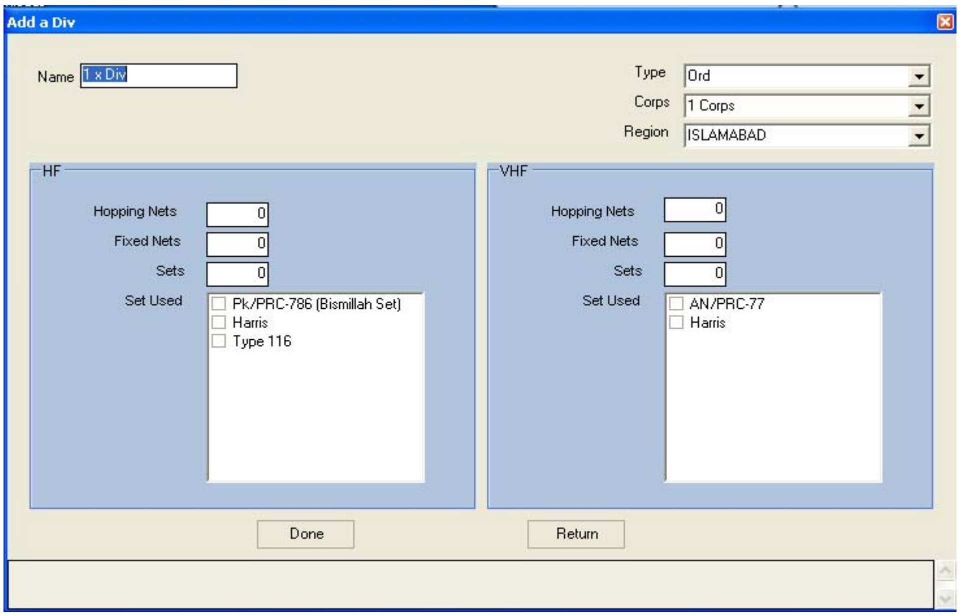

Figure-29: Form of 'Add a Div'

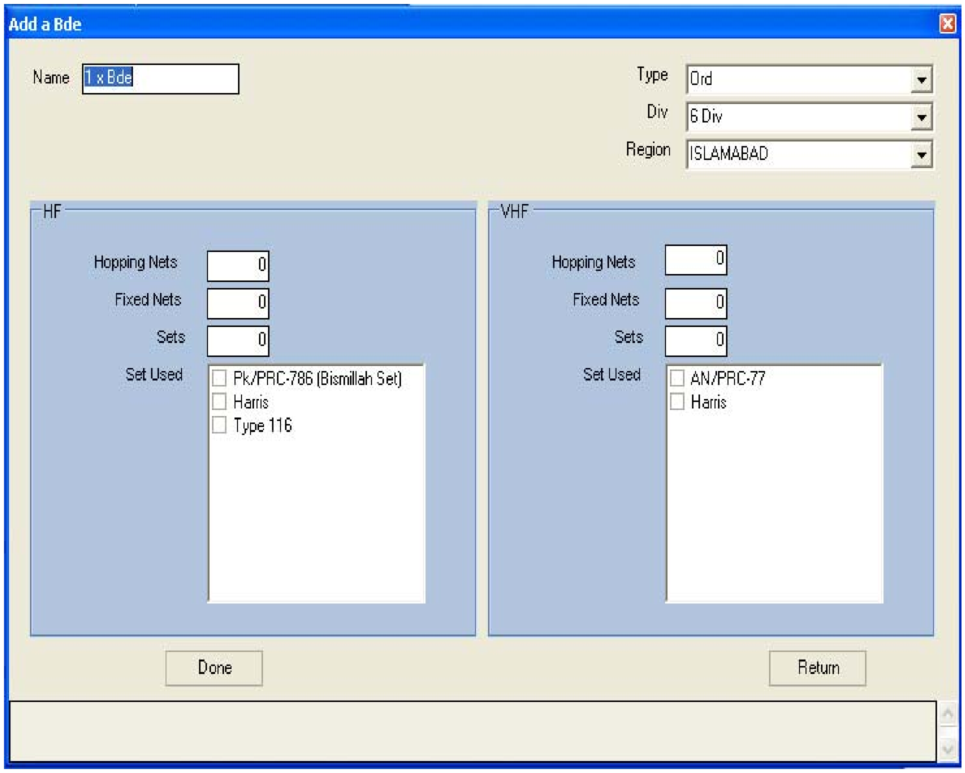

Figure-30: Form of 'Add a Bde'

- **<u>'Add Details Form'</u>**. This form includes complete detail of the communication links required to be established by the user. They include various aspects like region of operation, type of equipment and net or nets, number of nets etc. Figure-31 shows this form.

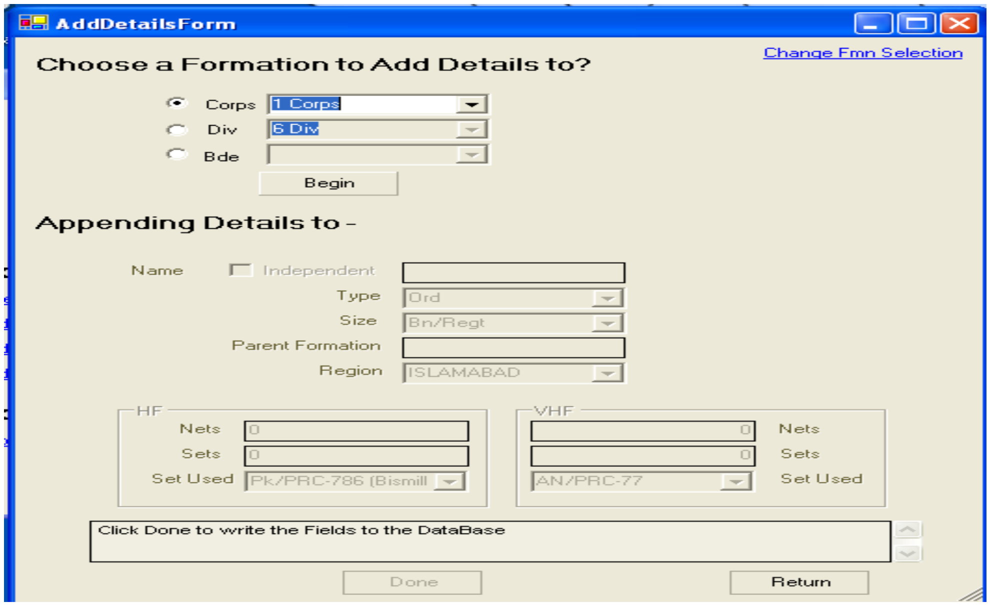

Figure-31: Form of 'Add Details'

- **<u>'View Edit & Delete'</u>**. This form is meant to give the user information about the editing or deleting the records of the database.

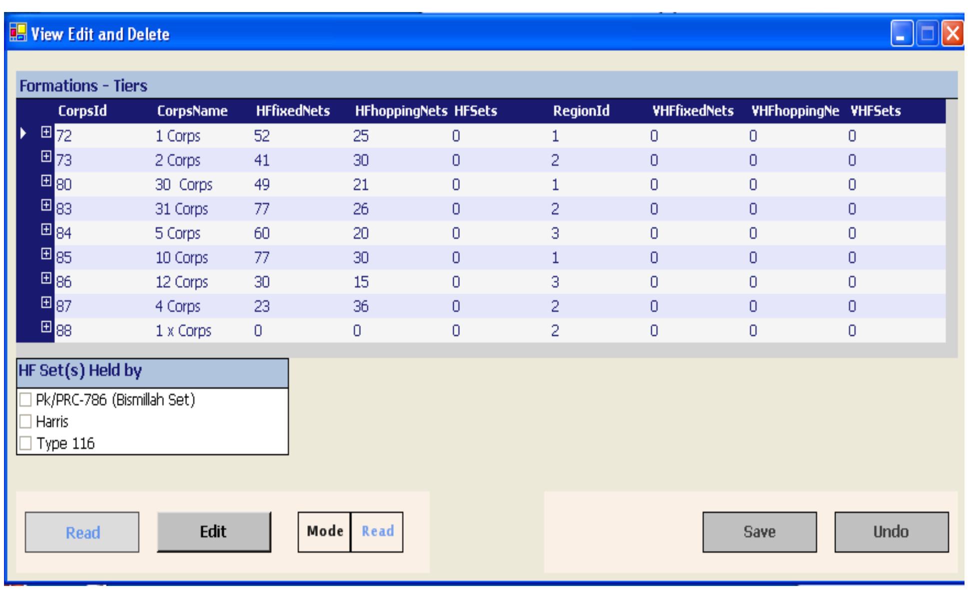

Figure-32: Form of 'View Edit & Delete'

- **'Radio Sets '**. This form contains the technical characteristics of all radio sets working in HF frequency band. User has the facility to add any new radio set as per his requirement.

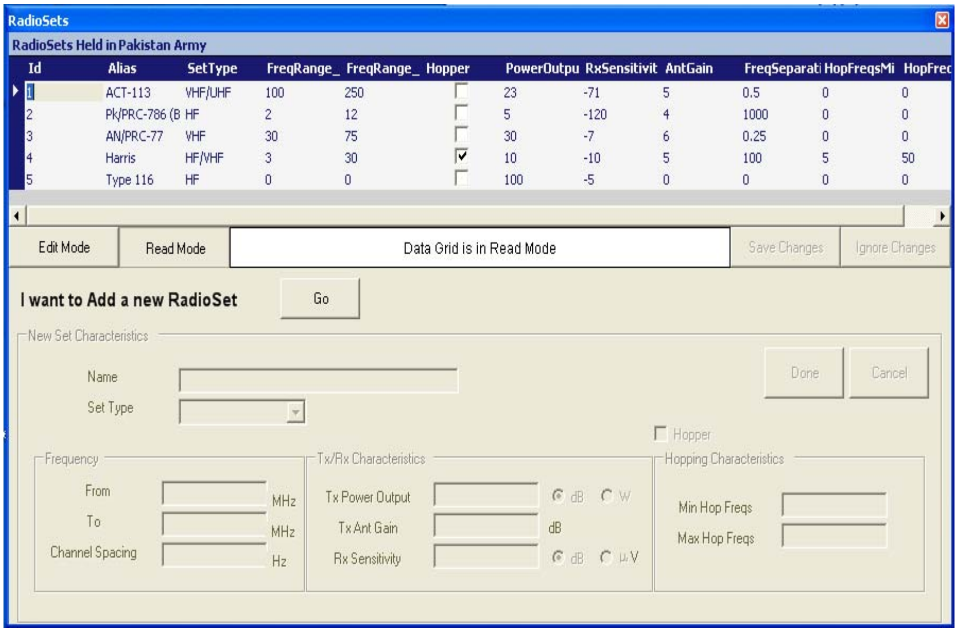

Figure-33: Form of 'Radio Sets'

- **'Miscellaneous Utilities'**. The different types of utilities included in this form are :-
  - Unauthorized Bands
  - Used Frequencies
  - Net Authorization
  - Sun Spot Numbers
  - Instructions
  - Ionospheric Regions
  - Formation Sizes
  - Formation Types

- o Authorized Band

These details are presented in the following diagram.

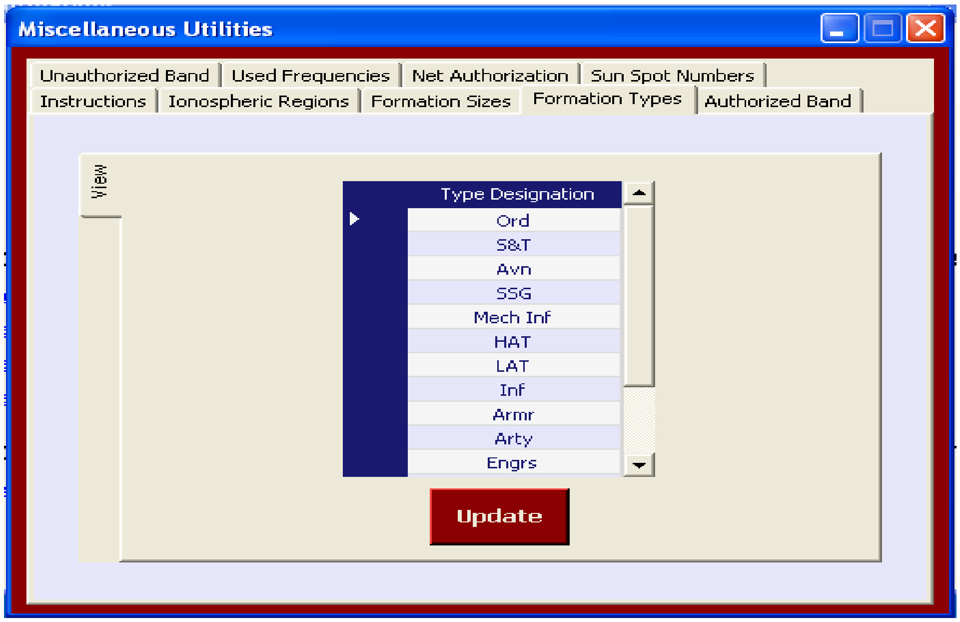

Figure-34: Form of 'Miscellaneous Utilities'

7.4.4.2 Hourly Median Values

The module 'IonCom' deals with the database pertaining to the hourly median values of the relevant ionospheric parameters. Figure-13 shows the appearance of 'IonCom'. The two sub-modules are:-

- **Add New Record** This form is meant to facilitate the user in order to add the new data of hourly median values. This data updation is necessary because it drives the calculation of feasibility of frequency.
- **Manage Existing Records**. This form is essential for finding any record or viewing the records of a particular month.

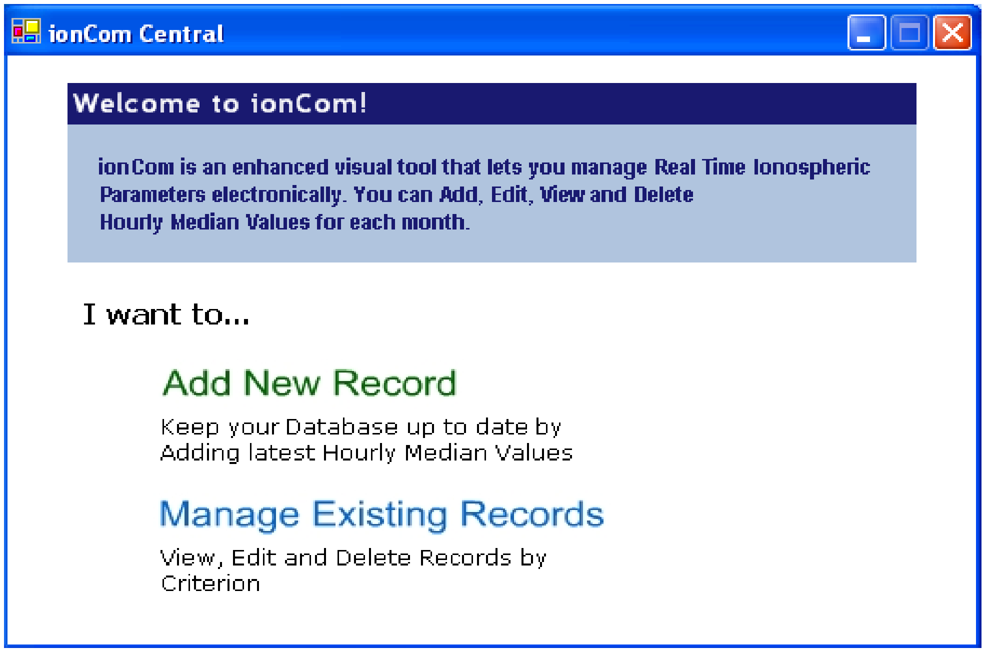

Figure-34: Opening Form 'IonCom'

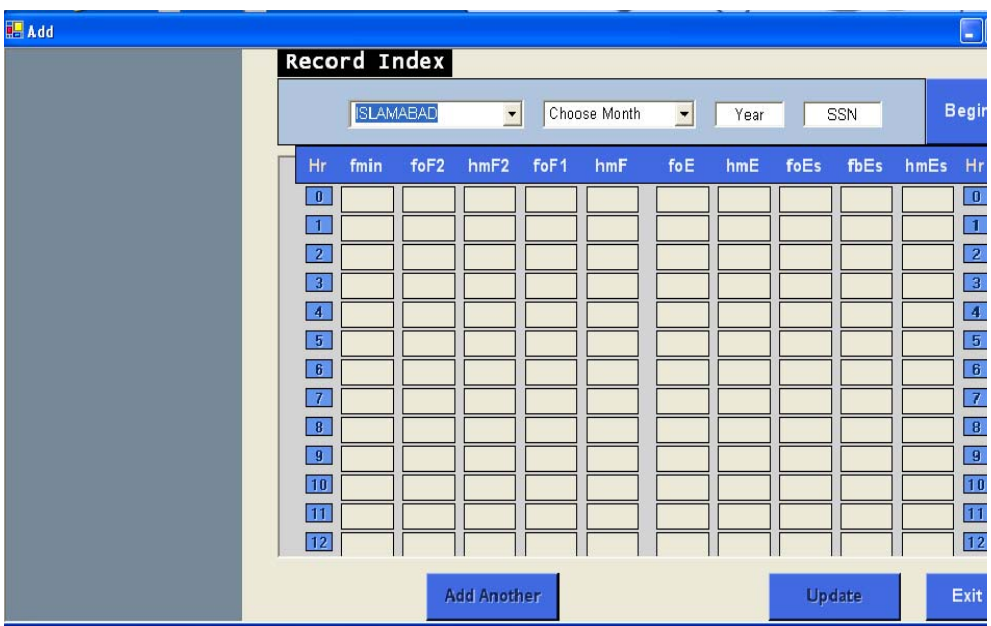

Figure-35: Form for 'Add New Records'

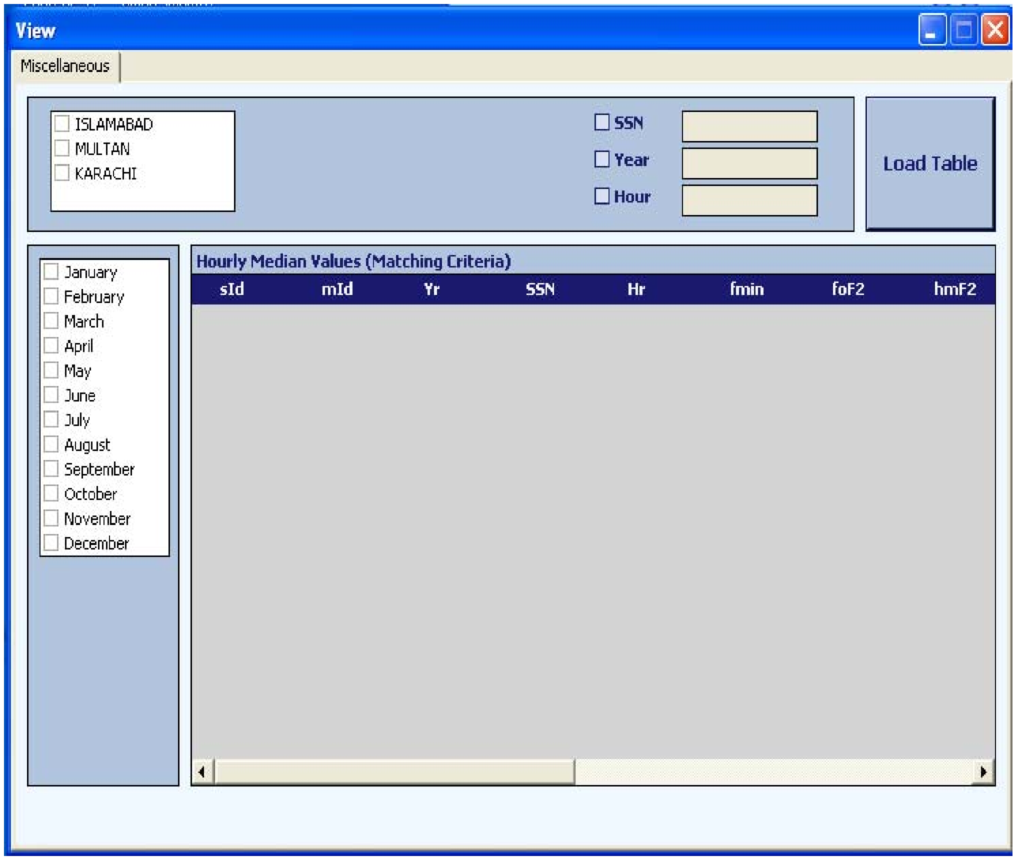

Figure-36: Form to 'View'

7.4.5 Reports

The reports generated show the output of the program. The reports are generated in the following fashion. User can customize the level of details he wants to see, moreover the user can save these reports in any format such as .doc, .txt etc. In addition these reports can be printed and the interface provides the built-in page set-up dialog box.

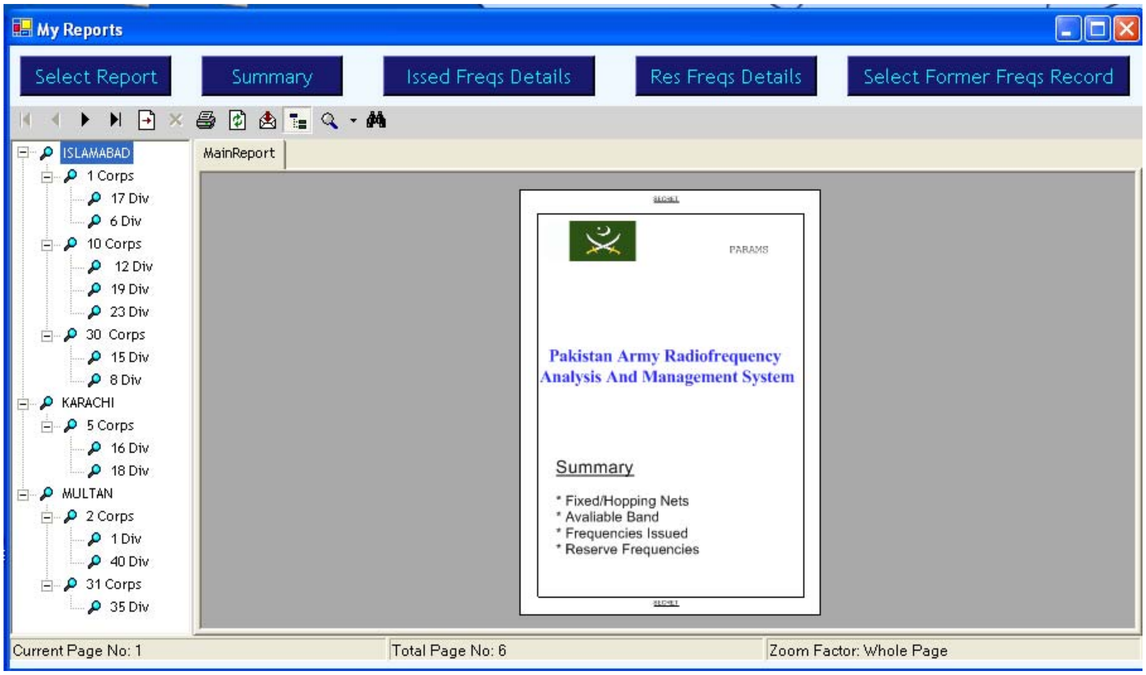

Figure-37: Summary of Total Reports

The user can view all the processed outputs. The region-wise frequencies, frequencies of formations in a particular region along with the details of issued frequencies, reserve frequencies and details of the previously issued frequencies can also be viewed.

7.5 Summary

The complete features of the program have been given in this chapter which is necessary for its operation. The details and instructions for the user have been provided including the installation procedure. The importance and the concept of database have also been given with necessary guidelines for its updation on the part of user.

8. CARDINAL ASPECTS

8.1 Introduction

This chapter deals with various cardinal aspects of PARAMS. These aspects are important in the realization of the software. They include the limitations of the program along with the room for future work. The various related issues have also been discussed in the recommendations section.

8.2 Limitations

The limitations of the program are:-

- It only incorporates ionospheric regions of Pakistan; therefore HF frequency communication to units outside Pakistan cannot be planned.
- It does provide frequencies required for Frequency Hopping nets; however it does not provide a continuous hopping band.
- If number of nets exceeds number of frequencies, program will generate error messages.

8.3 Room for Future Work

Time constraint disallowed the syndicate to further improve the program which includes:-

- The software can be uploaded on ADN with slight additions/alterations.

- Nets working outside Pakistan can be catered for if the required ionospheric data of the world is included in database.
- Link probability calculation can be incorporated.
- Similar program for VHF, UHF and PATCOMS can be done but will require some time.

8.4 Recommendations

The pertinent recommendations are:-

- As the programming has been done by UG students; the software is still in its incubation period.
- The software must be kept under observation for identification of bugs by an officer.
- The frequencies are calculated on the basis of theoretical knowledge; therefore communication trials must be conducted in different geographical locations.
- Frequency Allocation Board (FAB) should be approached for allotment of a definite band instead of frequency spots for usage by Army.
- Like any other software, PARAMS might require constant up gradation relative to new technologies.
- If it is to be inducted in Corps of Signals; arrangements to be made for making the users understand its concept.

- If the programming language being taught in Telecommunication Engineering has to be C++, then Visual C++ should be taught keeping in view its role in final year projects.

8.5 Summary

The contents of this chapter deal with the practical issues of this software. The syndicate can definitely do many additions and improvements in the functioning of the software if this effort is considered worth implementing in any organization.

9. CONCLUSION

PARAMS is a dynamic software that gives a new dimension to frequency management. This report gives an insight into the background, designing, and implementation of the frequency analysis and management system. The extensive research of the subject matter has been presented. The layout has been designed in a manner that facilitates the user in understanding the concept of PARAMS. An effort has been made to encompass all necessary ingredients of the software development.

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APPENDIX 'A'

Flow Charts

Broad Operational View

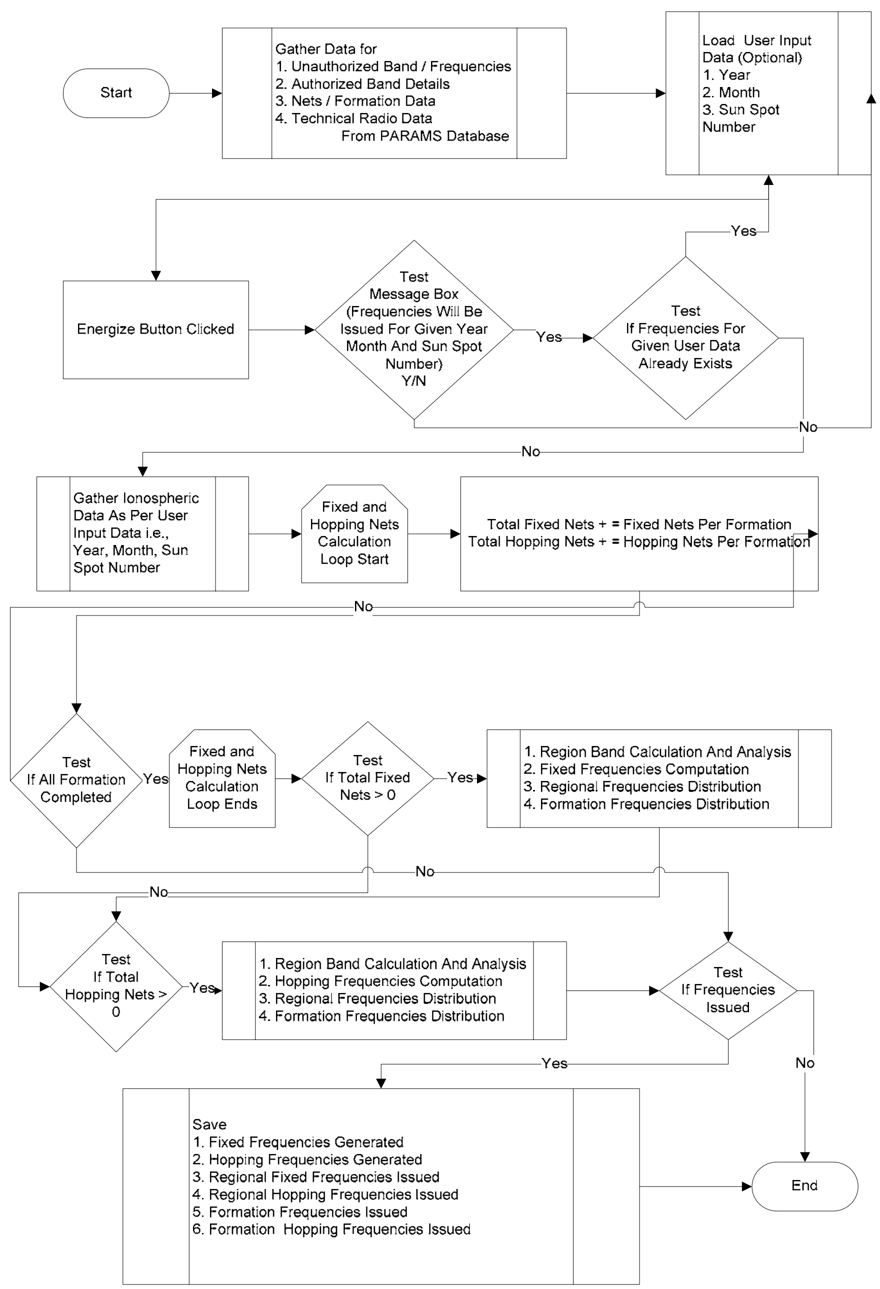

Figure-38: Broad Operational View