Chapter one

Introduction

1.1 Preface

Digital broadcasting has drastically changed broadcasting services. With Digital technique, a wide variety of broadcasting services such as high `available by satellite broadcasting in the 12-GHz band. However, broadcasting-subscribers are demanding more and more entertainment programs, and in response, broadcasters have to establish new transmission channels that have wider bandwidths and higher reliability.

The 21-GHz band is to be available for satellite broadcasting, and a total information bit rate of more than 1 Gbps is expected to be available. Much more digital broadcasting services such as Ultra-high-definition TV etc are expected in this band. However, rain attenuation in this band causes much more serious program outage than that in the 12-GHz band that has been conventional satellite broadcasting band. Hence some compensation techniques for heavy rain attenuation must be employed for reliable satellite broadcasting in the 21-GHz band. In this regards, we have been studying rain fading mitigation techniques, in which the radiation power is increased locally in the area of heavy rainfall while keeping uniform power in the other whole area with a same frequency. It is effective for improving the service availability to adopt the rain fading mitigation technique in this band.

1.2 Problem statement

Ka band is currently allocated by ITU as a primary service for Broadcasting Satellite Services (BSS) of EHRI (extremely high resolution imagery, including High Definition TV and its evolutions). This frequency band presents several challenges for the implementation of a BSS.

However, this band suffers from severe fading due to rain, gases, clouds and scintillations. In this regards, a reconfigurable antenna with multiple feed elements is effective to exploit the limited resources because of its ability to control radiation pattern in order to increase locally in the area of severe fading

While keeping flat radiated power. In addition, the multi-feed antenna enables to combine enough power for large capacity signal transmission using such a wide band width. In this system, the radiation pattern changes dynamically in accordance with the movement of the severe fading area.

1.3 Literature Review

Some compensation techniques for rain attenuation have already been introduced for satellite digital broadcasting:-

- The fixed allocation of high equivalent isotropic ally radiated power (EIRP) to rainy area.
- Hierarchical transmission with robust digital modulations and error correction techniques against low C/N ratio**.**
- Site Diversity.

1.4 Aim and Objectives

The main aim of this thesis is to use control phased array antenna for rain fading mitigation of 21GHz band broadcasting satellite.

The objectives of this thesis are: -

- To study the rain fading parameters.
- To design a new phased array antenna with the consider for mitigation rain fading in 21GHz.
- To simulate the system under various conditions, heavy rain, attenuation, rain phases.
- To compare the achieved results with the other works done in the field.

1.5 Methodology

Rainfall induces heavy rain attenuation has a characteristic happens very locally. Hence concentrating some portions of satellite-transmitting power within the heavy rainfall area can achieve adaptive compensation for rain attenuation in that area without hefty increase in total satellite-transmitting power and sacrificing program qualities.

In this thesis firstly we calculate rain fade attenuation in dB by using rain fall data that we collected over the past four year along seventeen Sudanese cites. Then we mention a phased array transmitting antenna used in which each radiating element is individually fed by transmit active module so we can get large number of narrow spot beams which allow effective reallocation of the RF power and we focused it on the areas that suffers from rain attenuation by change the radiation patterns of beams.

1.6 Research plan

This thesis contain five chapters with the following description Chapter one is introduction about the topic of thesis and the problem statement and short note about methodology and literature view.

Chapter two explain the satellite communication, and type of attenuations that faced the down link RF power, also in this chapter we mention the types of antenna.

Chapter three present methodology that we used to mitigate rain attenuation , and chapter four consist of the numerical result of the equations which we mention in chapter three , and chapter five the consolation.

Chapter Two

Literature Review

2-1 Introduction

Future satellite communications systems operating in Ka-band frequency band are subject to degradation produced by the troposphere which is much more severe than those found at lower frequency bands. These impairments include signal absorption by rain, clouds and gases, and amplitude scintillation's arising from refractive index irregularities.

Rain attenuation in satellite communications systems operating at Ka-band frequencies is much more severe than that usually experienced at lower frequency bands: rain attenuation at 20 GHz (Ka-band down-link), for instance, is almost three times that at 11GHz (Ku band down-link). This fact makes rain attenuation one of the most important limiting factors to be taken into account in the design of a 20/30 GHz satellite communications system.

2-2 Basic Satellite System

The satellite system consist of a space segment serving a specific ground segment, the characteristics of each one depends on whether the system is for fit mobile or direct broadcasting applications. The main elements of the satellite communication system are shown in Figure (2-1)

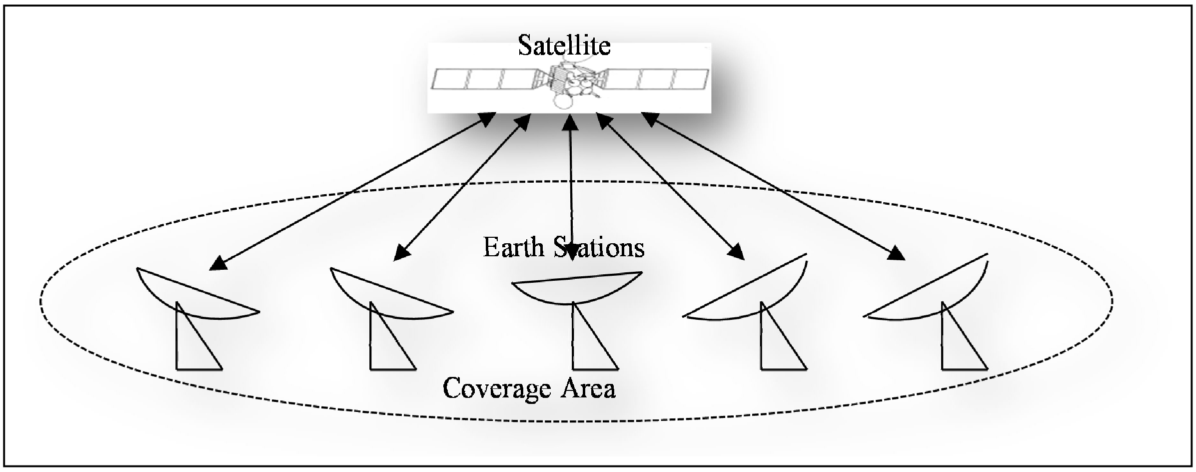


Figure (2-1) satellite communication coverage area

The ground station in a network transmit radio frequency “Rf” signals to the satellite, the received signals are processed at the encoder, translated into another radio frequency and further amplification then retransmitted towards the desire regions of the earth, the communication can be established between all earth stations located within the coverage regions.

The satellite at the geostationary orbit are at altitude of (35786Km) above the equator, so it rotates in unisons with the earth appearing stationary to an observers on the ground, it rotates at a period of 24 hours which matched the earth speed so appears to remain fixed over a given longitude on the earth below.

Single geostationary satellite can provides communication over a large area (1/3one third of the earth),thus three geostationary satellites placed 120° apart can provides coverage to the almost all the populated areas of the world as shown in Figure (2-2).

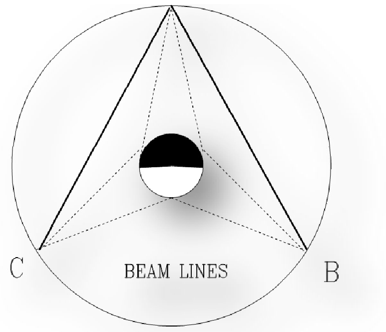


Figure (2-2) three geostationary satellites

2-3 Satellite Links

A satellite link consists of an uplink (transmit earth station to satellite) and a Downlink (satellite to the receive earth station). Signal quality over the uplink depends on how strong the signal is when it leaves the source earth station and how the satellite receives it. Also, on the downlink side, the signal quality depends on how strongly the satellite can retransmit the signal and how the receiving earth station receives the signal.

Satellite link design involves a mathematical approach to the selection of link subsystem variables in such a way that the overall system performance criteria are met. The most important performance criterion is the signal quality; that is, the energy per bit noise density ratio $\left(\frac{E_b}{N_o}\right)$ in the information channel, which carries the signal in the form in which it is delivered to the user(s). As such, in designing a satellite communication system, the designer must attempt to ensure a minimum $\left(\frac{E_b}{N_o}\right)$ in the receiver's baseband channels, which also meets constraints on satellite transmitter power and RF bandwidth.

For digital transmission, energy per noise density ratio $\left(\frac{E_b}{N_o}\right)$ in a baseband channel depends on several factors: carrier-to-noise ratio $\left(\frac{C}{N}\right)$ of the receiver, the type of modulation used to impress the baseband signal onto the carrier, and the channel's bandwidth.

2-4 Satellite Frequency Allocation

The ITU has categorized radio services according to their broad function, we are

Concerning here with three services:-

1- FSS: Fixed satellite services apply to a system which interconnected fixed point such as telephone exchange.

2- MSS: Mobile satellite services apply to mobile communication between earth stations and moving target such as aircraft, ships, etc.

3- BSS: Broadcasting satellite services applies to broadcasts by satellite the television and radio programs and other services directly to the public.

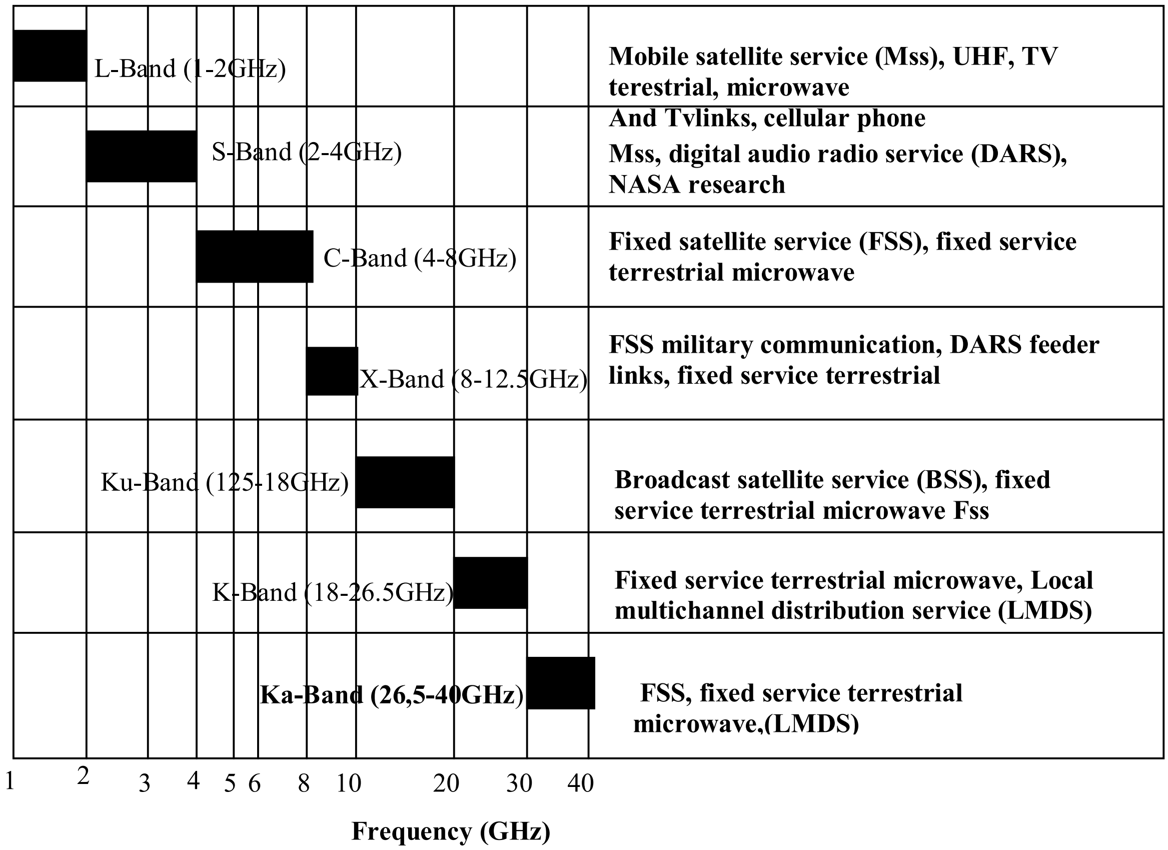
ITU divided the world in to three regions for the purpose of the frequency allocation these are:

Region1: Europe, Africa, Middle East and Asian region of USR.

Region2: America.

Region3: remainder of Asia plus Australasia.

The most attraction portion of radio spectrum for satellite communication lies between 1-30GHz, the relation between frequency, application and bandwidth for each service shown in Figure (2-3).



Fig(2-3) Radio Spectrum for Satellite Communication

2-5 Attenuation with Respect to Free Space (AFS)

The attenuation with respect to free space, AFS, is the usual designation for attenuation due to ALL attenuation (signal level loss) effects produced by the atmosphere (other than free space path loss). These effects could include one or more of the following:

- Gaseous Attenuation
- Cloud Attenuation
- Fog Attenuation
- Worst Month Statistics
- Rain attenuation

2-5-1 Atmospheric Gaseous Attenuation

To provide predictions of attenuation due to gaseous absorption, compute specific attenuation, or attenuation rate, in dB/Km, assume a stratified atmosphere and divide it into small layers, for which a description of the moisture (or humidity) content, temperature and barometric pressure is imposed on these layers. The specific attenuation is computed at these layers, and the total path attenuation is obtained by integrating the specific attenuation from the surface of the earth to a zenith height of 30 km typically. This integral gives the total path attenuation vertically, 90° perpendicular to the earth's surface, and is called the zenith attenuation. To obtain the gaseous absorption along the satellite path the zenith attenuation is scaled as a function of the elevation angle, measured relative to the local horizontal.

The scaling is the cosecant of the elevation angle for angles between 10° and 90°. The barometric pressure, air temperature and humidity at various levels in the atmosphere are needed to compute specific attenuation. Actual measurements of these weather parameters, obtained by launching a balloon with ambient temperature, humidity and pressure instruments attached (radiosonde), at these levels would be ideal, but are not practical to obtain on a regular basis. In lieu of these measurements, a set of "profiles" describing functionally how each of these weather parameters varies with height are used.

2-5-2 Cloud Attenuation

Clouds (and fog) may be categorized generically as hydrosols. Hydrosols are suspended droplets of liquid water, which are typically less than 0.01 cm in diameter.

The attenuation caused by hydrosols becomes significant particularly for systems operating above 20 GHz. This significance becomes more prominent with increasing frequency and decreasing elevation angle. Portion of clouds and fog that are frozen do not cause significant attenuation though they may be responsible for signal depolarization. The specific attenuation coefficient represents the "point" attenuation at the specified frequency and a given water vapor concentration. The total attenuation due to clouds is then computed by multiplying the specific attenuation coefficient, $\boldsymbol{k_1}$ by the total columnar liquid water content of the cloud, L, and dividing by the sine of the elevation angle.

2-5-2 Fog Attenuation

Fog results from the condensation of atmospheric water vapor into water droplets that remain suspended in air. Fog is characterized by optical visibility, which is defined as the distance over which a black target against the sky horizon background can just be discerned by the human eye. The international definition of fog is satisfied when visibility is less than one kilometer. There are two main types of fog, differing in the locale and method of formation:

- Advection fog

Is coastal fog that forms when warm, moist air moves over colder water . The liquid water content of advection fog does not normally exceed 0.4 g/m3.

- Radiation fog

Forms inland at night, usually in valleys and low marshes, and along rivers. Radiation fog can have liquid water content up to 1 g/m3.

Empirical relations have been found between the liquid water content, ρ_l, and the visibility, V(km).

$$\rho_l = (18.35V)^{-1.43} \quad \rightarrow \quad \text{for advection fog} \quad .....(2.1)$$

$$\rho_l = (24.00V)^{-1.54} \quad \rightarrow \quad \text{for radiation fog} \quad .....(2.2)$$

2-5-3 Worst Month Statistics

Communications systems performance is often specified in terms of "worst month" or "any month" criteria, rather than the annual or yearly performance criteria. Propagation margins for rain are then specified as not to exceed values over the "worst month", rather than not to exceed values for an average year, or annual basis. The worst month specification is particularly prevalent in the broadcast industry, and specification of broadcast satellite service (BSS) performance requirements often are in terms of monthly rather than annual time references.

An unambiguous definition of worst month is important to assure that performance specifications are consistent and will be correctly implemented.

The definitions are:

1- The fraction of time during which a pre-selected threshold is exceeded in the worst month of a year is referred to as .the annual worst-month time fraction of excess.

2- The statistic relevant for the performance criteria referring to any month. Is the long-term average of the annual worst-month time fraction of excess.

3- The worst month of a year for a pre-selected threshold for performance degrading mechanism, [is] that month in a period of twelve consecutive calendar months, during which the threshold is exceeded for the longest time.

4- The worst month is not necessarily the same month for all threshold levels [ITU Recommendation P.841 Approved in 2005-03].

2-6 Rain Attenuation

Rain affects the transmission of an electromagnetic signal in three ways:

1- It attenuates the signal.

2- It increases the system noise temperature.

3- It changes the polarization. All three of these mechanisms cause degradation in the received signal quality and become increasingly significant as the carrier frequency increases.

At C-band the effects are minor and at Ku-band, while they are noticeable, can be accommodated. But at higher frequencies, such as Ka-band or V-band, the degradation can be so great that it simply cannot be compensated at the level of availability usually expected for lower frequencies. The first, and most well known, effect of rain is that it attenuates the signal. The attenuation is caused by the scattering and absorption of electromagnetic waves by drops of liquid water. The scattering diffuses the signal, while absorption involves the resonance of the waves with individual molecules of water. Absorption increases the molecular energy, corresponding to a slight increase in temperature, and results in an equivalent loss of signal energy [Okumura's model] Attenuation is neglible for snow or ice crystals, in which the molecules are tightly bound and do not interact with the waves.

The attenuation increases as the wavelength approaches the size of a typical raindrop, which is about 1.5 millimeters. Wavelength and frequency are related by the equation $c = \lambda f$, where λ is the wavelength, f is the frequency, and c is the speed of light (approximately 3 x 108 m/s). For example, at the C-band downlink frequency of 4 GHz, the wavelength is 75 millimeters. The wavelength is thus 50 times larger than a raindrop and the signal passes through the rain with relatively small attenuation. At the Ku-band downlink frequency of 12 GHz, the wavelength is 25 millimeters. Again, the wavelength is much greater than the size of a raindrop, although not as much as at C-band. At Ka-band, with a downlink frequency of 20 GHz, the wavelength is 15 millimeters and at V-band, at a downlink frequency of 40 GHz, it is only 7.5 millimeters. At these frequencies, the wavelength and raindrop size are comparable and the attenuation is quite large.

Two common rain types are convective rain and stratiform rain. Convective rain arises from vertical atmospheric motions resulting in vertical transport and mixing. The convective flow occurs in a cell whose horizontal extent is usually several kilometers. The cell may be isolated or embedded in a thunderstorm region associated with a passing weather front. Because of the motion of the front and the sliding motion of the cell along the front, the high rain rate usually only lasts for several minutes. These rains are the most common sources of high rain rate events. Stratiform rain typically shows a stratified horizontal extent of hundreds of kilometers, durations exceeding one hour, and low rain rates of less than 25 mm/hr. For communication applications, stratiform rain occurs for sufficiently long periods of time that a link margin may be required to exceed the resulting attenuation. Stratiform rain covers large geographic areas, and the spatial distribution of total rainfall is expected to be uniform. Likewise the rain rate averaged over several hours is expected to be rather similar for ground sites located up to tens of kilometers apart [Effect of Rain Attenuation on Satellite Video Transmission (Advanced Digital Sciences Center Singapore)].

2-7 Types of antennas

An antenna is defined by Webster's Dictionary as "a usually metallic device (as a rod or wire) for radiating or receiving radio waves." The IEEE Standard Definitions of Terms for Antennas (IEEE Std 145–1983) ∗ defines the antenna or aerial as "a means for radiating or receiving radio waves." In other words the antenna is the transitional Structure between free-space and a guiding device.

For wireless communication systems, the antenna is one of the most critical components. A good design of the antenna can relax system requirements and improve overall system performance. A typical example is TV for which the overall broadcast reception can be improved by utilizing a high-performance antenna. Thus the antenna must also serve as a directional device in addition to a probing device. It must then take various forms to meet the particular need at hand, and it may be a piece of conducting wire, an aperture, a patch, an assembly of elements (array), a reflector, a lens, and so forth.

2-7-1 Wire Antenna

Wire antennas are familiar to the layman because they are seen virtually everywhere on automobiles, buildings, ships, aircraft, spacecraft, and so on. There are various shapes of wire antennas such as a straight wire (dipole), loop, and helix, Loop antennas need not only be circular. They may take the form of a rectangle, square, ellipse, or any other configuration. The circular loop is the most common because of its simplicity in construction.

2-7-2 Aperture Antennas

Aperture antennas may be more familiar to the layman today than in the past because of the increasing demand for more sophisticated forms of antennas and the utilization of higher frequencies. Antennas of this type are very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft. In addition, they can be covered with a dielectric material to protect them from hazardous conditions of the environment.

2-7-3 Micro strip Antennas

Micro strip antennas became very popular in the 1970s primarily for space borne applications today they are used for government and commercial applications. These antennas consist of a metallic patch on a grounded substrate. The metallic patch can take many different configurations However, the rectangular and circular patches, are the most popular because of ease of analysis and fabrication, and their attractive radiation characteristics, especially low cross-polarization radiation. The micro strip antennas are low profile, conformable to planar and no planar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and very versatile in terms of resonant frequency, polarization, pattern, and impedance. These antennas can be mounted on the surface of high-performance aircraft, spacecraft, satellites, missiles, cars, and even handheld mobile telephones.

2-7-4 Reflector Antennas

The success in the exploration of outer space has resulted in the advancement of antenna theory. Because of the need to communicate over great distances, sophisticated forms of antennas had to be used in order to transmit and receive signals that had to travel millions of miles. A very common antenna form for such an application is a parabolic reflector Antennas of this type have been built with diameters as large as 305 m. Such large dimensions are needed to achieve the high gain required to transmit or receive signals after millions of miles of travel.

2-7-5 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape.

2-7-6 Arrays Antennas

Many applications require radiation characteristics that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geometrical arrangement (an array) will result in the desired radiation characteristics. The arrangement of the array may be such that the radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others, or otherwise as desired. Usually the radiation pattern of a single element is relatively wide, and each element provides low values of directivity (gain). In many applications it is necessary to design antennas with very directive characteristics (very high gains) to meet the demands of long distance communication. This can only be accomplished by increasing the electrical size of the antenna.

Enlarging the dimensions of single elements often leads to more directive characteristics.

Another way to enlarge the dimensions of the antenna, without necessarily increasing the size of the individual elements, is to form an assembly of radiating elements in an electrical and geometrical configuration. This new antenna, formed by multi-elements, is referred to as an array. In most cases, the elements of an array are identical. This is not necessary, but it is often convenient, simpler, and more practical. The individual elements of an array may be of any form (wires, apertures, etc.).

The total field of the array is determined by the vector addition of the fields radiated by the individual elements. This assumes that the current in each element is the same as that of the isolated element (neglecting coupling). This is usually not the case and depends on the separation between the elements. To provide very directive patterns, it is necessary that the fields from the elements of the array interfere constructively (add) in the desired directions and interfere destructively (cancel each other) in the remaining space. Ideally this can be accomplished, but practically it is only approached. In an array of identical elements, there are at least five controls that can be used to shape the overall pattern of the antenna. These are:

The geometrical configuration of the overall array (linear, circular, rectangular, Spherical, etc.).

2. The relative displacement between the elements.
3. The excitation amplitude of the individual elements.
4. The excitation phase of the individual elements.
5. The relative pattern of the individual element.

There are a plethora of antenna arrays used for personal, commercial, and military applications utilizing different elements including dipoles, loops, apertures, micro strips, horns, reflectors, and so on. A linear phased array with equal spaced elements is easiest to analyze and forms the basis for most array designs. Figure (2.4) schematically illustrates a corporate feed linear array with element spacing d. It is the simplest and is still widely used. By controlling the phase and amplitude of excitation to each element, as depicted, we can control the direction and shape of the beam radiated by the array. The phase excitation, $\varphi_{(n)}$, controls the beam pointing angle, θ_0, in a phased array. To produce a broadside beam, $\theta_0=0$, requires phase excitation, $\varphi_{<(n)} = 0$. Other scan angles require an excitation, $\varphi(n) = nkd \sin(\theta 0)$, for the n^{th} element where k is the wave number $(2\pi/\lambda)$. In this manner a linear phased array can radiate a beam in any scan direction, $\theta 0$, provided the element pattern has sufficient beam width. The amplitude excitation, A_n, can be used to control beam shape and side lobe levels. Often the amplitude excitation is tapered in a manner similar to that used for aperture antennas to reduce the side lobe levels. One of the problems that can arise with a phased array is insufficient bandwidth, since the phase shift usually is not obtained through the introduction of additional path length. However, it should be noted that at broadside the corporate feed does have equal path length and would have good bandwidth for this scan angle.

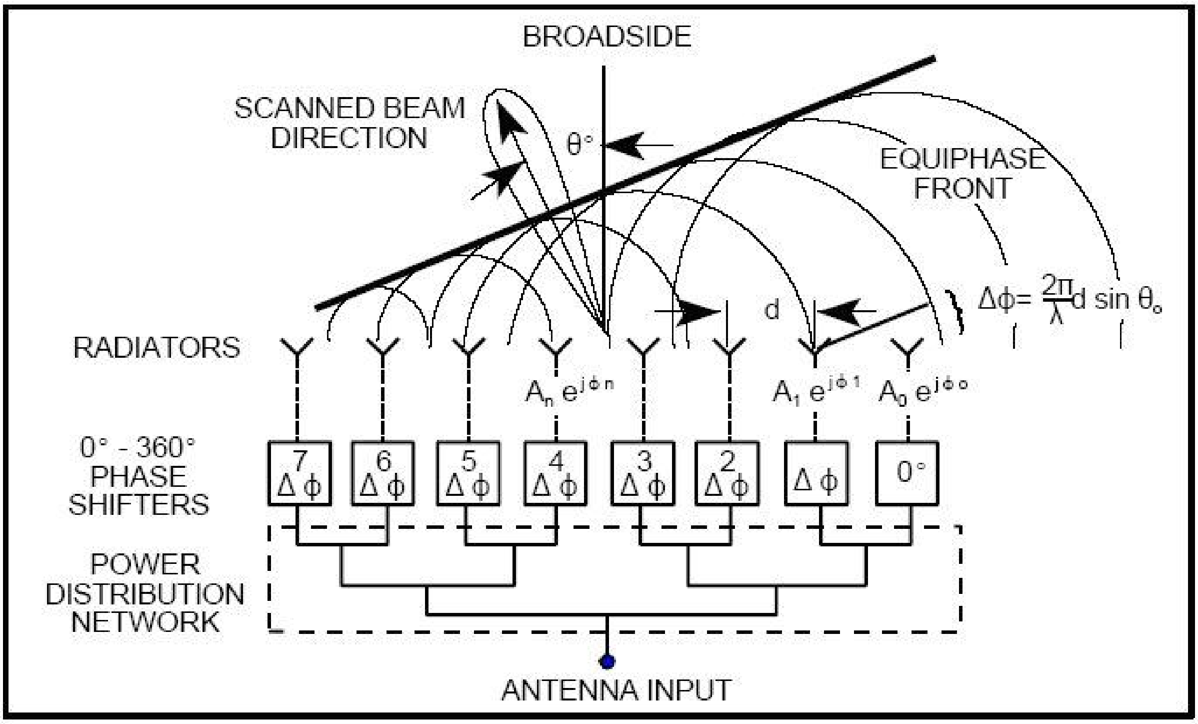


Fig (2.4) control the direction and shape of the beam radiated by the array with element spacing d

2.8 Phased Array Architecture

2.8.1 Phased Arrays based on feed network design

Phased arrays are usually composed of a feed network and a number of phase shifters. Feed networks are used to distribute the output signal of the transmitter to the radiation elements and phase shifters control the phase of the signals at each radiating element to form a beam at the desired direction. There are almost many ways to feed arrays as there are arrays in existence. In general, array feed networks can be classified into three basic categories: constrained feed, space feed and semi constrained feed which is usually the simplest method of feeding an array, generally consists of a network which takes the power from a source and distributes it to the antenna elements with a feed line and passive devices. The constrained feed itself can be categorized into two basic types: parallel feeds and series feeds. The architectures based on these two types of feed network are the most common approach to design phased arrays.

2.8.1.1 Parallel-fed Arrays

In parallel feed networks, which are often called corporate feeds, the input signal is divided in a corporate tree network to all the antenna elements as shown in Fig (2.5)

These networks typically employ only power dividers. Therefore their performance critically depends on the architecture of the power splitter/combiner used. 2N number of radiation elements is preferred for these types of arrays, where N is the number antennas in the phased array.

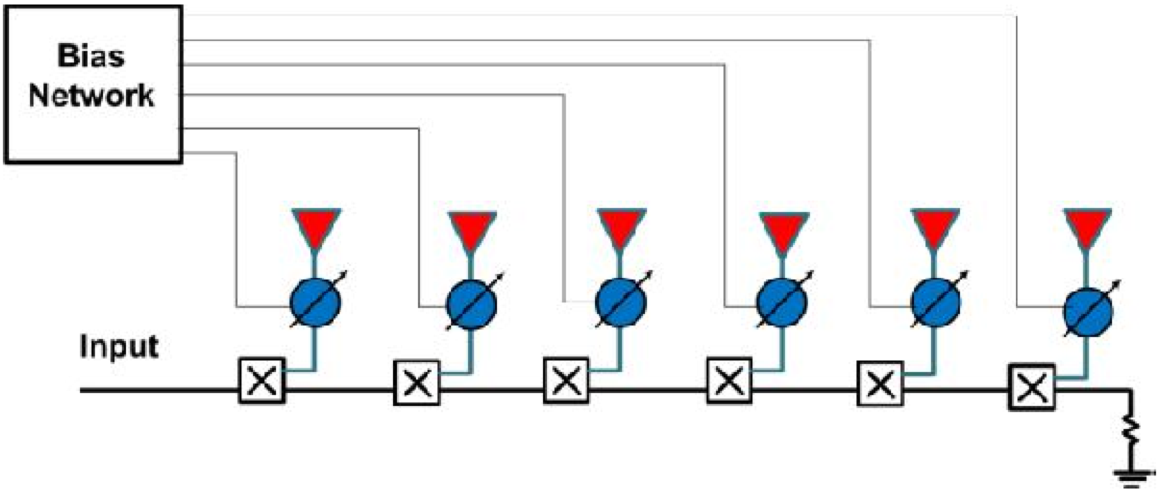


Fig (2.5) parallel- fed array

2.8.1.2 Series-fed Arrays

In a series-fed array the input signal, fed from one end of the feed network, is coupled serially to the antenna elements as shown in Fig (2.6). The compact feed network of series-fed antenna arrays is one of the main advantages that make them more attractive than their parallel-fed counterparts. Beside compactness, the small size of series-fed arrays results in less insertion and radiation losses by the feed network.

The cumulative nature of the phase shift in series arrays also relaxes the design constraints on the phase tuning range of the phase shifters. In an N-element series-fed array, the required amount of phased shift is smaller than parallel fed arrays by a factor of *(N-1)*. However, the cumulative nature of phase shift through the feed network results in an increased beam squint versus frequency, which is one of the main limitations in series-fed designs. The loss through the phase shifters is also cumulative in series fed arrays which can be an issue in the design of arrays with a large number of array elements.

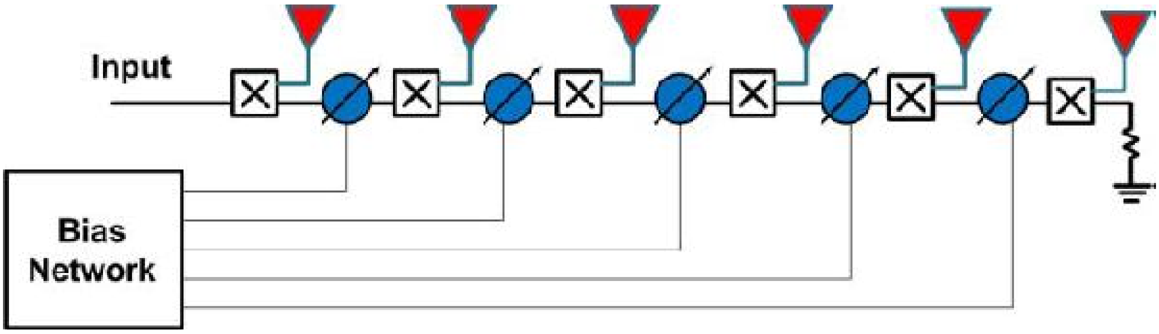


Fig (2.6) series-fed array

2.8.2 Phased array based on phase shift stage

Phase shifters can be placed at any stage of phased array. Based on the stage in which phase shifting is performed, phased arrays can be categorized into four district types: RF-phase shifting, LO-phase shifting, IF-phase shifting and digital phased arrays.

In the following sections, each of these types of phase arrays is discussed.

2.8.2.1 RF phase shifting

In this architecture, the signals at the antenna elements are phase-shifted and combined in the RF domain. The combined signal is then down converted to baseband using heterodyne or homodyne mixing.

Designing phased arrays using RF phase-shifting has been traditionally more common compared to the other architectures. Since this technique requires only a single mixer and there is no need of LO signal distribution, it usually results in the most compact architecture among other phase array designs. Furthermore, it provides insulation of a larger portion of the receiver chain from interference emanating from undesired directions. Moreover, since phase shifting and the signal combining are performed prior to down conversion in the RF phase shifting architecture, the interferer is filtered at RF stage prior to the mixer; therefore, the requirement on dynamic range of down conversion mixer is not as stringent as other types of phased array architectures.

The main challenge of using phase shifting at RF stage in the design of phased arrays is implementing high performance phase-shifters capable of operating at RF frequencies. Regardless of the technology used to implement phase shifters such as BST, MEMS, GaAs or CMOS, passive phase shifters, in general, tend to be excessively lossy at microwave and millimeter regime while active phase shifters usually suffer from low dynamic range. Dynamic range of phase shifters is particularly important in the operation of phased arrays as phase shifters are required to operate in the presence of strong interferers. Furthermore, phase shifter used in receive phase arrays are in the RF signal path and therefore, their noise performance can be critical for the sensitivity of receivers. Another factor that should be taken into consideration is the amplitude variation of the signal at each channel. As the signal combining and null forming at undesired directions is significantly affected by the amplitude of the signal at each channel, the phase shifters are required to not just have a low insertion loss but also maintain a constant loss within their phase tuning range. Variable gain amplifiers can be used to main the signal amplitude at each channel, however their insertion phase should be constant as their amplitudes are changing.

2.8.2.2 LO phase shifting

The phase of RF signal at each channel is basically the sum of phases of IF and LO signals. Therefore, tuning the phase of LO signals would translate into changing the phase of RF signals. The advantage of this approach compared to other architectures is that the phase-shifters are not placed on the signal path. As a result, the loss, nonlinearity and the noise performance of the phase-shifters would not have a direct impact on the overall system performance. Furthermore, performance of the required phase shifter on LO signal path, such as bandwidth, linearity and noise figure will not be as stringent as the phase shifters on the signal path. However, this method compared to RF phase shifting requires a large number of mixers, therefore; in general, the overall complexity and power consumption will be higher than phased arrays based on RF stage phase shifting.

2.8.2.3 IF phase shifting

The general architecture of phased arrays based on IF phase shifting the phase of RF signal at each channel is the sum of phases of IF and LO signals. Therefore, tuning the phase of RF signals can be achieved by tuning through tuning the phase of IF signal. The main advantage of this approach over RF and LO phase shifting is that the phase-shifting is performed at much lower frequencies, therefore, designing phase shifters with much better performance can be possible at IF path. As a result, the loss, nonlinearity and the noise performance of the phase-shifters can be much better when IF phase shifting is used. However, in this architecture similar to LO phase shifting phased arrays large number of mixers are required that can add to the overall system complexity and its power consumption.

Furthermore, since the interfere cancellation occurs only after the IF stage, all the mixers are required to have a high level of linearity capable of handling strong interference emanating from undesired directions.

2.8.2.4 Digital Phased Arrays

In digital phased array design, the signal at each array element is digitized using an Analog-to-Digital Converter (ADC) and the digital signal are then processed using a Digital Signal Processing unit (DSP) . In this architecture, interference emanating from undesired directions is not canceled out after signal processing, therefore, all the elements including the RF mixer and ADC and the DSP unit must have sufficient dynamic range capable of handling the interferers. Furthermore, in general each channel requires the entire RF chain front end circuits. As a result, power consumption is relatively high in this architecture. The main advantage of the digital array is its multifunction capability such as creating many beams. An extensive variety of complex, signal-processing algorithms can be implemented using DSP units. For instance, multi-beam and multiple-input multiple- output (MIMO) functionality can be achieved by the digital phased arrays. Such phased arrays can be capable of distinguishing among desired signals, multipath and interfering signals, as well as demonstrating their directions of arrival. Furthermore, digital phased arrays can adaptively update their beam patterns; so as to track the desired phased arrays can be capable of distinguishing among desired signals, multipath and interfering signals, as well as demonstrating their directions of arrival. Furthermore, digital phased arrays can adaptively update their beam patterns, so as to track the desired.

2.9 Challenges in design of Phased Array Antenna

There are numerous areas that can benefit from phased arrays. However, there are disadvantages associated with the current implementations of phased arrays that can deter their broad deployment. In order to pave the way for wider employment of phased arrays in various applications, there are several challenges that should be addressed. The primary limitations of utilizing phased arrays consist of cost, size, weight, power consumption, and their high complexity. These constraints have restricted this technology to military, aerospace arena which usually requires low quantity prototypes. The systems used in this arena usually can afford to accommodate high cost and complexity of phased arrays in return of high performance to meet their stringent requirement. It is expected that by addressing these technical hurdles and substantially reducing system costs, more ubiquitous use of phased arrays particularly in commercial markets will be possible. Thus, any substantial reduction in the cost and complexity of phased array systems will facilitate their much wider consumer use which requires unit costs well below what is currently possible.

The high cost and complexity of phased array typically ties in with the cost of multiple receive or transmit/receive modules, whose output and control data are multiplexed into a backend processor unit, which is separate from the T/R modules. One of the critical elements of these T/R modules is a phase shifter. Phased arrays usually require complex integration of many expensive solid-state, MEMS or ferrite based phase shifters, control lines, together with power distribution networks. Phase shifters typically contribute to a significant amount of the cost of producing a phased array antenna and it is not uncommon for the cost of the phase shifters to represent nearly half of the cost of the entire phased arrays. Furthermore, a major complexity of phased array design can be attributed to the complexity of their phase shifters. Since the advent of the array theory and development of the early beam steerable phased arrays, phase shifters have been widely recognized as the most complex and sensitive part of a phased array. The complexities in the corporate feed network and biasing network for the phase shifters as well as their parasitic radiation and interactions with the radiating elements, render implementation of phased arrays very challenging. This is particularly true where a large number of phase shifters with accurate phase control are required. Conventional linear phased arrays, capable of scanning in azimuth or elevation, require one phase shifter circuit for each antenna element. In two dimensional scanned arrays, the number of required phased shifters is even larger. Each phase shifting circuit is connected to bias lines and the associated driver circuitry for its phase control. To better illustrate the level of complexity introduced by the individual phase shifters within the array. Independent of the type of phase shifter used, design of phased array systems is considered to be complicated and costly mostly due to the number and cost of phase shifting elements required. Thus, in order to reduce the cost of phased arrays, ongoing efforts are underway to develop new architectures that allow for designing phased arrays with reduced complexity. In the next section, different approaches proposed by researchers to allow for phased array cost and complexity reduction are discussed in more details.

2.10 Literature Review

Some compensation techniques for rain attenuation have already been introduced for satellite digital broadcasting.

2.10.1 The fixed allocation of high equivalent isotropic ally radiated power (EIRP) to rainy area.

In the system, total output power of the beam is controlled, while the antenna pattern is left unchanged. The EIRP in the service area varies uniformly.

Typically, strong rains occur locally. To compensate for local rain attenuation, the EIRP is increased for the whole coverage area. Apart from areas with strong rain, the rest of the service area in clear-sky conditions can be overcompensated. It is undesirable from the viewpoint of sharing with the other systems. In this respect, the adaptive power control of such single beam systems is less effective than those of multi beam systems.

The total required radiation power is high and the increase in radiation power is frequent since the single beam covers the whole region.

The following parameters are used for the definition of the system:

EIRP value E_N with nominal condition in the service area;

EIRP value E_M with maximum EIRP increase in the service area.

The EIRP values in certain areas vary, ranging from E_N to E_M.

2.10.2 Hierarchical transmission with robust digital modulations and error correction techniques against low C/N ratio

Two or more modulation schemes of different C/N requirements are time-multiplexed to form a hierarchical transmission signal. The fundamental information, such as minimum quality video signal and audio, is transmitted at a low data-rate by using a robust modulation/channel coding scheme with a low C/N requirement. On the other hand, the high data-rate signal part, such as for HDTV or 5.1-channel surround sound, is transmitted by using a higher efficiency modulation scheme with a higher C/N requirement. The receiver chooses the appropriate data stream depending on the actual receiving C/N condition. Therefore, a hierarchical transmission can be used to realize a stepwise degradation in the digital system that degrades the picture quality gradually in accordance with the decrease in the receiving C/N.

In the BSS bands from 17.3 GHz onwards, the rain attenuation is considerably higher than that in the 12 GHz band. By applying hierarchical transmission, service interruptions due to rain attenuation can be reduced.

The hierarchical transmission scheme can be integrated with the other techniques. For example, the different types of service such as non-real-time broadcasting assuming storage reception described in Annex 3 and ordinary real-time broadcasting, can be transmitted simultaneously using the hierarchical transmission scheme. In this scheme, multi-level modulation signals of BPSK, QPSK, and 8-PSK can be time-multiplexed.

The hierarchical transmission scheme can also be integrated with scalable video coding (SVC) technology. SVC technology generates a scalable video elementary stream with the base and enhancement layers. The scalable encoded video data are processed by a variable coding and modulation (VCM) scheme. In VCM, low-quality data (base layer) can be delivered using a more robust modulation scheme than high-quality data (enhancement layer). Therefore, in a clear-sky condition, both base and enhancement layers can be received and this enables provision of HD services. On the contrary, in a rain-faded condition, only the base layer can be received for low-quality video services.

2.10.3 Site diversity

Site diversity is one of the most popular methods to combat rain attenuation. A site diversity satellite system consists of two or more spatially separated ground stations, and hence, provides separate propagation paths to the signal. In practice, the two ground station diversity system is the most common. The plan view of the ground stations of a site diversity system is shown in fig (2-7).

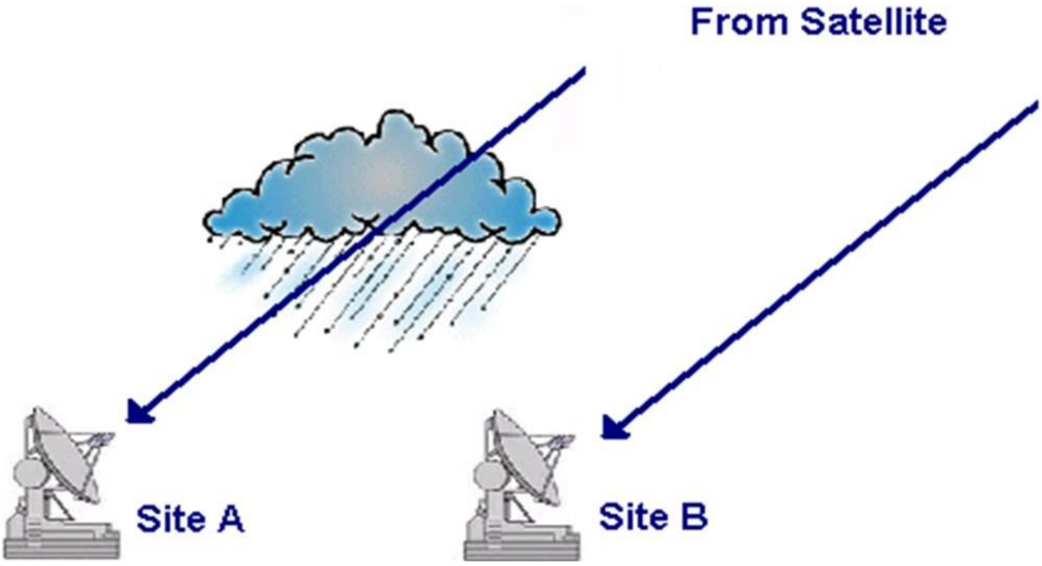


Fig (2.7): Plan view of site diversity system

The basic assumption of site diversity systems is that the rain attenuation will not significantly affect the two different propagation paths simultaneously as shown in Figure(2.7). Hence, by switching to the ground station with the higher received signal level at that instant in time, the effect of rain attenuation will be reduced significantly. This is the concept of selection combining diversity.

Chapter Summary

In this chapter we explain satellite communication system and satellite link, we also talk about frequency bands and we know that Ka- frequency band presents several challenges for the implementation of a BSS, its offers relatively larger bandwidths but requires higher satellite EIRPs to compensate for higher link fading. We mention the attenuation with respect to free space (AFS) Gaseous attenuation, cloud attenuation, fog attenuation, worst month statistics and rain attenuation.

The antenna serves to a communication system the same purpose that eyes and eyeglasses serve to a human. In addition to receiving or transmitting energy, an antenna in an advanced wireless system is usually required to optimize or accentuate the radiation energy in some directions and suppress it in others.

Chapter three

Methodology

3.1 Introduction

Ka- frequency band presents several challenges for the implementation of a BSS, its offers relatively larger bandwidths but requires higher satellite EIRPs to compensate for higher link fading.

Rain attenuation in satellite communications systems operating at Ka-band frequencies is much more severe than that usually experienced at lower frequency bands: rain attenuation at 20 GHz (Ka-band down-link), for instance, is almost three times that at 11GHz (Ku band down-link). This fact makes rain attenuation one of the most important limiting factors to be taken into account in the design of a 20/30 GHz satellite communications system.

3.2 Rain Fade Calculations

Rain attenuation varies with frequency, location, polarization and rainfall rate. The depth of fade in dB can be calculated from:

$$L_{RAIN} = \gamma_R D_{RAIN} \qquad \text{….. (3-1)}$$

Where

LRAIN is the rain loss in dB

R is the specific attenuation (dB/Km)

DRAIN is the path length through the troposphere in Km

To calculate the rain attenuation we need to know:

- Latitude and longitude of the earth station in degree.
- Altitude of the station in Km.
- The frequency of operation.
- The polarization of the signal.
- The required availability of the satellite circuit.

Determining DRAIN

DRAIN is effectively the slant range of the portion of the signal that lies below the freezing point (zero degree isotherms) in the atmosphere fig (3.1). The assumption is that all rain originates at this level.

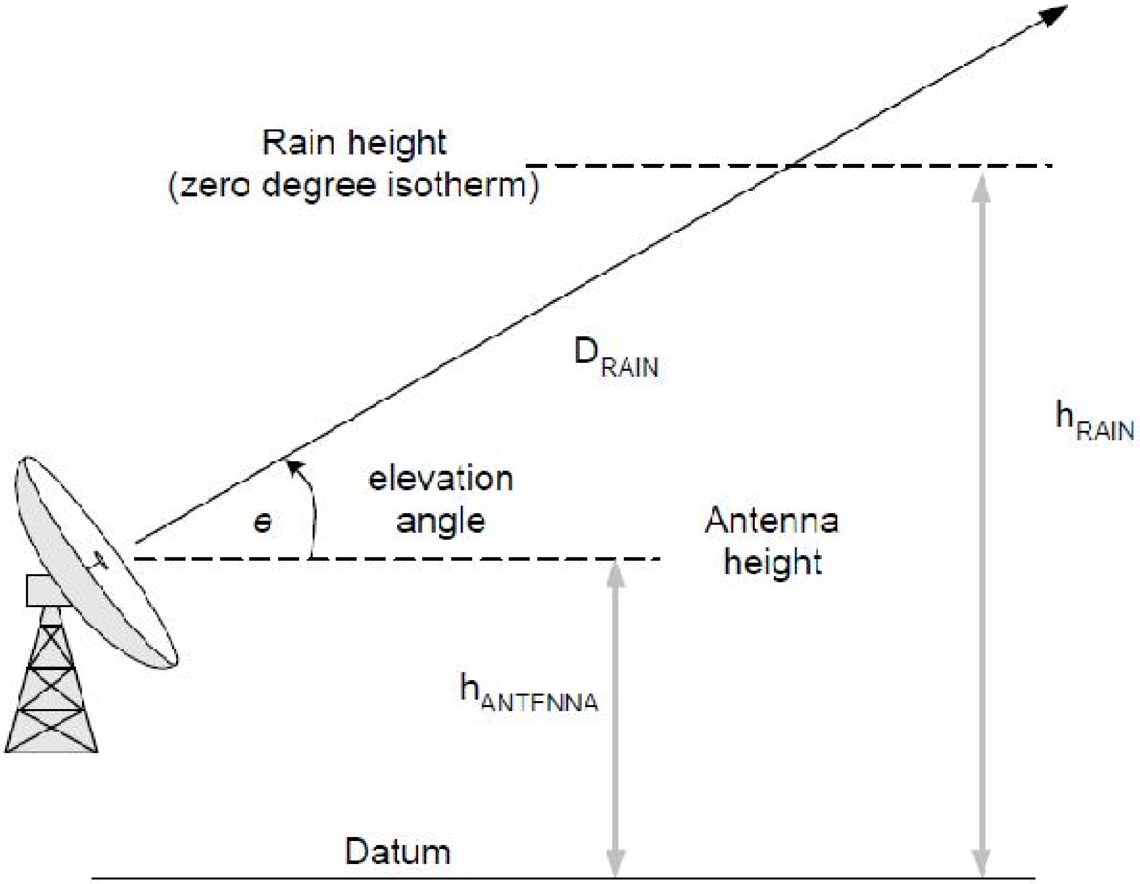


Fig (3.1) Drain parameters

DRAIN can be calculated from simple trigonometry from the above diagram.

$$D_{RAIN} = \frac{(h_{RAIN} - h_{ANTENNA})}{SIN(e)} \qquad \text{…..} \ (3.2)$$

This implies knowledge of the rain height h RAIN. ITU-R Recommendation P.839. Relates rain height to location, It is reproduced at table (3-1).

Table (3-1) world regions

Latitude		Region
φ >23N	5 – 0.07 (φ-23)	N hemisphere (except N America & Europe)
0≤φ≤23N	5	N hemisphere (except N America & Europe)
	3.2 - 0.075(φ- 35)	N hemisphere (except N America & Europe) West of 60 E Longitude
0≥φ≥21S	5	S hemisphere
21S>φ>71S	5 + 0.1(φ +21)	S hemisphere
71S>φ	.	S hemisphere

From this we can calculate h RAIN, and through that DRAIN.

Determiningγ_R

In order to determine it is $\boldsymbol{\gamma_R}$ first necessary to identify the rainfall region from the attached maps (appendix 1). Table (2-2) links the rainfall rate to the percentage of the time it is exceeded in any year by rainfall region. Locations of cites and it's elevations at table (3-2).

Table (3-2) Worlds Zones

Percentage of time R exceeded	Zone														
	A	B	C	D	E	F	G	H	J	K	L	M	N	P	G
01	<0.1	0.5	0.7	2.1	0.6	1.7	3	2	8	1.5	2	4	5	12	24
0.3	0.8	2	2.8	4.5	2.4	4.5	7	4	13	4.2	7	11	15	34	49
0.1	2	3	5	8	6	8	12	10	20	12	1.5	22	35	65	72
0.03	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.01	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

This gives the value of the rainfall rate R, which can be used to determine _R Specific attenuation, can be found from:

$$\gamma_R = KR^{\alpha} \qquad \text{…. (3.3)}$$

The values of K and α can be found from ITU-R Recommendation the table (3.3)

Table (3.3) K&α values

Frequency QHZ	**Horizontal polarization**		**Vertical Polarization**	
	K	α	K	α
1	0.0000387	0.912	0.0000352	0.880
2	0.000154	0.963	0.000138	0.923
4	0.000650	1.121	0.000591	1.075
6	0.00175	1.308	0.00155	1.265
7	0.00301	1.332	0.00265	1.321
8	0.00454	1.327	0.00395	1.310
10	0.0101	1.276	0.00887	1.264
12	0.0188	1.217	0.0168	1.200
15	0.0367	1.154	0.0335	1.128
20	0.751	1.099	0.0601	1.1065
25	0.124	1.061	0.113	1.030
30	0.187	1.021	0.167	1.000
35	0.263	0.979	0.233	0.963
40	0.350	0.939	0.310	0.929

3.3 N-element linear array: uniform amplitude and spacing

The array factor is a function of the geometry of the array and the excitation phase By varying the separation d and/or the phase β between the elements, the characteristics of the array factor and of the total field of the array can be controlled. Let us assume that all the elements have identical amplitudes but each succeeding element has a β progressive phase lead current excitation relative to the preceding one (β represents the phase by which the current in each element leads the current of the preceding element). An array of identical elements all of identical magnitude and each with a progressive phase are referred to as a uniform array. The array factor can be obtained by considering the elements to be point sources. If the actual elements are not isotropic sources, the total field can be formed by multiplying the array factor of the isotropic sources by the field of a single element. This is the Pattern multiplication rule (3-1) and it applies only for arrays of identical elements.

E (total) = [E (single element at reference point)] × [array factor … (3-4)

The array factor is given by

$$\boldsymbol{AF = \sum_{n=1}^{N} e^{j(n-1)\psi}} \quad \text{… .. (3-5)}$$

Where

$$\boldsymbol{\psi = kd\ cos\theta + \beta} \quad \text{….. (3-6)}$$

This can also be written as

$$\boldsymbol{AF = \left[\frac{sin(n\psi|2)}{sin(\psi|2)}\right]} \quad \text{… (3-7)}$$

The maximum value of (3-4) is equal to N. To normalize the array factors so that the maximum value of each is equal to unity is written in normalized form as

$$\boldsymbol{(AF)n = 1/N\left[\left(sin(N\psi|2)\middle|sin(\psi|2)\right)\right]} \quad \text{….. (3-8)}$$

To get a deeper understanding of the array factor equation for various values of N and d. It should be noted that a larger N gives a narrower major lobe. Larger element spacing will also give a narrower major lobe. This means that the directivity of an array can be increased by either increasing the number of elements or the element spacing. It is also seen that increasing N gives a lower side lobe level.

3.3.1 Broadside Array

In many applications it is desirable to have the maximum radiation of an array directed normal to the axis of the array [broadside; $\theta 0 = 90^\circ$]. To optimize the design, the maxima of the single element and of the array factor should both be directed toward $\theta 0 = 90^\circ$. The requirements of the single elements can be accomplished by the judicious choice of the radiators and those of the array factor by the proper separation and excitation of the individual radiators.

Referring to (3-5), the first maximum of the array factor occurs when

$$\psi = kd\cos\theta + \beta = 0 \qquad \text{….. (3-9)}$$

Since it is desired to have the first maximum directed toward

$\theta 0 = 90^\circ$, then

$$\psi = kd\cos\theta + \beta|_{\theta=90^\circ} = \beta = 0 \qquad \text{….. (3-10)}$$

Thus to have the maximum of the array factor of a uniform linear array directed broadside to the axis of the array, it is necessary that all the elements have the same phase excitation (in addition to the same amplitude excitation). The separation between the elements can be of any value. To ensure that there are no principal maxima in other directions, which are referred to as grating lobes, the separation between the elements should not be equal to multiples of a wavelength

($d \neq n\lambda$, $n = 1, 2, 3 \ldots$) when $\beta = 0$.

If $d = n\lambda$, $n = 1, 2, 3\ldots$ and $\beta = 0$

then

$$\psi = kd\cos\theta + \beta$$

$$= 2\pi n\cos\theta \quad = \pm 2n\pi \qquad \text{…. (3-11)}$$

$d=n\lambda$

$\beta=0$

n=1, 2, 3...

This value of ψ when substituted in (3-8) makes the array factor attain its maximum value. Thus for a uniform array with $\beta = 0$ and $d = n\lambda$, in addition to having the maxima of the array factor directed broadside ($\theta 0 = 90^\circ$) to the axis of the array, there are additional maxima directed along the axis ($\theta 0 = 0^\circ$, 180°) of the array (end- fire radiation).

One of the objectives in many designs is to avoid multiple maxima, in addition to the main maximum, which are referred to as grating lobes. Often it may be required to select the largest spacing between the elements but with no grating lobes. To avoid any grating lobe, the largest spacing between the elements should be less than one wavelength ($d\text{max} < \lambda$)

3.3.2 Ordinary End-Fire Array

Instead of having the maximum radiation broadside to the axis of the array, it may be desirable to direct it along the axis of the array (end-fire). As a matter of fact, it may be necessary that it radiates toward only one direction (either $\theta 0 = 0^\circ$ or 180°.

To direct the first maximum toward $\theta 0 = 0^\circ$,

$\psi = kd \cos\theta + \beta|\theta=0^\circ = kd + \beta = 0 \Rightarrow \beta = -kd$ ….. (3-12)

If the first maximum is desired toward $\theta 0 = 180^\circ$

then

$\psi = kd \cos \theta + \beta|\theta=180^\circ = -kd + \beta = 0 \Rightarrow \beta = kd$ ….(3-13)

Thus end-fire radiation is accomplished when $\beta = -kd$

(for $\theta 0 = 0^\circ$) or $\beta = kd$ (for $\theta 0 = 180^\circ$).

If the element separation is $d = \lambda/2$, end-fire radiation exists simultaneously in both directions ($\theta 0 = 0^\circ$ and $\theta 0 = 180^\circ$). If the element spacing is a multiple of a $= n\lambda$, $n = 1, 2, 3 . . .$), then in addition to having end-fire wavelength (d radiation in both directions, there also exist maxima in the broadside directions.

Thus for $d = n\lambda$, $n = 1, 2, 3 . . .$ there exist four maxima; two in the broadside directions and two along the axis of the array. To have only one end-fire maximum and to avoid any grating lobes, the maximum spacing between the elements should be less than $d_{max} < \lambda/2$.

3.3.3 Phased (Scanning) Array

In the previous two sections it was shown how to direct the major radiation from an array, by controlling the phase excitation between the elements, in directions normal (broadside) and along the axis (end fire) of the array. It is then logical to assume that the maximum radiation can be oriented in any direction to form a scanning array.

Let us assume that the maximum radiation of the array is required to be oriented at an angle θ_0 ($0^\circ \leq \theta_0 \leq 180^\circ$). To accomplish this, the phase excitation β between the elements must be adjusted so that

$$\psi = kd\cos\theta + \beta|_{\theta=\theta_0} = kd\cos\theta_0 + \beta = 0$$

$$\Rightarrow \beta = -kd\cos\theta_0 \qquad \text{.....} \ (3\text{-}14)$$

Thus by controlling the progressive phase difference between the elements, the maxi-mum radiation can be squinted in any desired direction to form a scanning array. This is the basic principle of electronic scanning phased array operation. Since in phased array technology the scanning must be continuous, the system should be capable of continuously varying the progressive phase between the elements. In practice, this is accomplished electronically by the use of ferrite or diode phase shifters. For ferrite phase shifters, the phase shift is controlled by the magnetic field within the ferrite, which in turn is controlled by the amount of current flowing through the wires wrapped around the phase shifter.

For diode phase shifter using balanced, hybrid-coupled varactors, the actual phase shift is controlled either by varying the analog bias dc voltage (typically 0–30 volts) or by a digital command through a digital-to-analog (D/A) converter.

Differential phase shift, provided by switching on and off the two paths, is given by

$$\varphi = k\,(l2 - l1) \qquad \ldots\ldots (3\text{-}15)$$

By properly choosing l1 and l2, and the operating frequency, the differential phase shift (in degrees) provided by each incremental line phase shifter can be as small as desired, and it determines the resolution of the phase shifter. The design of an entire phase shifter typically utilizes several such incremental phase shifters to cover the entire range (0 − 180°) of phase.

The total beam width is the difference between two angles and can be written as

$$\boldsymbol{\theta}_{\boldsymbol{h}} = \boldsymbol{cos^{-1}}\left[\frac{\lambda}{2\pi d}\left(\boldsymbol{kd\cos\theta_0} - \frac{2.782}{N}\right)\right] - \boldsymbol{cos^{-1}}\left[\frac{\lambda}{2\pi d}\left(\boldsymbol{kd\cos\theta_0} + \frac{2.782}{N}\right)\right] \qquad (3\text{-}16)$$

Since $N = (L+d)/d$

$$\boldsymbol{\theta}_{\boldsymbol{h}} = \boldsymbol{cos^{-1}}\left[\boldsymbol{\cos\theta_0} - 0.443\frac{\lambda}{(L+d)}\right] - \boldsymbol{cos^{-1}}\left[\boldsymbol{\cos\theta_0} + 0.443\frac{\lambda}{(L+d)}\right] \qquad (3\text{-}17)$$

How to avoid grating lobes??..

Grating lobes are unwanted in most applications since they transmit and receive energy in unwanted directions. Grating lobes occur when the spacing between elements are large enough to permit in-phase addition of radiated fields in more than one direction .Elements must be spaced properly in order to avoid grating lobes. The equation for maximum spacing is a function of wavelength of operation and maximum look angle:

$$d_{max} = \frac{\lambda}{1+\sin(\theta)} \qquad \ldots\ldots \ (3\text{-}18)$$

Where

λ=*wave length*

θ=*look angle*

Thus for a 30 degree look angle, d max is (2/3)x lambda, while for a 60 degree look angle, d max is 0.54 lambda.

3.3.4 Calculating antenna gain in a phased array

Gain at broadside in a phased array is both a function of the individual element gain and the number of elements. The aperture gain is calculated by:

$$G_{A=4\pi\frac{A\mu}{\lambda^{2}}} \qquad \ldots\ldots(3\text{-}19)$$

Where

A=Aperture area

μ= Aperture effectiony

λ=wave length

The number of elements required in an electronically-scanning phased array antenna can be estimated by the gain it must provide. A 30 dB gain array needs about 1000 elements and a 20 dB gain array needs about 100.

The gain of the individual elements is a function of what radiator is used. This is a case where you don't want the element to have too much gain, because the entire idea behind a phased array is that you want to maximize scan volume; you don't want system gain to rapidly drop off as you move away from broadside due to the element pattern. In practice, most radiators used in phased arrays provide about six dB gain. So, what happens to gain as you scan off of broadside? The gain drops a cosine of the angle. Thus at 60 degrees you are at 1/2 the gain at broadside, and when you get to end-fire condition, gain is down to zero. This is the one problem with phased arrays that might make you want to reconsider a gimbaled approach. To get a full 360 degree coverage usually takes four phased arrays, you could do that with a single, rotating antenna.

3.3.5 Radiation Pattern

An antenna radiation pattern or antenna pattern is defined as "a mathematical function or a graphical representation of the radiation properties of the antenna as a function of space coordinates. In most cases, the radiation patter determined in the far field region and is represented as a function of the direction coordinates. Radiation properties include power flux density, radiation intensity, field strength, directivity, phase or polarization." The radiation property of most concern is the two- or three dimensional spatial distribution of radiated energy as a function of the observer's position along a path or surface of constant radius. A trace of the received electric (magnetic) field at a constant radius is called the amplitude field pattern. On the other hand, a graph of the spatial variation of the power density along a constant radius is called an amplitude power pattern.

Often the field and power patterns are normalized with respect to their maximum value, yielding normalized field and power patterns. Also, the power pattern is usually plotted on a logarithmic scale or more commonly in decibels (dB). This scale is usually desirable because a logarithmic scale can accentuate in more details those parts of the Pattern that have very low values, which later we will refer to as minor lobes. For an antenna, the

1. Field pattern (in linear scale) typically represents a plot of the magnitude of the electric or magnetic field as a function of the angular space.
2. Power pattern (in linear scale) typically represents a plot of the square of the magnitude of the electric or magnetic field as a function of the angular space.
3. Power pattern (in dB) represents the magnitude of the electric or magnetic field, in decibels, as a function of the angular space.

$$E(a) = \frac{\sin\,(N\pi\left(\frac{d}{\lambda}\right).\sin(\theta))}{\sin\,(\pi\left(\frac{d}{\lambda}\right).\sin(\theta))} \qquad \ldots\ldots \quad (3\text{-}20)$$

Where θ =angle of incidence

3.3.6 Directivity

Directivity is defined as the ratio of an antenna's radiation intensity in a given direction over the radiation intensity of an isotropic source (one that radiates equally in all directions). Directivity is often expressed in dBi and represents the dB ratio w.r.t the isotropic radiator, much the same way as dBm is used for rf power. It can be calculated using

$$D = \frac{U_{max}}{\frac{1}{4\pi} P_{rad}} \qquad \text{.......} \; (3\text{-}21)$$

Where

$U_{max} = (E_{max} - E^{*}{}_{max})$: Maximum radiation intensity (W / solid angle)

P_{rad} : Total radiated power (W)

The 4π refers to the number of steradians in a sphere thereby giving the denominator units of (W / solid angle) as well. It also means that the denominator represents the average radiation intensity over the sphere.

For a non isotropic antenna (all practical antennas) the total power radiated P_{rad} be found by integrating the radiated power pattern U (θ,ϕ) over a full sphere. Substituting this integrated expression for P_{rad} into Eq (3-17) gives

$$D = \frac{U_{max}}{\frac{1}{4\pi}\int_0^{2\pi} \int_0^{\pi} U(\theta,\phi).\sin(\theta).d\theta\, d\phi} \qquad \text{....} \; (3\text{-}22)$$

The numerical equivalent of equation 4.1-2 can be written

$$D = \frac{U_{max}}{\frac{1}{4\pi}\sum_{j=1}^{M}[\sum_{i=1}^{N} P\left(\theta_i,\phi_j\right).\sin(\theta_i).\Delta\theta\Delta\phi]} \qquad \text{....} \; (3\text{-}23)$$

In practice the theta and phi summations use values:

Theta=(start Δθ : step Δθ: stop(π- Δθ)) and Phi=(start Δϕ : step Δϕ : stop(2π-Δϕ)

Chapter summary

The design of a Broadcasting system must comply with current ITU-R recommendations for Broadcasting Satellite Systems (BSS) concerning the power flux density for this frequency band.

In this thesis attenuation is neglible expect rain attenuation which varies with frequency, location, polarization and rain fall rate and we calculate the depth of fade in db.

Antenna technology uses direct radiating phased-array antennas in which all the radiating elements contribute to each of the spot beams. The number of the outage areas using dynamically controlled radiation pattern formed by the array-fed reflector antenna with that using static radiation pattern formed by shaped reflector antenna while assuming the same input power to the antenna. Hence concentrating some portions of satellite transmitting power within the heavy rainfall area can achieve adaptive compensation for rain attenuation in that area without hefty increase in total satellite-transmitting power and sacrificing program qualities.

Chapter four

Numerical Results and Dissections

4.1 Rain fades calculations

To calculate the rain attenuation we need to know:

- Latitude and longitude of the earth station in degree.
- Altitude of the station in Km.
- The frequency of operation.
- The polarization of the signal.
- The required availability of the satellite circuit.

In our thesis we take seventeen cites (W-halfa , Dongla , Atbra , Khartoum , N-halfa ,W-madni , Kassla , Elgadarif , Sennar , Elginina , Kosti , Elobied , Elnahood , Nyla , Eldmazin , Babanusa , Kadogli).

According to longitude and latitude of these cites we calculate their elevations to Arabsat satellite in 26 °E , then we collected the data about rain fall rate of these cites during the years(2011 , 2012 , 2013) .All these data a beers in table (4.1) .

Table (4-1): Locations and Rainfall of Sudanese cites

City	Lat(N)	Long(E)	Rainfall (mm)2011	Rainfall (mm)2012	Rainfall (mm)2013	Elevation	Zone
Wadi-half	21.70	31.37	TR	1.0	5.0	63.9	A
Dongola	19.10	30.4	0.0	TR	16.0	67.0	A
Atbara	16.70	30.4	41.1	1.0	61.2	69.8	C
Khartoum	15.60	32.4	50.4	86.6	86.8	70.2	E
New-halfa	15.30	35.7	249.7	162.3	230.7	68.8	E
Wd-mdani	14.20	33.3	1652.2	286.7	244.5	71.3	E
Kassala	15.04	36.4	121.7	66.5	143.2	68.6	E
El-gedaref	14.03	35.3	502.8	596.8	462.5	69.3	E
Sennar	13.50	33.5	291.4	497.9	375.5	71.9	E
El-genina	13.40	22.4	460.9	560.6	364.3	73.7	K
Kostei	13.10	32.6	324.3	482.8	408.9	72.8	E
El-obeid	13.10	30.2	357.3	523.0	358.3	73.9	E
El-nahud	12.60	28.4	477.5	483.1	261.5	74.9	K
Nyala	12.20	24.8	462.4	420.7	546.2	75.6	K
El-dmazin	11.70	34.35	530.7	659.5	680.3	73.1	E
Babanusa	11.30	27.8	445.9	674.0	331.1	76.5	K
Kadugli	11.02	29.7	660.5	570.8	532.8	76.3	K

Note:

TR: Trace: Rainfall less than 0.1mm

As mentioned in equations (2-18) ,(2-19) and(2-20) we need to determine the height of antennas of earth stations that we used , due to its small values when we compared it with h_{rain} that we get from table (2-1) so we assumed that our antennas are in the sea level. Also we to identify the rainfall region from the attached map (appendix 1). Table (2-2) links the rainfall rate to the percentage of the time it is exceeded in any year by rainfall region and gives the value of the rainfall rate R. The values of K and α can be found from ITU-R Recommendation table (2-3).

In figure (4-1) we compare rain attenuation that faced the RF power in the same area with same conditions at 12GHZ band and 20 GHZ band, from the results we get we note that the attenuation caused by rain at Ka band is three times more than attenuation at Ku band ,also we Compare the result between rain attenuation with availability 99.9% and availability 99.7% and availability 99% in fig(4-2),then it was clear that the attenuation is Compare the result between rain attenuation at vertical polarization and horizontal polarization at12GH and 20 GHZ in fig(4-3) a and b.

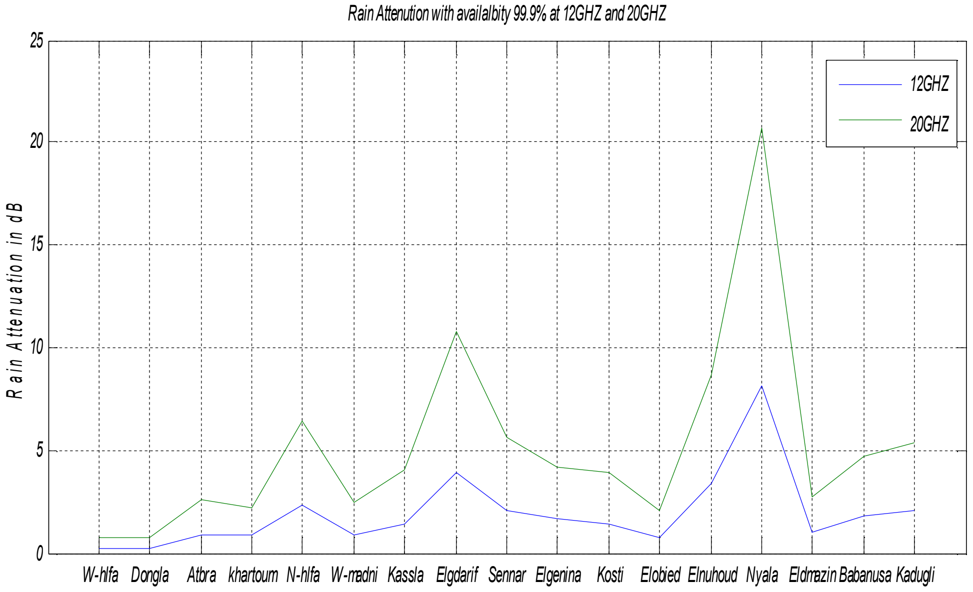


Fig (4-1): Rain attenuation at Ka band and Ku band

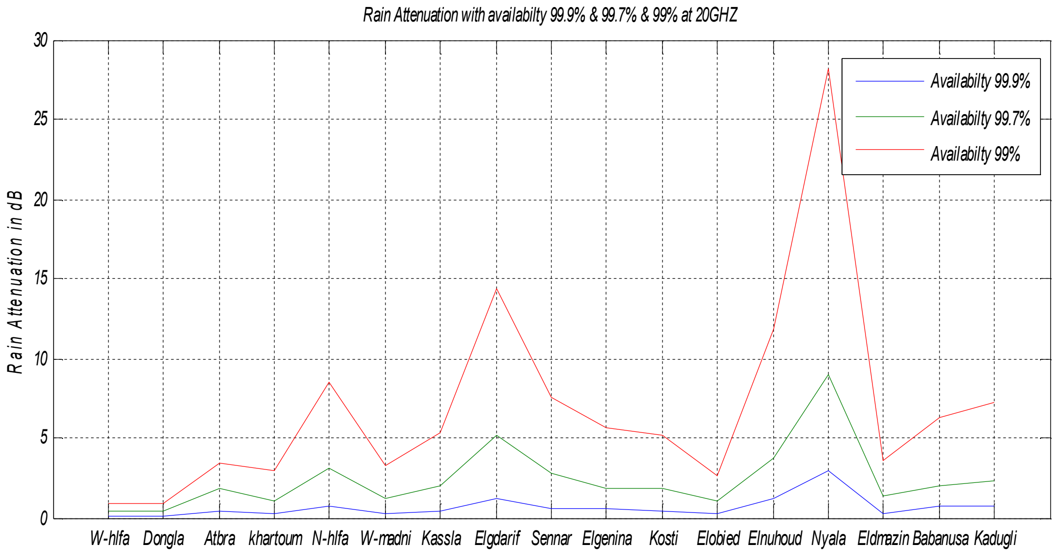


Fig (4.2): Rain attenuation with availability 99.9%&99.7%&99%

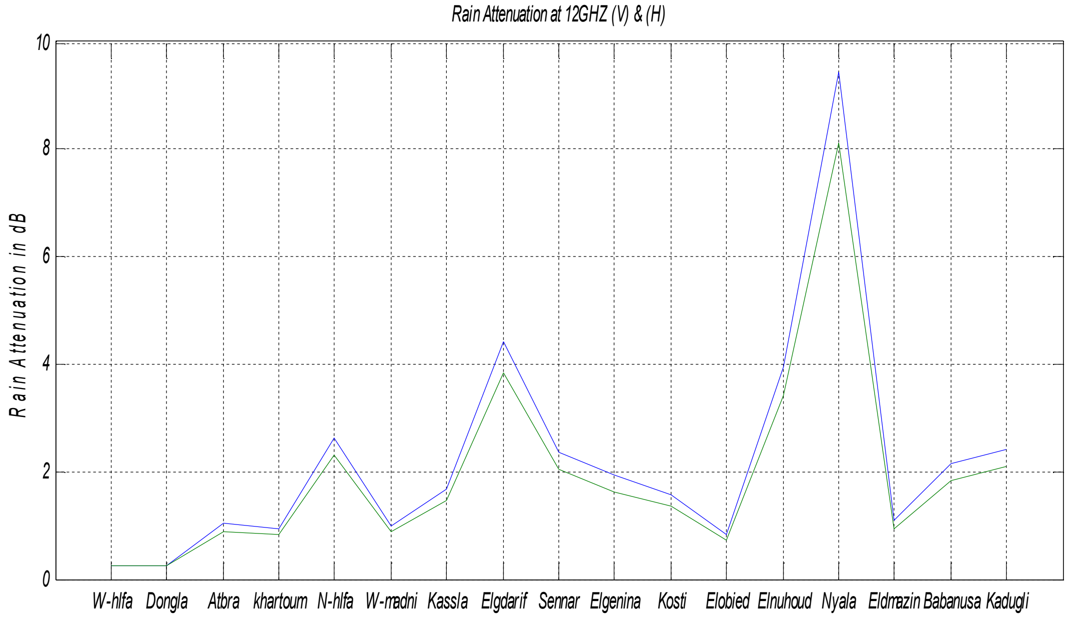


Fig (4.3a): Rain attenuation at 12GHZ (V) & (H)

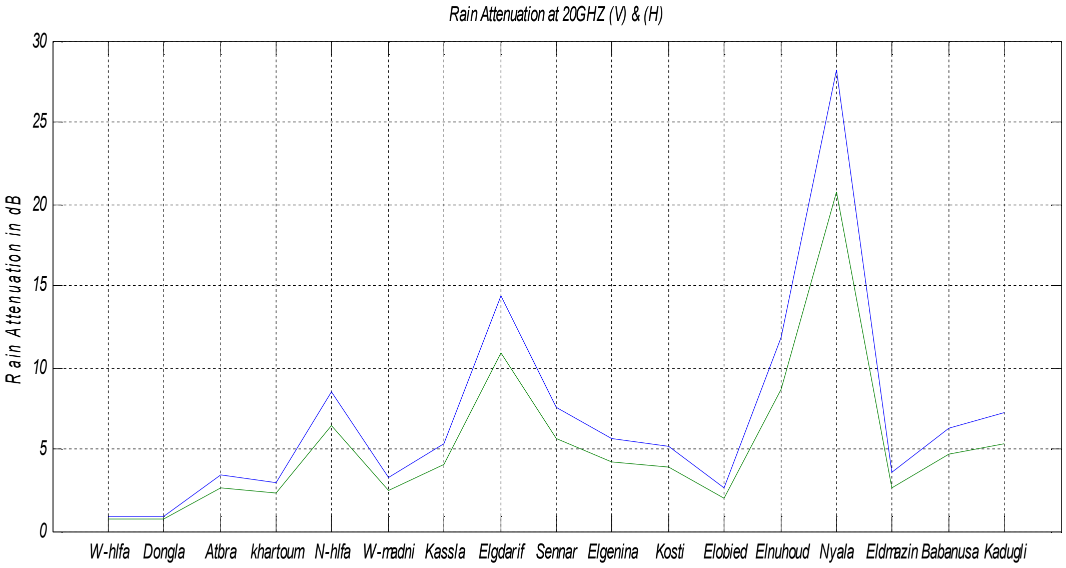


Fig (4.3b): Rain attenuation at 20GHZ (V) & (H)

4.2 Array Factor

As mentioned in array factor equation (3.5) for various values of N and d, we noted that a larger N gives a narrower major lobe. Larger element spacing will also give a narrower major lobe. This means that the directivity of an array can be increased by either increasing the number of elements or the element spacing. It is also seen that increasing N gives a lower side lobe level. We used various values of N, the values we used is listed below get results shown in figures (4.4a), (4.4b), (4.4c), (4.4d) and (4.5).

F	
C	
D	
Ψ	40°
N	5,10,20,60

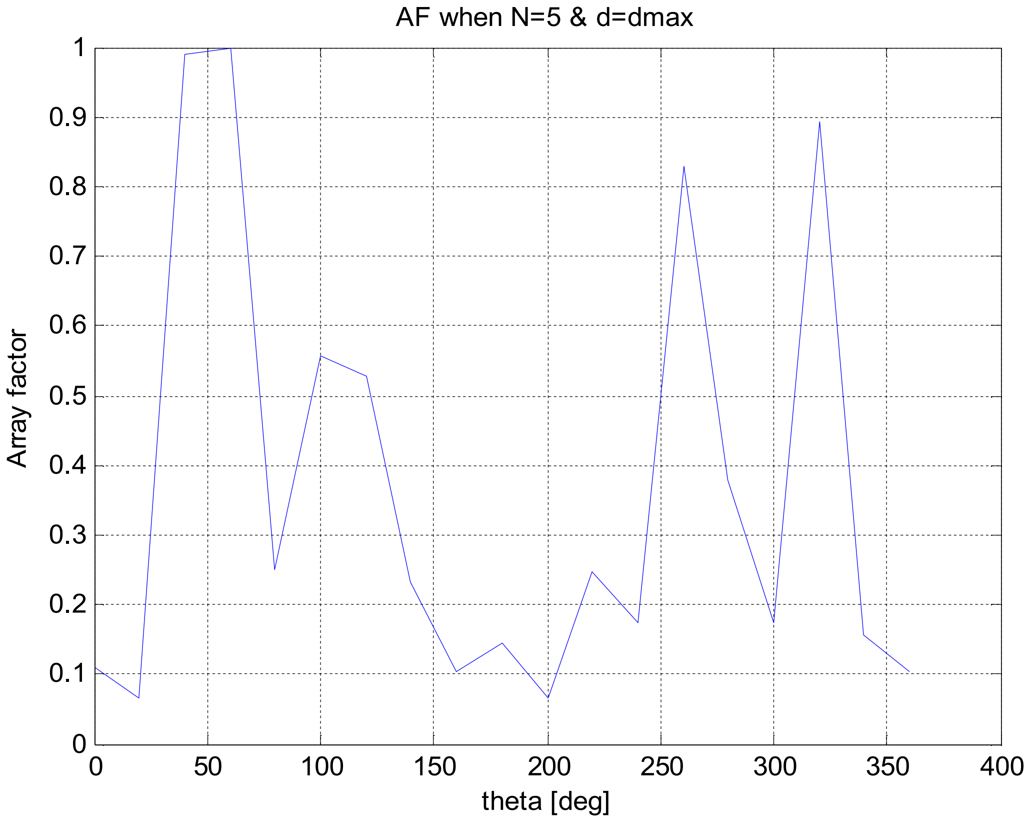

AF when N=5 & d=dmax
Array factor
theta [deg]
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
50
100
150
200
250
300
350
400

Fig (4.4a): N=5

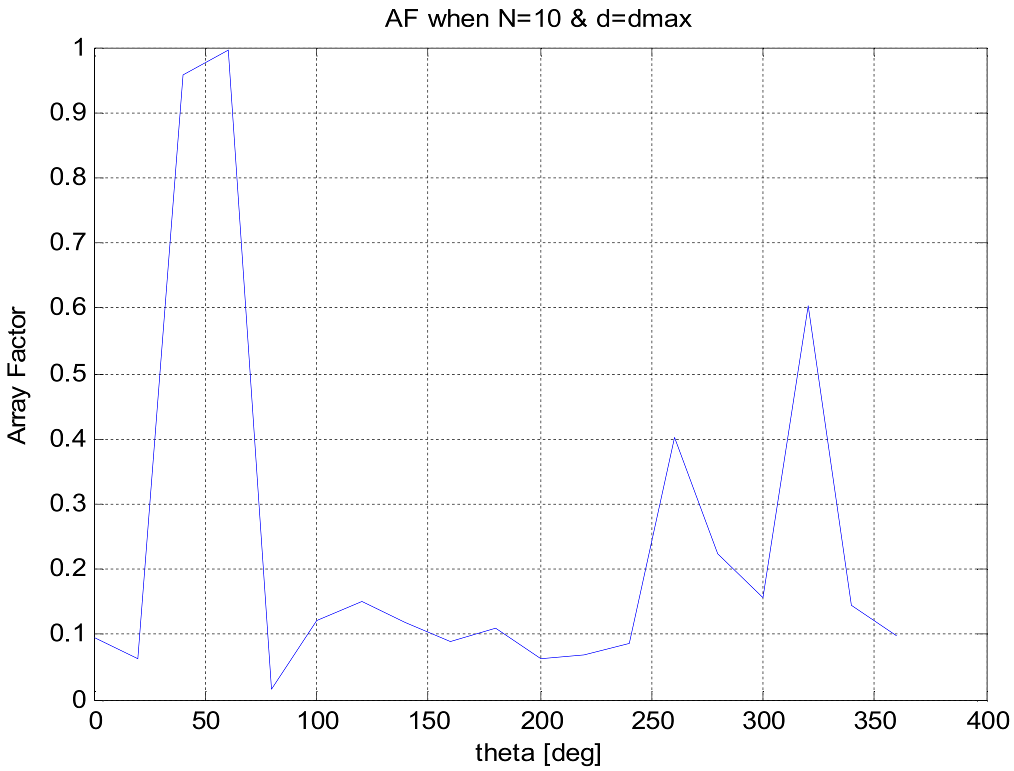


Fig (4.4b): N=10

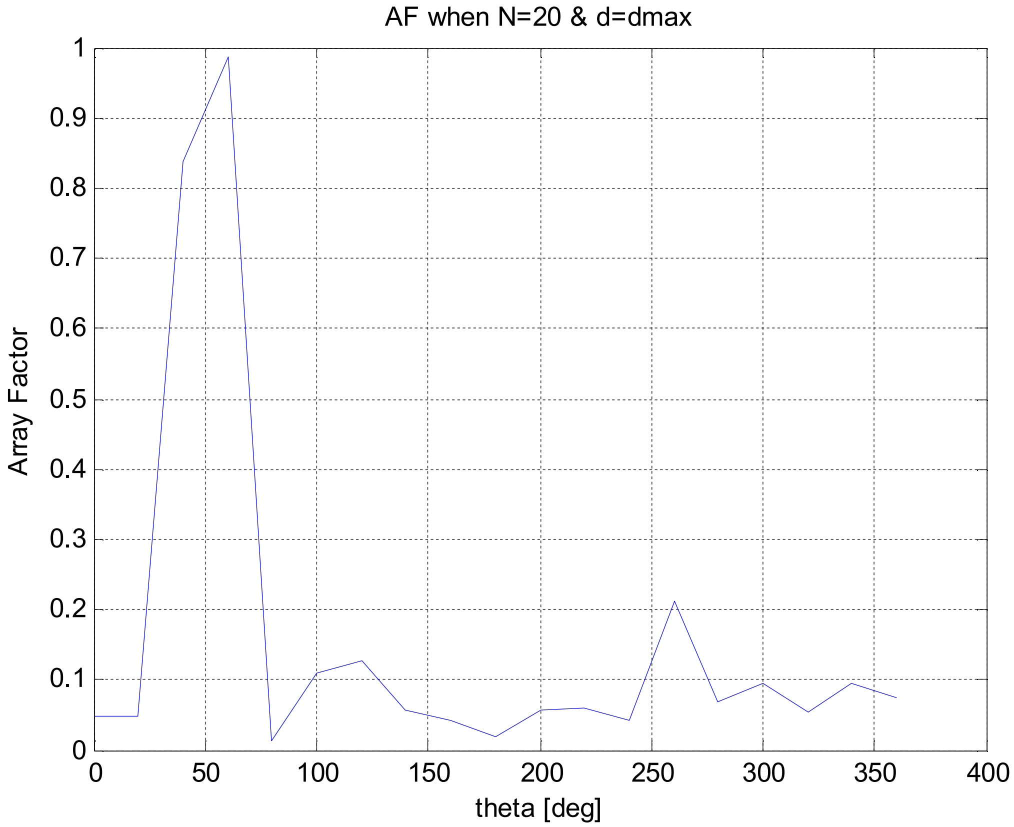


Fig (4.4c): N=20

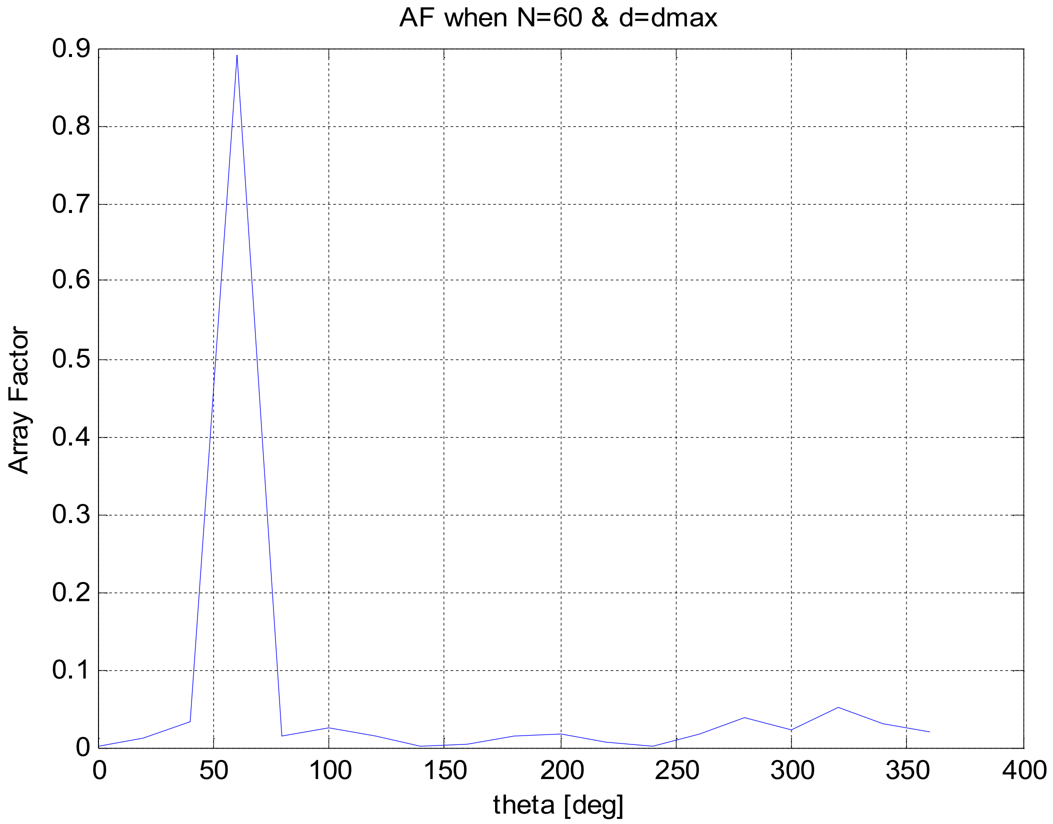


Fig (4.4d): N=60

Fig (4.4): Array factor when d=d_{max} &N=5, 10, 20, 60

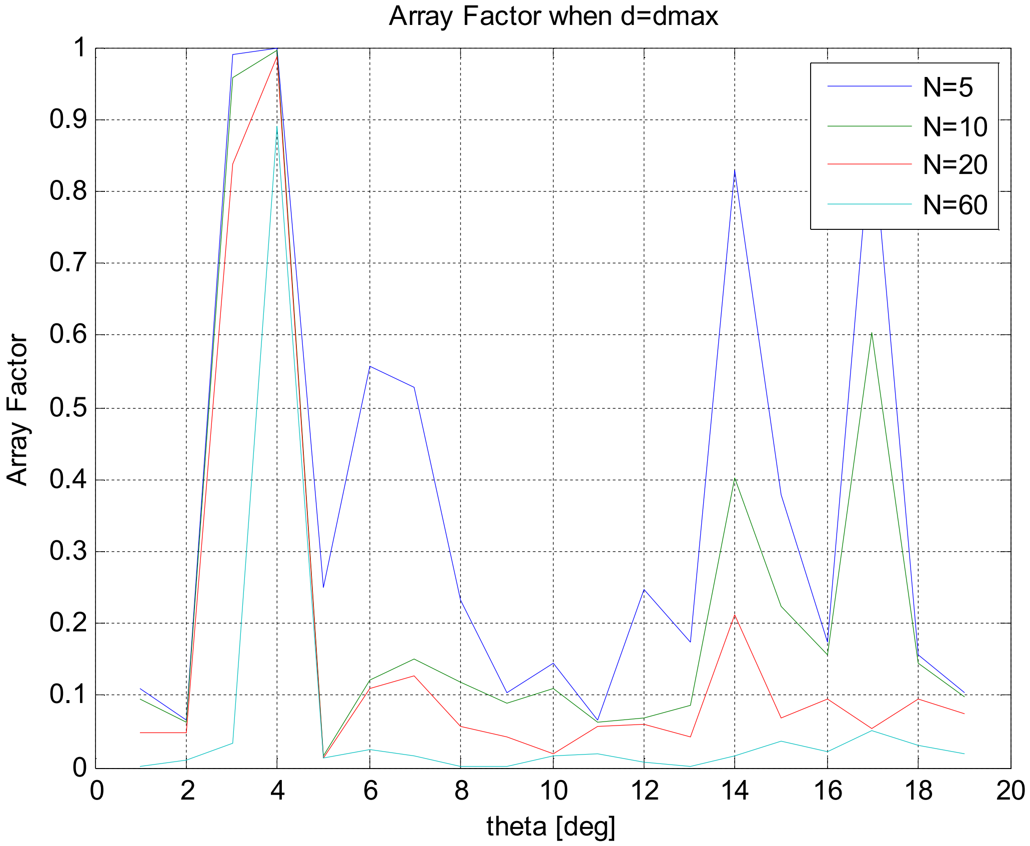


Fig (4.5): Array factor when d=d_{max} N=5, 10, 20, 60

```
Array factors when d=dmax/2 with variables Number of elements
N=5, 10, 20
```

F	
C	
D	
Ψ	40°
N	5,10,20

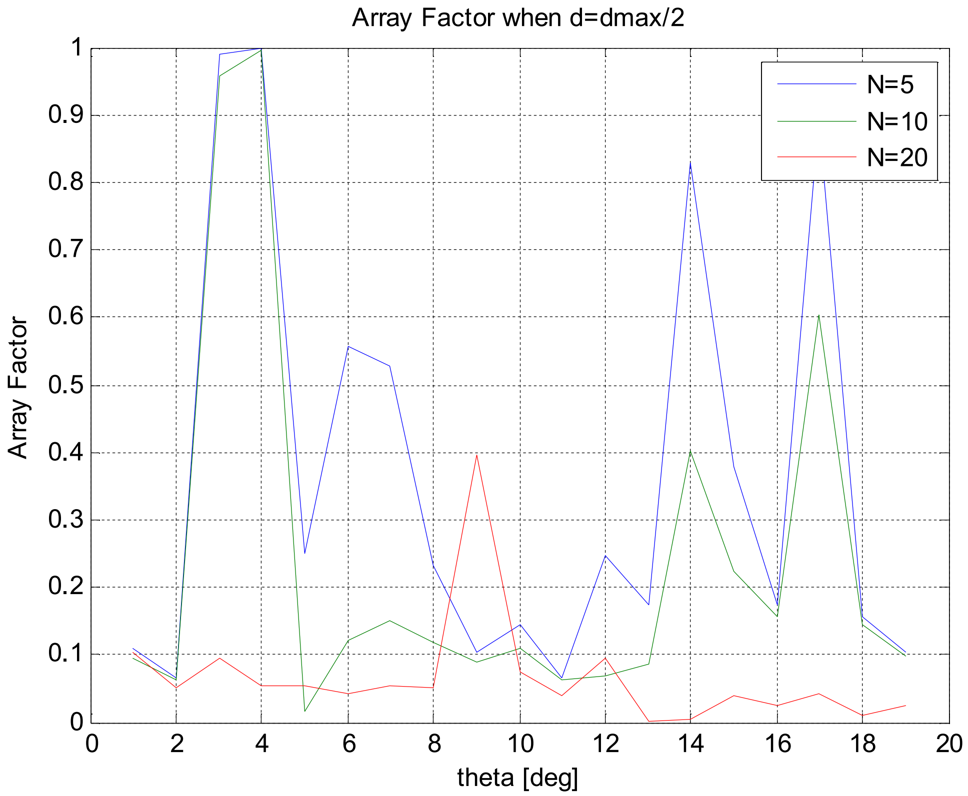


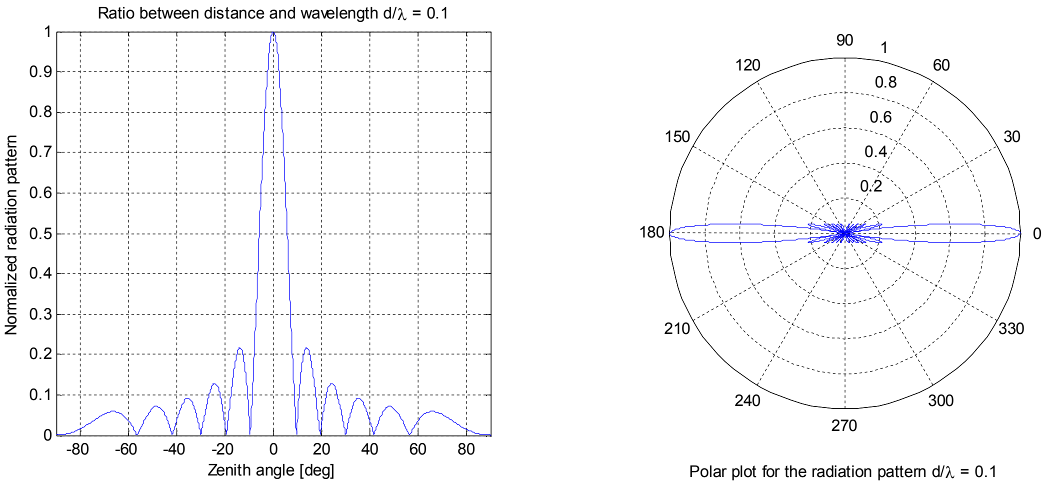
Fig (4.6): Array factor when d=$\frac{d_{max}}{2}$ & N=5, 10, 20

4.3 Phased Array Antenna, Radiation Pattern and Array Configuration

The parameters we need in equation (3.17) are listed below

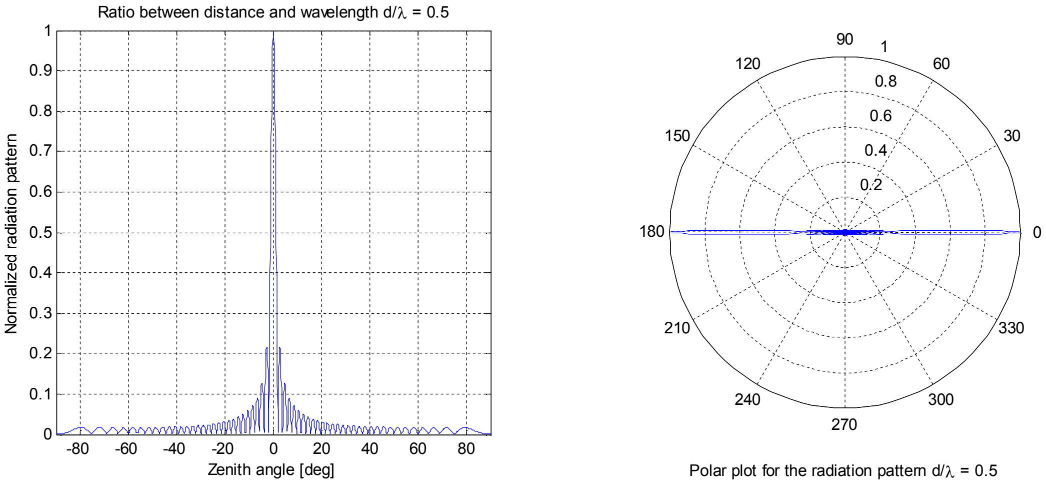
N	60
Alfa	-90. 90
D	$(0.1,0.5,1,2,5) * \lambda$

So we get the figures (4.7a), (4.7b), (4.7c), (4.7d) and (4.7e) as results that explain the Ratio between wavelength and distance between individual elements Linear Array of N isotropic radiators.



Polar plot for the radiation pattern d/λ = 0.1

Fig (4.7a): d=0.1λ



Polar plot for the radiation pattern d/λ = 0.5

Fig (4.7b): d=0.5λ

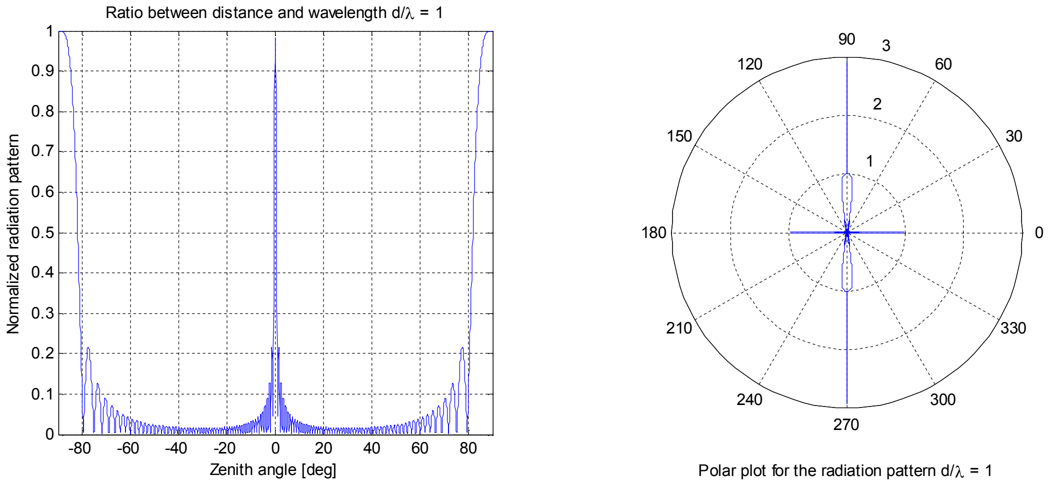
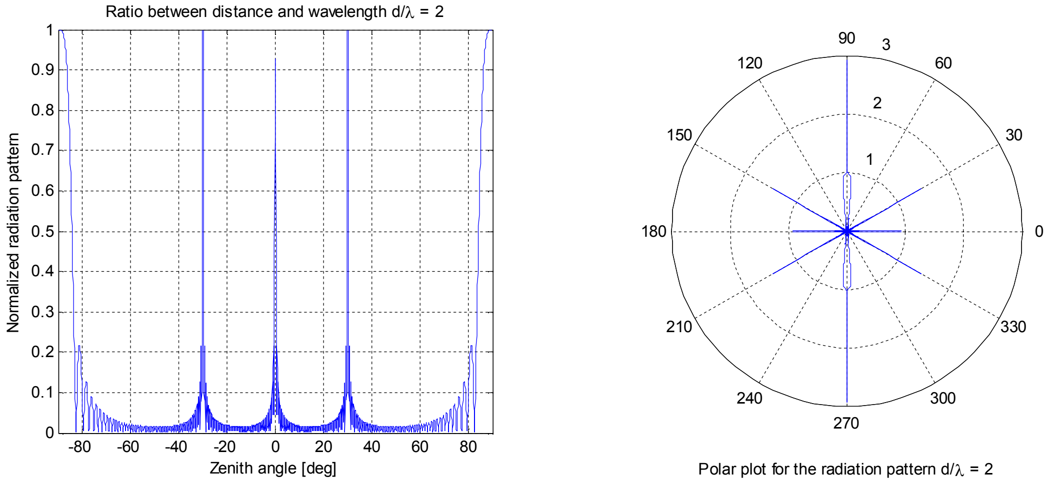
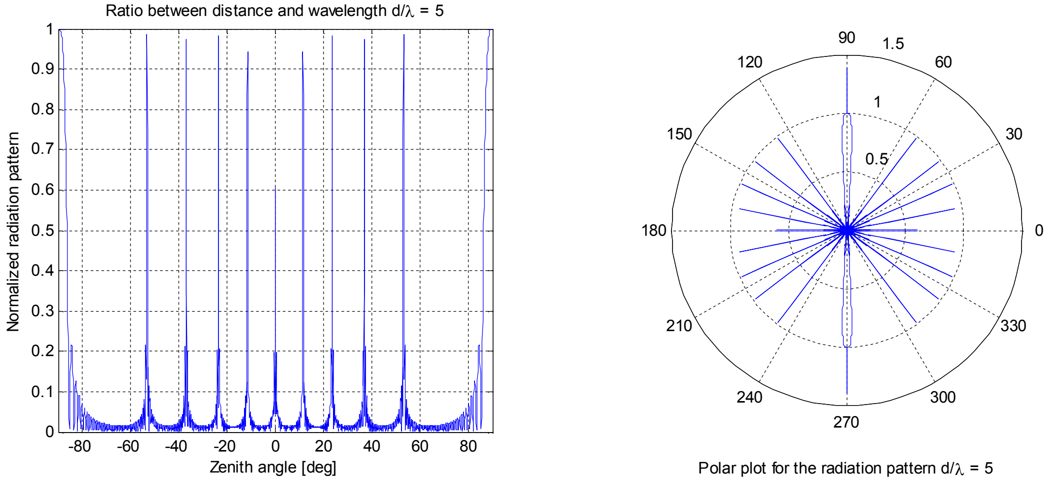


Fig (4.7c): d=λ



(4.7d): d=2λ



(4.7e): d=5λ

Fig (4.7): Radiation pattern N=60 with different no of spaces between elements

We try various Numbers of antenna elements, and the distance between individual elements equals to the half wavelength of the signal N= [4, 16, 60, 100, 180] , figures (4.8a) ,(4.8b), (4.8c), (4.8d) and(4.8e) shows the effect of increasing the number of elements that decreasing the grating lobe

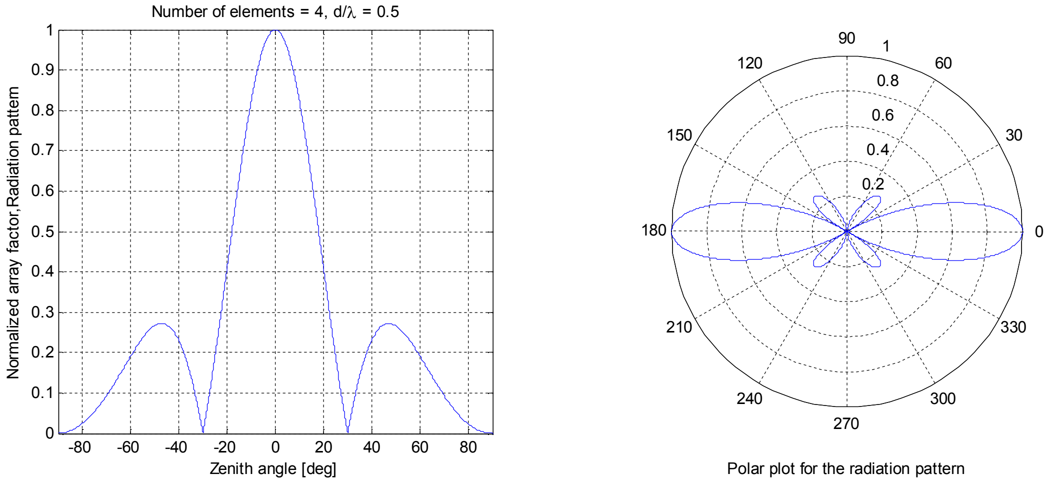
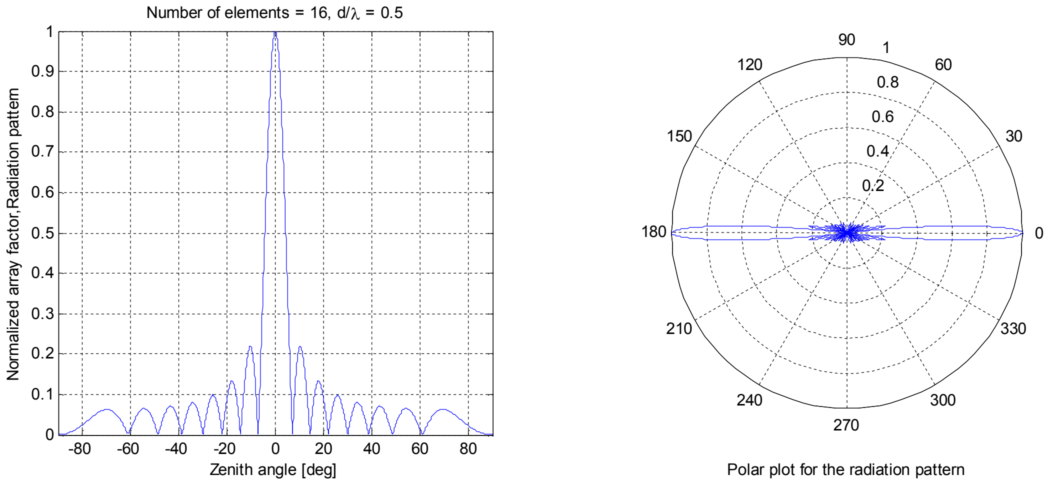
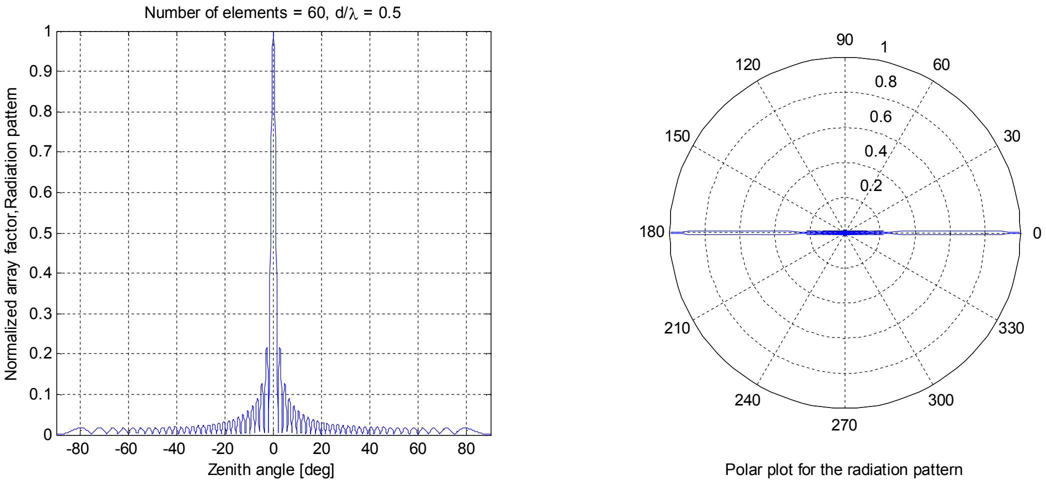


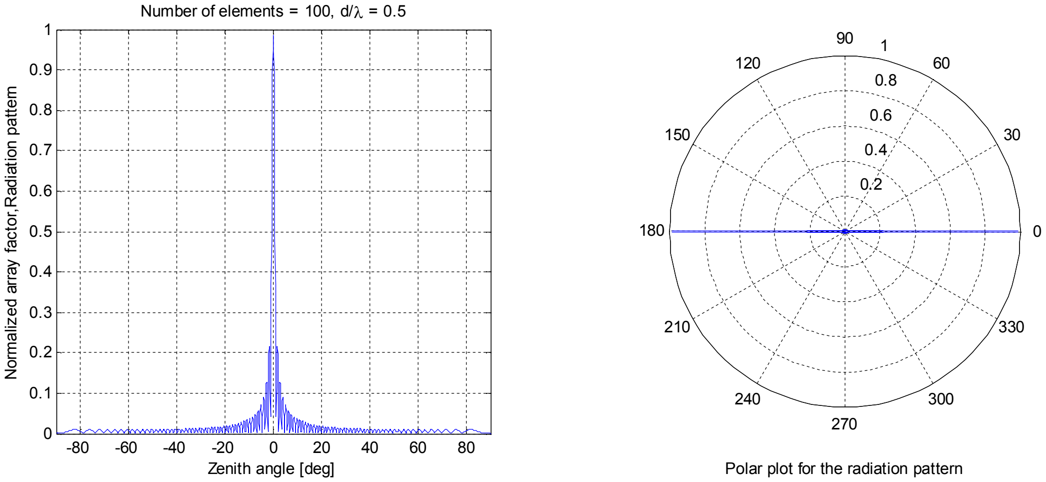
Fig (4.8a): N=4



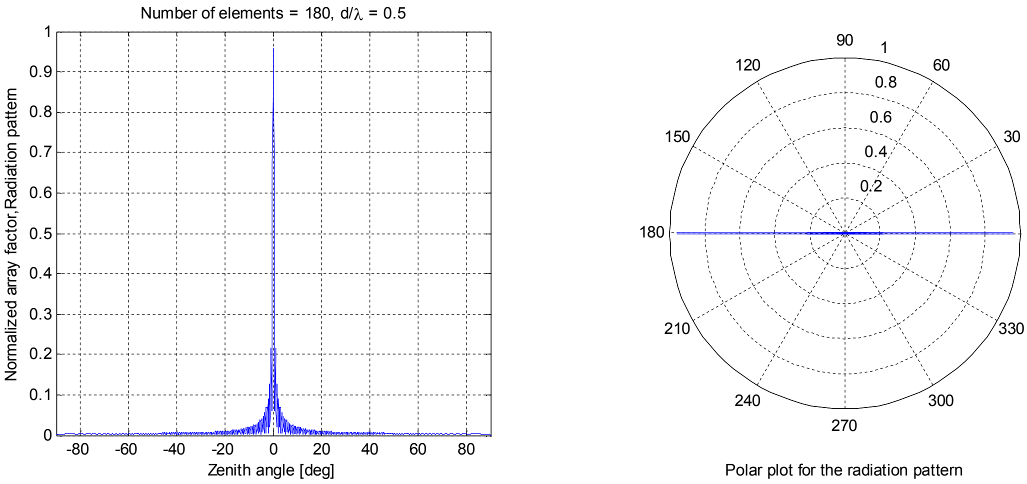
(4.8b): N=16



(4.8c): N=60



(4.8d): N=60



(4.8e): N=100

Fig (4.8): Radiation pattern d=0.5λ with different no of elements

Finally we control change radiation pattern from one location to other one in fig (4.9)

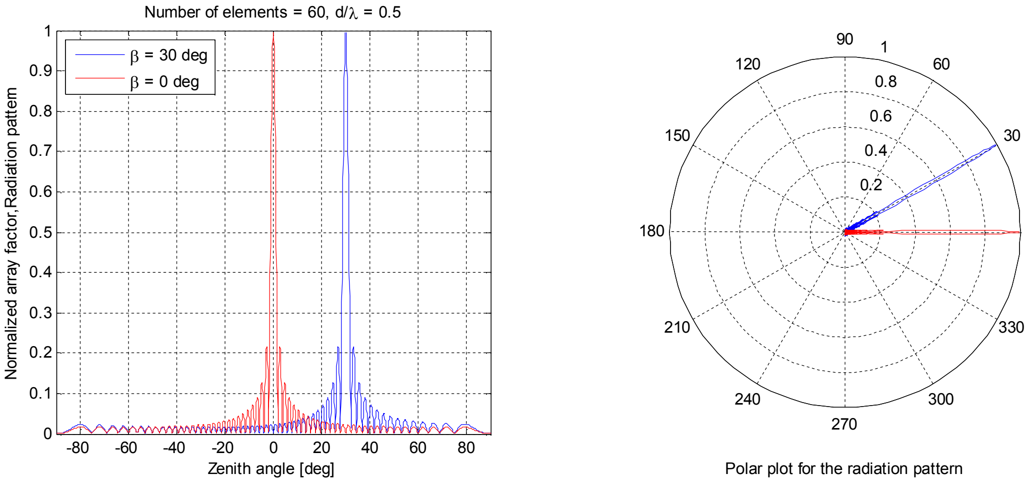


Fig (4.9) Radiation pattern change

4.4 Results

Rain along the transmission path is the major weather effect of concern for satellite communications operating at frequencies above 10 GHz, adverse weather conditions impact Ka-band more than at lower frequencies ,fig(4-1) explain that The rain attenuation at 21.7 GHz is approximately four times as large as those at 12.0 GHz.

At fig (4-2) the rain attenuation with availability 99.9% is larger than attenuation with availability 99.7% which itself is more than that with availability 99%, also if we compare the attenuation at Horizontal polarization with that at Vertical polarization at both 20 GHZ and 12GHZ fig (4-3a) and fig (4-3b) it will be clear that the attenuation at Horizontal polarization is slightly more than the attenuation at Vertical polarization.

Array Factor is afuction dependent only on the Geometry of the array and excitation (amplitude, phase) of the elements, uniform array is defined by uniformly-spaced identical elements of equal magnitude with a linearly progressive phase from element to element.

The distance between radiating elements play an important factors towards shaping of beam and controlling grating lobes, we noted that larger element spacing will also give a narrow major lobe.

Phased array is an array of identical element which achieves a given pattern through the control of the element excitation phasing, phasing arrays can be used to steer the main beam of the antenna without physically moving the antenna. Figs from (4-4a) to (4-8e) shows that directivity of an array can be increased by either increasing the number of elements or the element spacing,

It's also seen that increasing N gives a lower side lobe level, finally in fig (4-9) radiation pattern change by varying the direction of the major lobe.

Chapter five

Conclusions and Recommendations

5.1 Conclusion

Ka band suffers from severe fading due to rain, gases, clouds and scintillations, a reconfigurable antenna with multiple feed elements is effective to exploit the limited resources because of its ability to control radiation pattern in order to increase locally in the area of severe fading while keeping flat radiated power. In addition, the multi-feed antenna enables to combine enough power for large capacity signal transmission using such a wide band width. In this system, the radiation pattern changes dynamically in accordance with the movement of the severe fading area.

The rain attenuations in the 12 GHz and 20 GHz bands were calculated for 17 cities of Sudan for 0.1% & 0.3% and 1% time of an average year, and we calculated it at horizontal and Vertical down link .The rain attenuation in the 20 GHz band is considerably higher than in the 12 GHz band.

The required EIRP in the rainy area can be obtained by using phased -array antennas which offer a better control of the down-link EIRP, each radiating element is individually fed by a transmit active module make possible a full reallocation of the RF power among the radiated beams.

In Sudan it was clear that north of Sudan doesn't faced the rain attenuation effects because that the rain rate at that area according to the Meteorological Authority reports is almost (TR) which means that the rain rate is less than 0.01 mm/h for example Wadi-halfa and Dongola for two years there rain fall rate is near to zero ,at the same time East, West and South of Sudan suffer a lot from rain attenuation which need more power that we can achieve by using an adaptive satellite power control method in which the radiation power is increased locally in the area having heavy rainfall using phased array antenna.

Number of radiators should be determined by taking into consideration the system parameters such as size and shape of the service area, this analysis suggest the choose of a 60 radiators elements for implementing a low cost and simple calculations, for better results we have to use more radiators elements to get more spot beams which make controlling the radiated power effective.

5.2 Recommendations

Future work can be carried out antenna design with N-element not less than 200 elements and system that controlling the radiation patterns of beams and mange changing the radiation pattern from undesired areas (Nile for example) to the rainy areas (Nyla for example)