Department of: Technical programs

Principles of digital microwave
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This document consists of 157 pages
Chapter 1: Introduction to Digital microwave Radio Technology

Aim of study

Recognize the transmission media types, Point-to-point digital microwave radio, Microwave Radio Configurations, frequency planning.

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Chapter 1

Introduction to Digital microwave Radio Technology

1.1 Telecommunication

Telecommunication

Wire

Wireless

Terrestrial

Global

Analog

Digital

1.1.1 Transmission Media

- Guided transmission
- Unguided transmission

Guided transmission

<table>
<thead>
<tr>
<th>Cable Type</th>
<th>Bandwidth</th>
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<tbody>
<tr>
<td>Open Wire</td>
<td>Open Cable</td>
</tr>
<tr>
<td>Twisted Pair</td>
<td>Twisted Pair</td>
</tr>
<tr>
<td>Coaxial Cable</td>
<td>Coaxial Cable</td>
</tr>
<tr>
<td>Optical Fiber</td>
<td>Optical Fiber</td>
</tr>
</tbody>
</table>
• Unguided transmission
  RF – Propagation
  1. Ground Wave

![Ground Wave Propagation](image)

Figure (1-1) Ground Wave Propagation

2. Ionosphere

![Ionosphere Propagation](image)

Figure (1-2) Ionosphere Propagation

3. Line of sight (LOS) Propagation

![Microwave Transmission](image)

Figure (1-3) Microwave Transmission
1.2 Microwave Communication

Figure (1-4)

1.3 Atmosphere Layer

Figure (1-5)
1.4 Microwave Definition

Advantages

a. They require no right of way acquisition between towers.

b. They can carry high quantities of information due to their high operating frequencies.

c. Low cost land purchase: each tower occupies small area.

d. High frequency/short wavelength signals require small antenna.

Disadvantages

a. Attenuation by solid objects: birds, rain, snow and fog.

b. Reflected from flat surfaces like water and metal.

c. (split) around solid objects

d. Refracted by atmosphere, thus causing beam to be projected away from receiver.

1.5 Components of Microwave Systems

Microwave Transceivers

1. Antenna

2. Transmitter

3. Receiver

4. Control unit

5. Power supply

6. Amplification
1.6 **Introduction to DMR**

Point-to-point digital microwave radio (DMR), as the name implies, is a digital transmission technology that provides a wireless radio link operating at microwave frequencies between two points. A terminal at one end of the link communicates exclusively with a complementary terminal at the other end of the link. Each terminal is fitted to a parabolic dish antenna and communication is by line-of-sight beams between the dishes.

DMR is very flexible and does not depend on other elements such as satellite, cable, or optical fibre. Compunction distances can be a short as a few meters (e.g., across the street between buildings in the city) or very long (up to 80Km) in the country. To achieve line-of-sight, antennas and at least a portion of the terminal are typically mounted on rooftops, on hills or on towers. Links can also be daisy-chained to avoid major obstructions or to cover virtually endless communication distances.

DMR links can be used to carry a wide variety of traffic. In the telecommunications industry, they are used to carry data, voice, fax while in the broadcast industry, they carry video and audio signals. In the wireless data communications market, DMR links carry Ethernet traffic between Local Area Network (LAN) sites. Other applications include security, telemetry, monitor and control and many other applications requiring transport of digitized information.

Radio spectrum usage and data transmission standards are subject to regulatory frameworks throughout the world, in the interests of efficient spectrum usage and interoperability. The European Telecommunications Standards Institute (ETSI) incorporates International Telecommunications Union (ITU) recommendations into the European regulatory framework, and these are followed in much of the rest of the world. The Federal
Communications Commission (FCC) oversees radio spectrum usage in the US, where American National Standards Institute (ANSI) data standards are typically used.

For telecommunications, the traffic usually carried by DMR is structured in a hierarchy of data rates and formats known collectively as Plesiochronous Digital Hierarchy (PDH) according to standards set by the ITU and ANSI.

The microwave operating frequencies and the structure of the actual frequencies and bandwidths used are standardized by the ITU and FCC into operating bands. The frequency chosen for a particular link will depend upon many factors including the region (higher frequencies are attenuated by rain and cannot be used in tropical environments) and the service (there are more frequency allocations available at higher frequencies and they are used in areas of higher traffic density, such as cities).

The products offered by Codan have operating frequencies ranging from 7GHz to 38GHz with data interfaces allowing flexible combinations of PDH data streams and Ethernet traffic. The maximum aggregate data rate that can be carried is 52Mbs, depending on the data standards and spectrum licensing arrangements in the country of use.

A substantial driver for the development of the DMR industry in recent times has been deregulation of the telecommunications industry in many countries. Today, fixed and mobile network operators and even private users can establish their own networks throughout the world, with the right to provide the transmission infrastructure independently of the dominant carriers. DMR allows private voice and data networks and cellular networks to be established very quickly, efficiently and at substantially lower cost than cable systems.

As more countries deregulate their telecommunications infrastructure, as communications services are extended to more regions of the world, and as
the demand for ever higher data rate capacities expands, the market for communications by digital microwave radio is expected to expand rapidly.

Let us now focus on the applications of digital microwave radio and its main users, while also trying to explain the reasons for an explosive growth in demand for such products.

### 1.6.1 Cellular Applications

The greatest growth area for the use of digital microwave radio is currently associated with the emergence of new cellular mobile operators as part of a liberalized telecommunications environment. It is normal for newly licensed operators to be granted the rights to self-provide the transmission infrastructure.

It is also the trend that the terms of such competitive licenses commit the operators to challenging operational obligations, i.e. to provide service throughout a certain percentage of the country within an ambitious time frame. Furthermore, operators need to provide service at the earliest opportunity to realize revenues in line with their business plans.

Faced with this scenario, mobile operators are very conscious of the advantages of digital microwave radio. The speed of installation and flexibility to upgrade in line with network requirements has meant that almost all mobile operators who are independent from the PTT organizations and have the right to self-provide have chosen digital microwave radio as the interconnect solution for base stations.
1.6.2 PTT fixed network applications

Newly licensed competitive operators are not the only users of microwave radio, and a number of factors are leading to a growing demand from incumbent fixed network operators. With the growing liberalization in telecommunications, PTT’s are now finding themselves operating in a more competitive environment. As a result, users are being offered greater quality of service and learning that they can demand more from service operators. Time scale for provision of service is a major differentiator for a PTT operator wishing to offer competitive services.

Because of the flexibility of microwave radio and the ease and speed of installation, these products are increasingly finding their way into PTT access or back-haul networks. Elsewhere, in many developing markets, operators who wish to provide international telephone and data services to customers...
are utilizing microwave direct from exchanges to the customer premises in order to bypass local networks that are often inadequate.

Utilizing microwave radio as an access medium direct to a customer's premises has been common for a number of years. However, a number of factors are leading to an increase in this application.

New operators are being licensed who, unlike the entrenched PTT’s, do not have established cable networks but do have a need to connect customers quickly. Likewise, microwave radio is commonly used within these networks in back-haul applications, i.e. connecting from a strategic distribution point within the network (such as a business park) back into the switched network. Figure (1-7) illustrates a few of these applications.

Figure (1-7) PTT Fixed Network
1.6.3 Private network applications

In certain parts of the world, utility and government organizations have long had discretionary rights to build their own networks, and have historically been users of microwave radio. With growing liberalization, many other private users are recognizing the benefits of digital microwave radio. The applications in this arena are quite varied, ranging from the users who wish to interconnect a network of PBXs in multiple locations throughout a region, to the smaller users who simply wish to interconnect two LANs in two different buildings within a single site.

1.7 Benefits to Fixed Wire, GSM, CDMA, WLL and PTT operators

The above network applications have mentioned many reasons why a network operator, given the right to self-provide transmission infrastructure, should choose microwave radio as opposed to utilizing leased lines or implementing their own cable based systems. In summary, the advantages of microwave radio systems are as follows.

- Economical compared to fibre or leased lines - Significant whole-life cost savings can be achieved by building self-provided networks as opposed to leasing services from the local PTT

- Ownership - A self-provided transmission network remains under the control and ownership of the end user, which removes a dependency upon the incumbent PTT (often a competitor) and provides operational benefits.

- Flexibility - Modern microwave radio architecture has been designed to provide a high degree of flexibility in terms of distance and traffic capacity, enabling links to be designed to precisely fit operator
requirements and local conditions. Link capacities can also be field upgraded to cater to a network's growing traffic requirements as subscriber numbers increase.

- **Reliability** - Self-provided networks can be planned to provide a higher quality of service than often guaranteed by the PTT. Radio based solutions can be engineered to provide availability at least equivalent to cable based systems when viewed over many years, during which it is possible that a cable will be dug up or severed several times.

- **Right of way not required** - Laying cable requires time-consuming and potentially costly rights of way to cross third-party property. Microwave radio avoids this problem by utilizing the air that is a free resource.

- **Speed of Installation** - A microwave link can, in the majority of circumstances, be installed and commissioned in a much shorter period of time than cable based alternatives, because a microwave link does not require the same degree of civil works associated with laying cables.

- **Ability for re-deployment** - Microwave radio links can be easily removed and re-deployed to another geographical area, without leaving valuable assets in the ground.

- **Availability** - Microwave radio is commercially available and can be supplied in extremely short time scales.

- **Gives a competitive edge** - Finally, microwave radio gives a new operator the ability to minimize time to market, hence maximizing revenue.

Microwave radio provides a clear, cost-effective and feasible solution against leased lines or self provided cable-based alternatives.
1.8 Microwave Radio Configurations

Microwave radio systems can be found in various configuration types, including:

- Indoor rack mounted. In this configuration, the radio terminal consists of an indoor-mounted baseband shelf and RF transceiver, with a parabolic antenna connected to the indoor equipment via wave-guide.

  This configuration provides the advantages of:
  
  - Lightening protection – no electronic equipment on the tower
  - Ease of maintenance – no need to climb the tower

The main disadvantage is that you need to use expensive waveguide to connect the RF equipment to the antenna. These configurations are often deployed in extremely cold areas where ice forming on the tower prevents maintenance access. Installations in corrosive atmosphere situations like certain mining sites where outdoor mounted equipment may be damaged by the highly acidic emissions also use indoor mounted equipment.

- Split mount, In this configuration, the radio terminal consists of an indoor-mounted baseband shelf, an outdoor-mounted RF transceiver, and a parabolic antenna. The indoor unit provides the interfaces to other equipment, and is separated from the RF transceiver via standard coaxial cable by typically up to 300 meters.

  This is by far the most common type of configuration for PDH microwave link installations.

  The main advantage of this type of configuration is the ease and cost of the installation through the use of a single coaxial cable to connect the indoor and outdoor equipment.
The RF transceiver, when mounted outdoors, can be mounted directly behind the parabolic antenna, or the RF unit can be mounted remotely from the antenna. Systems are available in either non-protected (1+0) or protected (1+1) configurations.

A protected terminal provides full duplication of active elements in a terminal (i.e. both the RF transceiver and the baseband components), in a "hot standby" mode to protect the user against equipment failure. Automatic switching to the standby system during periods of equipment failure allow the operator to deliver the required service to their customers without any down time.

Space diversity (2 antenna) is a variation on the hot standby configuration that provide protection against reflections from the ground and other similar propagation anomalies. The theory behind this type of configuration is that when the microwave path causes a problem with one antenna, statistically speaking, the other one is able to operate without being affected by the problem. The advanced space diversity switching algorithm used in the Codan 8800 series optimises link performance under difficult conditions by selecting the best path on a frame-by-frame basis.

Digital Microwave Radio Codan 8800 series

1.9 Equipment Considerations

When selecting appropriate radio equipment for deployment within a Telecommunication Network, the following characteristics/specifications are among those that should be considered:

- Radio performance - A modern radio design will incorporate one or more facilities to counter the adverse effects of the radio wave
propagation through the atmosphere, generally seen as fading, or reduction, of the received signal. Fading countermeasures include interference rejection capability, forward error correction (FEC), and Automatic Transmit Power Control (ATPC) and space diversity arrangements.

All these features are supported by the Codan 8800 series. Additionally, the Codan 8800 uses Continuous Phase Modulation (CPM), which is inherently robust in the presence of propagation impairments.

- High spectral efficiency - An efficient modulation scheme to minimize channel bandwidth is a great benefit when planning the radio network, and is sometimes a prerequisite of the regulatory authority.

The Codan 8800 series uses 4-state CPM, which provides the spectral efficiency required in most countries.

- High system gain - This is a function of the radio output power and received signal threshold.

The Codan 8800 series compares favorably with most competing products.

- Low background BER - This is a measure of the performance (bit error rate) of the radio equipment in the absence of interference induced by propagation anomalies, and should ideally be less than $10^{-12}$.

The Codan 8800 is specified as to perform with a Background BER of $10^{-15}$.

- High environmental specification - Essential for reliable operation in harsh environments when equipment is located externally. Equipment must have a minimum operational temperature range of $-30^\circ C$ to $+55^\circ C$.
for outdoor equipment. Other important factors are ingress protection against water and dust or sand, and corrosion resistance.

The Codan 8800 is specified from −33°C to +55°C.

- Equipment reliability and maintainability - Important in ensuring a low life-cycle cost is the ability of the equipment to operate for long periods without failure (high mean time between failures, or MTBF). Equally, when failures occur they must be easily and rapidly repaired (low mean time to repair, or MTTR). This will be facilitated by spares commonality across a range of capacities and frequency ranges. An operator must also determine which links require protection, based upon the criticality of each link and the existence of alternative traffic routing in the case of failure.

The Codan 8800 series MTBF is expected to be in excess of 30 years. The mean time to repair a Codan 8800 series link by a trained field service engineer is less than 1 hour.

### 1.10 Network Design Process

To reach the stage where a microwave radio link can be deployed and brought into service, several steps must be successfully completed, often in an iterative process, leading to a final link design.

These steps are briefly:

- Determine design objectives, that is:
  - Availability target for network
  - Availability target for radio path
  - Required capacity (current and future)
– Maintainability, i.e. protected or non-protected

• Determine and produce network design. A network design is required to establish all of the nodes within the network that require transmission links between them. This can then be developed to become the main reference document for network planning and implementation

• Determine local frequency availability and regulatory restrictions.

• Select and survey sites

• Establish existence of line-of-sight

• Detailed network design - frequency planning.

1.10.1 Network Topologies

Figure (1-8), Figure (1-9) depict two common configurations that are adopted for the transmission system of a GSM Network.

▪ Star network

A star network topology will contain one or more hub sites at strategic locations that serve spurs or chains of subordinate sites from the centralized hub. A star network can be multilayered in that some of the nodes in a spur may be hub sites for further subordinate spurs.
Star networks have one major disadvantage in that outages on a single transmission link may affect many sites and have a significant effect on overall network availability. This can be reduced or alleviated by protecting some or all of the links with Hot Standby installations.
Ring network

Ring structures can be successfully achieved in PDH networks if the necessary routing and grooming intelligence exists at all appropriate equipment that is connected to the DMR links in the network. The capacity of all of the links in a ring has to be sufficient to support all sites in the loop, so that some links have increased capacity over the equivalent star structure.

Figure (1-9) Ring Network

1-11 Regulatory Considerations

Frequency spectrum is a valuable resource and is generally subject to appropriate planning and management to prevent misuse and interference between the many and varied applications. National administrations will allocate some or all these bands for fixed microwave radio use in line with local requirements. Before network
planning commences, an operator must determine available frequency bands and channel plans specific to that country. Often, and preferably, an operator may be able to obtain a number of frequency allocations as a block for nation wide use thus enabling him to perform his own network planning in advance without risk of interference from other users.

Most regulatory authorities also operate a local link length policy, where the length of a particular path will determine what frequency bands are available for the operator to choose from. Typically, the shorter the path the higher the frequency required.

The local requirement for equipment type approval will also vary from country to country, ranging from a simple paperwork exercise to a full product test program to local standards. Type approval is generally the responsibility of the radio supplier, but an operator should ensure that all requirements are satisfied before links are deployed.

Other limitations imposed by authorities can also have an impact upon microwave radio deployment - for example, tower height restrictions or limitations upon antenna size. These factors can restrict effective radio lengths at the planning stage and should be ascertained in advance of the detailed link design stage.

1-11-1 Site selection and survey

Selection of a suitable microwave radio site must encompass a number of issues. There are economical and engineering benefits to be gained by maximizing the sharing of infrastructure and sites between the various types of elements in the network, particularly regarding expensive civil infrastructure such as towers and equipment housings.

It is becoming more common for competing operators to share the
expensive and common portion of site construction like towers, shelters and mains power connection.

The location of good microwave sight, particularly in relation to hub sites, will be relatively high points to provide the maximum line of site availability. This information should be fed back into the network plan as it can affect both routing and path planning.

Attention should be given to future growth requirements in all areas, especially if the site is likely to develop into a future hub. It is always wise to inform the landowner of any potential future growth to prevent problems at a later date.

Attention should be paid to any local authority planning restrictions and approvals for structures or antenna installations planned. Such restrictions could be found to eliminate a site at a very late stage of the process and cause much wasted effort.

An operator should aim to perform only one site survey to minimize costs. Equipment installation requirements must be confirmed considering amongst other things, power, accommodation, and environmental conditions. The ease of service access for maintenance personnel, particularly tower mounted equipment can have significant impact on costs and repair time. Required loading needs to be calculated if new tower installations are proposed, and these must take into account the antenna wind and ice loading.

New terminals being added to an existing tower require calculations that ensure incremental loading can be accommodated. Cable and/or waveguide routing should be checked, including length and securing.

Digital Microwave Radio Codan 8800 series
1-11-2 Frequency bands

The International Telecommunication Union (ITU) ITU-R organization defines a number of specific frequency bands that are allocated to fixed services - i.e. for microwave point-to-point links. Table 1-1 shows the ITU-R bands covered by the Codan 8800 series, and outlines the usage for digital telecommunications purposes.

Table (1-1): Common Fixed Microwave Link Frequency Bands

<table>
<thead>
<tr>
<th>Band GHz</th>
<th>Range GHz</th>
<th>Distances*</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>7/8</td>
<td>7.1-8.5</td>
<td>50 km</td>
<td>Med. to High capacity</td>
</tr>
<tr>
<td>10.5</td>
<td>10.5-10.68</td>
<td>45 km</td>
<td>Low capacity, efficient modulation</td>
</tr>
<tr>
<td>13</td>
<td>12.75-13.25</td>
<td>40 km</td>
<td>Low to medium capacity</td>
</tr>
<tr>
<td>15</td>
<td>14.4-15.35</td>
<td>40 km</td>
<td>Low to medium capacity</td>
</tr>
<tr>
<td>18</td>
<td>17.7-19.7</td>
<td>25 km</td>
<td>Low to medium capacity</td>
</tr>
<tr>
<td>23</td>
<td>21.2-23.6</td>
<td>14 km</td>
<td>Low to medium capacity</td>
</tr>
<tr>
<td>38</td>
<td>37-39.5</td>
<td>8 km</td>
<td>Low to medium capacity</td>
</tr>
</tbody>
</table>

* Depending on antenna size, terrain, and rainfall, distances shown are typically the maximum for the given frequency.

Table (1-1) Common Fixed Microwave Link Frequency Bands

Different frequency bands are subject to differing propagation criteria, which results in attenuation in the link received signal. As a general
rule, the higher the frequency band, the shorter the usable distance of the link.

In the extreme case, use of frequency bands above 20 GHz in tropical areas will limit path length to just a few kilometres.

Frequency management organizations will also make most effective use of frequency spectrum by imposing a link length policy; i.e. shorter links will be licensed only in the higher frequency bands and vice-versa.

1-11-3 Confirmation of line of sight

A clear transmission path must exist between the two link nodes of any microwave radio link.

Furthermore, as the radio wave disperses as it moves away from the source, there must exist additional clearance over any obstructions to prevent attenuation of the transmitted signal. This additional clearance, known as the Fresnel zone, differs for the frequency band of the radio path, where higher frequency translates into a smaller clearance requirement.

See Figure below.

![Figure (1-10) Line of Sight](image)
Line of sight between two sites can be confirmed by either map-based studies or direct visual survey. In either event, the surveyor must allow for future obstructions that may impinge the radio path. These can be due to various causes, such as new buildings, tree growth, cranes, etc.

**1-11-4 Frequency planning**

Frequency planning is the coordination of link frequencies to minimize any interference between links within the network and those operated by other users. In some instances, the local regulatory authority undertakes frequency planning. However, if a block allocation has been obtained, then planning will be the responsibility of the operator. Several factors must be considered that will affect the calculations of interference that will determine the optimum channel frequency for each radio link.

There are a number of equipment performance parameters that become relevant when considering interference within a microwave network. These include:

- Path availability target considerations, since higher availabilities will require higher levels of protection from interference and hence increase planning difficulties. The level of availability must be considered in conjunction with the network plan and the physical position of the link. Availability targets can be relaxed for the lower capacity outer links where short outages may not cause disruption to subscriber services, due to overlapping coverage from adjacent cells, or the availability of diverse routing

- Radiated transmit power (EIRP)
Chapter 1: Introduction to Digital microwave Radio Technology

- Link operating frequencies
- The channel plan
- The Carrier to Interference (C/I) performance of the equipment which determines how well the radio equipment can discriminate the wanted signal in the presence of interference
- Antenna characteristics, such as radiation pattern envelope (RPE), gain and front-to-back ratio.

1-12 Summary

There are numerous economic and operational benefits in utilizing digital microwave radio in a transmission network. Radio presents an attractive alternative to both PTT-provided leased lines or self-provided cable based systems, and major operational advantages accrue from the fact that, being a wireless technology, microwave radio can be installed, commissioned and re-deployed easily and quickly.

For a new telecommunications operator in an existing or emerging competitive environment, these advantages can provide the crucial edge for success, and enable the operator to establish an operational network in a matter of months, thereby providing early revenue for re-investment and return to shareholders and other investors.

Many operators are now recognizing these benefits, and we are seeing significant growth in demand emerging, specifically from newly licensed cellular operators, as well as competitively licensed fixed network operators and even the incumbent PTT’s who have to operate in the new competitive environment.

PDH digital microwave radio's place as a key network element is well established and has a bright future.
• Transmitting Path

Figure (1-11) Transmitter Path

• Receiving Path

Figure (1-12) Receiver Path

1-13 Microwave Repeaters
1-14 Antenna Types

1. Win antennas i.e.: Dipole, Circular
2. Aperture antennas i.e.: Pyramidal horn
3. Micro strip antennas i.e.: Circular patch
4. Array antennas i.e.: Yagi-Uda array
5. Lens antennas i.e.: Convex lens and concave lens

1-15 Microwaves

Microwaves are short, high-frequency radio waves. It varies from .03937 inch to 1 foot (1 millimeter to 30 centimeters) in length. Like light waves, microwaves may be reflected and concentrated. But they pass easily through rain, smoke, and fog, which block light waves. They can also pass through the ionosphere, which surrounds the earth and blocks or reflects longer radio waves. Thus, microwaves are well suited for long-distance, satellite, and space communications and for control of navigation.

Microwaves are generated in special electron tubes, such as the klystron and the magnetron, with built-in resonators to control the frequency or by special oscillators are solid-state devices.
Microwaves first came to public notice through the use of radar in World War II (1939 – 1945). Today, many satellite communications systems use them. In TV, microwave transmission sends programs from pickup cameras in the field to the TV transmitter. These programs can then be sent via satellites to locations around the world. Microwaves have also many applications in meteorology, distance measuring, research into the properties of matter, and cooking food in microwave ovens.

Microwave ovens operate by agitating the water molecules in the food, causing them to vibrate, which produces heat. The microwaves enter through openings in the top of the cooking cavity, where a stirrer scatters them evenly throughout the oven. They are unable to enter a metal container to heat food, but they can pass through nonmetal containers.

Microwaves can be detected by an instrument consisting of a silicon-diode rectifier connected to an amplifier, and a recording or display device.

Exposure to microwaves is dangerous mainly when high densities of microwave radiation are involved, as with masers. They can cause burns, cataracts, damage to the nervous system, and sterility. The possible danger of long-term exposure to low-level microwaves is not yet well known, nevertheless, the U.S. government limits the exposure level, in general, to 10 milliwatts per square centimeter. Stricter limits are placed on microwave ovens.
High-frequency microwave transmissions are beamed from point to point using tall antennas. The antennas must be within sight of each other, since the microwave signals travel in straight, narrow paths.

Television antennas are built on tall towers so that high-frequency signals (which only travel in a straight line) can reach viewers without being blacked by nearby hills of buildings. Small dishes on this tower send and receive microwave signals from other stations or from reporters broadcasting live from nearby locations.

1-16 Antenna

Antenna, also referred to as an aerial, used to radiate and receive radio waves through the air or through space. Antennas are used to send radio waves to distant sites and to receive radio waves from distant sources. Many wireless communications devices, such as radio, broadcast television sets, radar, and cellular radio telephones, use antennas.
How Antennas Work?

A transmitting antenna takes waves that are generated by electrical signals inside a device such as a radio and converts them to waves that travel in an open space. The waves that are generated by the electrical signals inside radio and other devices are known as guided waves, since they travel through transmission lines such as wires or cables. The waves that travel in an open space are usually referred to as free-space waves, which travel through the air or outer space without the need for a transmission line. A receiving antenna takes free-space waves and converts them to guided waves.

Radio waves are a type of electromagnetic radiation, a form of rapidly changing, or oscillating, energy. Radio waves have two related properties known as frequency and wavelength. Frequency refers to the number of times per second that a wave oscillates, or varies in strength. The wavelength is equal to the speed of a wave (the speed of light, or 300 million m/sec) divided by the frequency. Low-frequency radio waves have long wavelengths (measured in hundreds of meters), whereas high-frequency radio waves have short wavelengths (measured in centimeters).

An antenna can radiate radio waves into free space from a transmitter, or it can receive radio waves and guide them to a receiver, where they...
are reconstructed into the original message. For example, in sending an AM radio transmission, the radio first generates a carrier wave of energy at a particular frequency. The carrier wave is modified to carry a message, such as music or a person's voice. The modified radio waves then travel along a transmission line within the radio, such as a wire or cable, to the antenna. The transmission line is often known as a feed element. When the waves reach the antenna, they oscillate along the length of the antenna and back. Each oscillation pushes electromagnetic energy from the antenna, emitting the energy through free space as radio waves.

The antenna on a radio receiver behaves in much the same way. As radio waves traveling through free space reach the receiver's antenna, they set up, or induce, a weak electric current within the antenna. The current pushes the oscillating energy of the radio waves along the antenna, which is connected to the radio receiver by a transmission line. The radio receiver amplifies the radio waves and sends them to a loudspeaker, reproducing the original message.

**b- Properties of Antennas**

An antenna's size and shape depend on the intended frequency or wavelength of the radio waves being sent or received. The design of a transmitting antenna is usually not different from that of a receiving antenna. Some devices use the same antenna for both purposes.

**c- Antenna Sizes**

An antenna works best when its physical size corresponds to a quantity known as the antenna's electrical size. The electrical size of an antenna depends on the wavelength of the radio waves being sent or received. An antenna radiates energy most efficiently when its length is a
particular fraction of the intended wavelength. When the length of an antenna is a major fraction of the corresponding wavelength (a quarter-wavelength of half-wavelength is often used), the radio waves oscillating back and forth along the antenna will encounter each other in such a way that the wave crests do not interfere with one another. The waves will resonate, or be in harmony, and will then radiate from the antenna with the greatest efficiency.

If an antenna is not long enough or is too long for the intended radio frequency, the wave crests will encounter and interfere with one another as they travel back and forth along the antenna, thus reducing the efficiency. The antenna then acts like a capacitor or an inductor (depending on the shape of the antenna) and stores, rather than radiates, energy. The electrical length of an antenna can be altered by adding a metal loop of wire known as a loading coil to one end of the antenna, thus increasing the amount of wire in the antenna. Loading coils are used when the practical length of an antenna would be too long. Adding a coil to a short antenna increases the antenna's electrical length, improves its resonance at the desired frequency, and increases the antenna's efficiency.

The radio waves used by AM radio have wavelengths of about 300 m (about 1,000 ft). most AM transmitter antennas are built to a height of about 75 m (about 250 ft), which, in this case, is the length of a quarter-wavelength. With a tower of this height, an AM radio antenna will radiate radio waves most efficiently. Since an antenna that is 75 meters tall would be impractical for a portable AM radio receiver, AM radios use a special coil of wire inside the radio for an antenna. The coil of wire is wrapped around an iron-like magnetic material called a ferrite.

When radio waves come into contact with the coil of wire, they induce
an electric charge within the coil. The magnetic ferrite helps confine and concentrate the electrical energy in the coil and aids in reception.

Television and FM radio use tall broadcast towers as well but use much shorter wavelengths, corresponding to much higher frequencies, than AM radio. Therefore, television and FM radio waves have wavelengths of only about 3 m (about 10 ft). As a result, the corresponding antennas are much shorter. Buildings and other obstructions close to the ground can block these high frequency radio waves. Thus the towers are used to raise the antennas above these obstructions in order to provide a greater broadcasting range. Receiving antennas for television sets and FM radios are small enough to be installed on these devices themselves, but the antennas are often mounted high on rooftops for better reception.

d- Antenna Shapes

Antennas come in a wide variety of shapes. One of the simplest types of antennas is called a dipole. A dipole is made of two lengths of metal, each of which is attached to one of two wires leading to a radio or other communications device. The two lengths of metal are usually arranged end to end, with the cable from the transmitter of receiver feeding each length of the dipole in the middle. The dipoles can be adjusted to form a straight line or a V-shape to enhance reception. Each length of metal in the dipole is usually a quarter-wavelength long, so that the combined length of the dipole from end to end is a half-wavelength.

The familiar "rabbit-ear" antenna on top of a television set is a dipole antenna.

Another common antenna shape is the half-dipole or monopole antenna, which uses a single quarter-wavelength piece of metal
connected to one of the twin wires from the transmitter of receiver. The other wire is connected to a ground, or a point that is not connected to the rest of the circuit. The casing of a radio or cellular telephone is often used as a ground. The telescoping antenna in a portable FM radio is a monopole. This arrangement is not as efficient as using both ends of a dipole, but a monopole is usually sufficient to pick up nearby FM signals.

Satellites and radar telescopes use microwave signals. Microwaves have extremely high frequencies and, thus, very short wavelengths (less than 30 cm). Microwaves travel in straight lines, much like light waves do. Dish antennas are often used to collect and focus microwave signals. The dish focuses the microwaves and aims them at a receiver antenna in the middle of the dish. Horn antennas are also used to focus microwaves for transmission and reception.

Receiving antennas come in many different shapes, depending on the frequency and wavelength of the intended signal. A portable FM radio uses a half-dipole antenna to receive radio signals. The other half of the dipole is attached to the radio casing and acts as a ground. VHF television antennas use multiple elements to receive a broader range of broadcast signals. Many TV antennas include directors and reflectors, which are extra pieces of metal that reflect and focus TV waves into the dipole elements. TV satellite dishes are also reflectors. They focus high-frequency microwaves from satellites into the receiving element mounted in front of the dish.

**Antennas Directivity**

Directivity is an important quality of an antenna. It describes how well an antenna concentrates, of bunches, radio waves in a given direction.
A dipole transmits or receives most of its energy at right angles to the lengths of metal, while little energy is transferred along them. If the dipole is mounted vertically, as is common, it will radiate waves away from the center of the antenna in all directions. However, for a commercial radio or television station, a transmitting antenna is often designed to concentrate the radiated energy in certain directions and suppress it in others. For instance, several dipoles can be used together if placed close to one another. Such an arrangement is called a multiple-element antenna, which is also known as an array. By properly arranging the separate elements and by properly feeding signals to the elements, the broadcast waves can be more efficiently concentrated toward an intended audience, without, for example, wasting broadcast signals over uninhabited areas.

The elements used in an array are usually all of the same type. Some arrays have the ability to move, or scan, the main beam in different directions. Such arrays are usually referred to as scanning arrays.

Arrays are usually electrically large and have better directivity than single element antennas. Since their directivity is large, arrays can capture and deliver to the receiver a larger amount of power. Two common arrays used for rooftop television reception are the Yagi-Uda array and the log-periodic array.

A Yagi-Uda consists of one or more dipoles mounted on a crossbar. The dipoles are of different lengths, corresponding to the different frequencies used in broadcast television transmission. Additional pieces of metal, which are called directors and reflectors, are placed on the crossbar in front of and behind the dipoles. Directors and reflectors are
not wired into the feed element of the antenna at all but merely reflect and concentrate radio waves toward the directors.

Yagi-Uda antennas are highly directive, and receiving antennas of this type are often mounted on rotating towers are basses, so that these antennas can be turned toward the source of the desired transmission. Log-periodic arrays look similar to Yagi-Uda arrays, but all of the elements in a log-periodic array are active dipole elements of different lengths. The dipoles are carefully spaced to provide signal reception over a wide range of frequencies.

While the dipole, monopole, microwave dish, horn, Yagi-Uda, and log-periodic are among the most common types of antennas, many other designs also exist for communicating at different frequencies. Submarines traveling underwater can receive coded radio commands from shore by using extremely low frequency (ELF) radio waves. In order to receive these signals, a submarine unravels a very long wire antenna behind as it travels underwater. Television camera crews broadcasting from locations outside the studio use powerful microwave transmitter antennas, which can send signals to satellites of directly to the television station. Amateur, or "ham," radio enthusiasts, who generally use frequencies between those of AM and FM radio, often construct their own antennas, customizing them for sending and receiving signals at desired frequencies.
1-17 Generators of Microwave Signals And Noise Effect

1-17-1 Frequency Converters

- Introduction

In the previous chapters, we discussed High Power Amplifiers (HPA) and Low Noise Amplifiers (LAN) and the requirement to maintain a constant power (eirp) to the satellite. We must also maintain the correct frequency as allocated by INTELSAT. The frequency stability is a mandatory requirement and varies with the particular service. For example, IDR carriers are required...
to remain within ±3.5KHz of the allocated frequency but SCPC/QPSK carriers are required to remain within ±250Hz of the allocated frequency. In order to achieve these limits the Up converter on the transmit side and the Down converter on the receive side are very important. This chapter discusses the principles of UP/DOWN Conversion.

- **Frequency Conversion Principle**

The key for the frequency conversion is the mixer, it is used to obtain frequencies which are the sums and differences of two input frequencies (see Figure1-16). In the mixer, the two mixed signals exist simultaneously in nonlinear devices (diodes). The non-linearity produces signals with the desired sum of difference of frequencies, but it also produces many other signals, which can cause problems.

To understand which frequencies are produced lets consider the following sine waves.

\[
L(t) = A \cos (\omega_\alpha t + \psi_\alpha) \quad \text{and;} \quad S(t) = B \cos (\omega_\beta t + \psi_\beta).
\]

Where:

- \( L(t) \) = Local oscillator signal.
- \( S(t) \) = Signal to be frequency converted.
- \( \psi \) = represents the instantaneous phase.

If both signals interacts in a non-linear device as the mixer is, the mixer output \( R(t) \) will be:

\[
R(t) = K_m.L(t).S(t) \quad \text{or} \quad (1)
\]
Chapter 1: Introduction to Digital microwave Radio Technology

\[ R(t) = K_m \left[ A \cos \{\omega_\alpha t + \psi_\alpha \} \right] \left[ B \cos \{\omega_\beta t + \psi_\beta \} \right] \]  
\[ \text{(1.2)} \]

Using the identity

\[ \cos x \cos y = \frac{1}{2} \left[ \cos(x + y) + \cos(x - y) \right] \]  
\[ \text{(1.3)} \]

equation (1.2) can be expanded to:

\[ R(t) = K_m \left[ \frac{1}{2} A \cos \{ (\omega_\alpha t + \omega_\beta t) + \psi_\alpha + \psi_\beta \} \right] + 
K_m \left[ \frac{1}{2} BA \cos \{ (\omega_\alpha t - \omega_\beta t) - \psi_\alpha - \psi_\beta \} \right] \]  
\[ \text{(1.4)} \]

Where: \[ K_m = \text{Mixer gain}. \]

The waveform \( R(t) \) has its spectrum shifted to the two center frequencies, \( \{\omega_\alpha t + \omega_\beta t\} \) and \( \{\omega_\alpha t - \omega_\beta t\} \). A band pass filter following the mixer can be tuned to select either the sum or the difference of the mixer output. Hence the input spectrum can be Up-converted to the sum frequency, or down-converted to the difference frequency.

It is still important to recognize the importance of stability of the master oscillator. Offsets in the oscillator produce offsets in the output frequency. Phase variations on the local oscillator such as phase noise variations, are transferred directly to the translated RF carrier. Theses effects become important, since they can cause phase and frequency errors to permeate the entire system.

- **Frequency converters**

1- Single conversion

a- Up Converter
By using the described principle, the up-converter (U/C) translate the intermediate frequency (IF) signal into a radio frequency (RF) signal (e.g., in the 6GHz or 14GHz band). Conversely, the down-converter (D/C) translate the RF signal (e.g., in the 4GHz or 11-12GHz band) into an IF signal.

Let us take an example of a "single" mixing technique for Up Conversion:

\[
\begin{align*}
  f_1 &= 70\text{MHz intermediate frequency} \\
  f_2 &= 6250\text{MHz mixing frequency} \\
  f_3 &= 6320\text{MHz wanted output frequency}
\end{align*}
\]
Figure (1-16) Single Conversion Up-converter

By mixing $f_1$ and $f_2$, the mixer will produce:

$$6250\text{MHz} + 70\text{MHz} = 6320\text{MHz},$$
and also

$$6250\text{MHz} - 70\text{MHz} = 6180\text{MHz}.$$  

The wanted frequency is 6320MHz, but we also have 6180MHz. These frequencies are called Upper Side Band and Lower Side Band respectively. We obviously need a good band pass filter to remove the unwanted sideband. The use of a narrow band pass filter in the Up/Converter output is the main disadvantage of single mixing converters.

b- Down Converter

If the single mixing process is used in a down converter, the process would mix an unwanted in-band "image" frequency and produce two outputs.

$$f_1 = 4150\text{MHz} \text{ Wanted Frequency to down convert}$$

$$f_2 = 4010\text{MHz} \text{ Image Frequency}$$

$$f_3 = 4080\text{MHz} \text{ Mixing Frequency}$$

4150 MHz mixed with 4080 MHz = 70 MHz

Also, 4010 MHz mixed with 4080 MHz = 70 MHz
This shows that incoming 4150 MHz and 4010 MHz will give the same 70 MHz output.

Figure (1-17) Single Conversion Down-converter

Therefore, a band pass filer must be inserted at the input to reject 4080 MHz. it can be seen from the examples that two bands of frequencies are produced:

a. The wanted band

b. The unwanted band

The tunable filers require a sharp band pass characteristic and can take up to a few hours to re-tune, which means that a set of filers with tuning equipment has to be kept on site. To eliminate this problem a broadband converter design using a double mixing techniques to operate across the total 500MHz band without the need for filter re-tuning is normally used in most earth stations.

- **Requirements**

Before describing the double mixing Up/Down Converter we need to look at the total requirements.
It the RF signal bandwidth is relatively narrow, as is the case for 36MHz bandwidth transponders, the intermediate frequency (IF) can be the conventional 70MHz frequency. However, if wideband RF signals are used, a higher intermediate frequency must be chosen in order to improve the filtering of the unwanted signals in the "image" frequency band. A 140MHz IF is usually selected. This is the case for transmission and reception of 120Mbit/s TDMA-PSK signals. It is also the case, for example, for IDR.

2- Double conversion

a- Up/Down Converters

Up and down-converters are usually composed of:
- an RF filter;
- two cascaded mixers.
- two local oscillators (LO); one fixed frequency and the other variable frequency.
- IF amplifiers(s), possibly with automatic gain control;
- IF filters;
- Group delay equalizer(s) (GDE).

The main performance characteristics of the double up-converters, and down-converters.

(i) **Bandwidth**

The RF bandwidth, which defines the capability of the converter to cover the operational RF band, i.e., to transmit (or receive), by
adjusting the LO’s frequency to cover the full RF bandwidth (about 575 Mhz).

The IF bandwidth depends on which IF frequency is selected. If the IF is 70MHz, the bandwidth will be 36MHz. with an IF of 140MHz the bandwidth will be 72MHz. with this type of converters, all the carriers of an entire transponder can be Up or Down converted, this means that every carrier will have different center frequency, and therefore the carrier frequency tuning and carrier i.f. filtering will take place in the modem.

Figure (1-18) Double Conversion Up-converter
Frequency agility

The frequency may be changed due to changes in the frequency plan to accommodate traffic increments or when changing to a new satellite. Therefore, up and down converters which can be readily adjusted in frequency over the whole RF bandwidth are required to make these changes. Variable frequency synthesized local oscillators are used to meet the frequency change requirements. As explained below, frequency agility (i.e. the ability to change the RF carrier frequencies) is improved by the use of double conversion U/C's and D/C's, without the constrain of filters tuning.

Equalization

The amplitude-frequency response and group delay of the transmit and receive sections of earth stations are equalized in their respective IF sections. (The group delay of satellite
transponders are usually equalized in the IF section of the frequency up converter).

(iv) **Linearity**

In IDR, IBS and SCPC systems (including the INTELSAT DAMA system), a number of carriers are frequency converted by one up or down converter, and intermodulation between carriers can occur. In the transmit section unit, it is necessary to keep these unwanted intermodulation products negligibly small compared to those in the HPA. Therefore, the up converter is required to have good linearity. For a carrier with a large bandwidth, good linearity is also necessary to decrease distortion noise caused by the parabolic component of the delay equalizer IF section for the whole system as well as to prevent AM-PM conversion occurring in the converter.

(v) **Carrier frequency tolerance**

The RF frequency tolerance (i.e: the maximum uncertainty of initial frequency adjustment plus long-term drift) for the transmission of IDR, IBS and SCPC/QPSK carriers in the INTELSAT system is specified as:

- IDR: ±0.025R ..... Hz. (but always less than ±3.5 KHz).
- IBS: ±0.025R ..... Hz. (but always less than ±10 KHz).

Where R is the carrier transmission rate in bit per second.

However, the frequency tolerance for the transmission of SCPC carriers is much more stringent, ie: ±250Hz. To realize this latter tolerance, the local oscillator has to use a crystal-controlled oscillator with a stability of the order of one part in $10^8$. 
3- Double mixing
   a- UP/DOWN

Converters

This type of converter features high frequency agility since tuning of the first local oscillator (1st LO or RF oscillator) is sufficient to change the RF frequency in the entire 500MHz operational RF band. This type of converter is used most often in modern earth stations. In down-converter the 4GHz receive input signal passes through a 500MHz microwave filter, and then enters a mixer (LO₁). It is then mixed with a variable oscillator frequency and converted into the first intermediate frequency (1st IF). The 1st IF signal passes through a band-pass filter with a 80MHz bandwidth and is converted into a 140MHz signal at the output of the 2nd mixer (LO₂). In this configuration, by making the 1st IF frequency higher than the RF bandwidth, the frequency in the operating band can be changed by only changing the frequency of (LO₁) without the need for readjusting the filter. Consequently, combined with a frequency synthesizer, this type of converter is very attractive, satisfying requirements for quick frequency change and remote frequency control. It is also effective as a single stand-by unit for multiple converters.

4- Local oscillators

The local oscillators used in frequency converters can be driven either by a crystal pilot or by a frequency synthesizer. In the first case, changing the frequency requires replacement of the crystal or switching between multiple crystals. In the second case, changing the frequency can be effected very simply by
thumbwheels or even by remote control. The required long term frequency stability may range from $\pm 10^{-5}$ for TV to $3 \times 10^{-9}$ for SCPC, IDR or TDMA.

Local oscillators must feature low frequency noise at baseband signal frequencies in order to comply with the general requirements on earth-station equipment noise. It should be noted that both low frequency noise requirements and frequency stability requirements are specially stringent in the case of digital transmission and reception. High performance crystal controlled oscillators or frequency synthesizers must be used in this case.

Local oscillators are constructed by taking a pure oscillator carrier and multiplying, dividing or both its output frequency to all the desired frequencies needed. Oscillators are simple electronic devices coupled to tune mechanisms via some type of feedback. Resonances of the tuning circuit allows a sustained feedback oscillation to occur, producing an output tone at the resonant frequency. The oscillator tuning circuits commonly used are the resistance, inductance, capacitance (RLC), crystal quartz resonator and the atomic resonators.

5- **RLC oscillators**

RLC circuits are the simplest and easiest to construct and therefore are the more frequently used oscillators. However components imperfections and aging often makes it difficult to set and maintain precise tone frequency over long time intervals.

6- **Crystal oscillators**
Crystal oscillators use the crystal structure itself as a component of a resonant circuit to produce a sharply tuned resonances and relatively stable output tones.

7- Atomic oscillators

The common atomic resonator is the cesium beam, which uses a stream of cesium atoms to interact with a magnetic field so as to produce an almost perfect oscillator at the specific frequency of 9.152 GHz. Rubidium resonator, using light beams interacting with rubidium vapor, produce a fixed oscillation at 6.8 GHz. Atomic oscillators are often inserted as frequency measurement standards and are used primarily as reference tones for systems requiring extreme frequency accuracy, such as the primary reference oscillator in a digital network.

An ideal oscillator produces a pure sinusoidal carrier with fixed amplitude, frequency and phase. Practical oscillators, however, produce waveforms with parameters that may vary in time, owing to temperature changes, component aging, inherent tuning circuit noise.

Amplitude variations are somewhat tolerable since they can be easily controlled with an electronic clipper circuit and limiting amplifiers. More important to a communication system are the variation in frequency and phase that may appear on an oscillator output. Although preliminary system design may be based on the supposition of ideal carriers, the possibility of imperfect oscillators are the degradation they may produce must severally be considered.

- Frequency offsets
Frequency offsets in oscillators are usually specified as a fraction of the oscillator design frequency. This fraction is generally normalized by a $10^{-6}$ factor and stated in units of parts per million (ppm). An offset of $\Delta f/\text{Hz}$ in an oscillator designed for $f_0 \text{Hz}$ output frequency will therefore be stated as having an offset of $(\Delta f/ f_0)10^6 \text{ ppm}$. This, for example, a 5-MHz oscillator, specified as having a stability of ±2 ppm, will be expected to produce an output frequency that is within $\pm2 \times 10^{-6} \times 5 \times 10^6 = \pm10 \text{ Hz}$ of the desired 5 MHz output.

Oscillator frequency offsets are contributed primarily by frequency uncertainty (inability to set the desired frequency exactly), frequency drift (long-term variations due to components changes), and short-term random frequency variations.

- **Phase noise**

  All electronic devices introduce random noise fluctuations due to thermal agitation of electrons. Oscillators are not immune to effects from random noise. The output signal is not pure, but contains phase/frequency and amplitude perturbations due to random noise. These noise perturbations appear as modulation sidebands around the oscillator carrier output.
This phase jitter effectively converts the fixed carrier phase of an ideal oscillator to a randomly varying phase noise process. This phase noise has a spectrum that is predominantly low frequency, extending out to about several kilohertz. In general, RLC and VCOs tend to have higher phase-noise than crystal oscillators, whereas atomic resonators have the lowest phase noise. Phase-noise will always be of primary concern in angle modulated systems, since oscillators phase noise will add directly to any phase modulation placed in the carrier.

Figure (1-20) Continuous single sideband phase noise requirement

The IESS specification, requests that every earth station shall satisfy the mask shown in Figure (1-21), for carriers less than 2.048 Mbit/s, taken into account that the carrier phase noise to be measured is the cumulative total caused by all the Up link path, including. Modem's carrier oscillators, Up Converters and HP As. Therefore the phase noise must be measured with a test equipment arrangement as shown in Figure (1-21) in the down
link path in is only required to check the down converter oscillators phase noise.

Although a number of methods are used to measure phase noise, only those stations equipped with high quality spectrum analyzers i.e. with resolution bandwidth of 10Hz and video bandwidth of 1 Hz, can make the measurement.

Figure (1-22), shows the test equipment set up and a typical appearance of phase noise side band spectrum. It has to be noted that we are not only measuring phase noise but discrete signals some hertz away from carrier frequency.

It is very important to make a difference between phase noise and discrete signals. Both have different origin but both can cause unwanted phase change in the digital signal.

---

**Figure.(1-21) Equipment Setup for Phase Noise Measurement and Noise Spectrum**

- **Discrete signals**
Are caused by lack of filtering of the main AC frequency in the power supply of every equipment of the chain but special attention should be paid to HP As, their frequency can be multiple of either main AC frequency or the internal oscillating frequency (for pulse width amplitude modulation power supplies). For every discrete signal it is true that:

\[
\text{Phase Deviation} = \{ 10 \exp (\text{dBC}/20) \} \times 57.3 \ \text{Deg}
\]

Where dBC is the distance in dB between the carrier and the measured noise spike.

As clearly can be seen, every noise spike will cause a carrier deviation. The discrete signals are stated separately and are quoted as the difference between the carrier level and the spike level. The IESS specifies that a spurious component at the fundamental AC line, shall not exceed –30dBC, and the sum (added on a power basis) of all others spurious components shall not exceed-36dBC.

- **Phase noise**

In a determined bandwidth, the carrier phase deviation caused by the phase noise is very difficult to calculate as an effective phase deviation. Then, as a tool to evaluate phase noise the single side band spectral noise density to the carrier level ratio is measured at a given frequency offset from the carrier and evaluated with the mandatory mask provided in the IESS. To certify that the system performance is according to the specification, several measurement at different frequency offset may be taken.

\[
\text{dBC/Hz}
\]
As a dimension unit, dBc/Hz is a ratio in dB, between the carrier center frequency and the noise measured in the side band, at a certain distance, but measured with a resolution bandwidth of 1 Hz.

A spectrum analyzer with a 1 Hz resolution bandwidth does not exist, then to evaluate a real measurement that is made with a resolution bandwidth filter different than 1 Hz, a correction factors must be used to mathematically reduce the filter resolution bandwidth to 1 Hz while accounting the spectrum analyzer peak detector noise response.

- **Phase Noise effects**

The largest problem experienced in satellite communications systems is local oscillator phase noise degrading the bit error rate (BER) performance of digital system employing any type of phase modulation.

In these systems, the combined effects of phase noise on the local oscillators used in the transmission path cause phase errors in the received signal which in turn degrades the BER of the demodulated data. In severe cases large bursts of errors may be generated which can cause synchronization loss in the digital equipment, making the service totally unusable.

This problem is more pronounced on low bit rate systems where the phase noise occupies a large proportion of the wanted signal.
bandwidth, and consequently has a greater effect on the system degradation than in higher bit rate systems.

- **Measuring Phase Noise using a Spectrum Analyzer**

A good quality spectrum analyzer can be used to measure phase noise directly, providing it has a very stable, synthesized, local oscillator.

In this method the signal under test is connected to the spectrum analyzer (as seen in Figure 1-21), tuned to the correct frequency, and the level of the noise sidebands relative to the carrier peak measured directly.

Two correction factors have to be applied to the measured noise level to convert the value to dBc/Hz: one to normalize the power to a 1 Hz bandwidth, the other to correct for the fact that the analyzer has been calibrated for sinusoidal signals rather than noise.

- To normalize to a 1 Hz bandwidth the measured power must be divided by the noise bandwidth of the filter used to make the power measurement. A good approximation for noise bandwidth is 1.2 times the nominal 3dB resolution bandwidth, e.g. for a resolution bandwidth of 100 Hz the noise bandwidth is 120 Hz. A more accurate value may be obtained by measuring the actual response of the filter and then computing the noise bandwidth, but this can take some time and is usually not necessary.

- The second correction factor compensates for the logarithmic IF amplifier and the peak detector used within analogue
spectrum analyzers, both of which give different results when measuring noise rather than sinusoidal signals. This correction factor is 2.5 dB which has to be added to the measured noise level.

As an example, suppose the analyzer gave a reading of -54.8 dB using a 100 Hz filter as a ratio between the carrier and the noise measured at 1 KHz away from the carrier. This value is converted to dBc/Hz by applying the previous correction factors, thus

\[ \text{Noise bandwidth of filter} = 100 \times 1.2 = 120 \text{ Hz} \]

\[ \text{Noise ratio in 1 Hz bandwidth} = -54.8 - 10 \log(120) = -75.6 \text{ dB} \]

\[ \text{Random noise correction} = -75.6 + 2.5 = -73.1 \text{ dBc/Hz} \]

Therefore a ratio of -54.8 dB measured in a 100 Hz filter and K KHz away from carrier is equivalent to a carrier to phase noise ratio of -73.1 dBc/Hz. (The specification mask for 1 KHz away from carrier is -70 dBc/Hz).

To measure the noise level accurately from a plot would be rather difficult due to the large variation in the noise spikes. Some form of averaging is therefore required to smooth out the response of the noise signal. This can be achieved by reducing the video bandwidth on the spectrum analyzer, but a more accurate method available in most good quality analyzers is to use video averaging. With video averaging successive scans are stored in memory and the average value is then displayed on the
screen. A much smoother display is obtained which allows a better estimate of the noise level to be made.

To perform the whole evaluation of phase noise with the spectrum analyzer, the frequency span must be incremented by 10 times in every measurement, from center frequency to 100 Hz, to 1 KHz, to 10 KHz and so on, at least three measurements per frequency span should be taken at 20%, 50% and 100% of the span, every measurement converted to dBc/Hz, plotted over semi-logarithmic paper and compared to the mask.

- **Measurement Limitations**

As different plots are taken, it would appear that the phase noise is going to exceed the specification at offsets less than 70 Hz. This illustrates one of the main limitations of this measurement method – it is not possible to measure close-in to the carrier due to the shape factor of the resolution filter.

The shape factor (or bandwidth selectivity) is defined as the ratio of the 60 dB and 3 dB bandwidth of the filter and is typically 10. This means that a filter with a 3 dB bandwidth of 10 Hz will have a 60 dB bandwidth of 100 Hz. Therefore a measurement made at a frequency offset close-in to the carrier will be corrupted by an attenuated version of the carrier itself. This effect also applies when measuring close to discrete spikes, such as the 50 Hz components. For this reason it is not recommended to make measurement at offsets of less than 100 Hz when using a 10 Hz resolution bandwidth filter.

Another limitation is the dynamic range and noise floor of the spectrum analyzer. It must be able to handle a large amplitude
carrier signal and also resolve low level noise components. A good check is to position the carrier peak at the top of the display, note the level of the noise sidebands, and then remove the input signal. The level of the noise floor due to the spectrum analyzer alone should now be at least 20 dB lower than the noise sidebands that are to be measured.

Also, the method cannot be used on sources with a large AM component, which shows up as noise sidebands, or on sources with a significant amount of drift.

In spite of these limitations the direct spectrum method is very suitable for making quick checks on the phase noise performance of sources generally encountered within earth stations such as synthesized or phase locked oscillators. The main limitation is the inability to measure close-in to the carrier, but in practice most problems have been encountered at larger frequency offsets, typically around 10 KHz.
Aim of study

Estimating Path Loss, how to measure the loss in a transmission link.

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Chapter 2

VHF/UHF/Microwave Radio Propagation: A Primer for Digital Experimenters

2.1 Abstract

This paper attempts to provide some insight into the nature of radio propagation in that part of the spectrum (upper VHF to microwave) used by experimenters for high-speed digital transmission. It begins with the basics of free space path loss calculations, and then considers the effects of refraction, diffraction and reflections on the path loss of Line of Sight (LOS) links. The nature of non-LOS radio links is then examined, and propagation effects other than path loss which are important in digital transmission are also described.

2.2 Introduction

The nature of packet radio is changing. As access to the Internet becomes cheaper and faster, and the applications offered on the “net” more and more enticing, interest in the amateur packet radio network which grew up in the 1980s steadily wanes. To be sure, there are still pockets of interest in some places, particularly where some infrastructure to support speeds of 9600 bps or more has been built up, but this has not reversed the trend of declining interest and participation. Nevertheless, there is still lots of interest in packet radio out there - it is simply becoming re-focused in different areas. Some applications which do not require high speed, and can take advantage of the mobility that packet radio can provide, have found a secure niche - APRS is a good example. Interest is also high in high-speed wireless transmission which can match, or preferably exceed, landline modem rates. With a wireless link, you can have a 24-hour network connection without the need for a dedicated
line, and you may also have the possibility of portable or mobile operation. Until recently, most people have considered it to be just too difficult to do high-speed digital. For example, the WA4DSY 56 Kbps RF modem has been available for ten years now, and yet only a few hundred people at most have put one on the air. With the new version of the modem introduced last year, 56 Kbps packet radio has edged closer to plug ‘n play, but in the meantime, landline modem data rates have moved into the same territory. What has really sparked interest in high-speed packet radio lately is not the amateur packet equipment, but the boom in spread spectrum (SS) wireless LAN (WLAN) hardware which can be used without a licence in some of the ISM bands. The new WLAN units are typically integrated radio/modem/computer interfaces which mimic either ethernet interfaces or landline modems, and are just as easy to set up. Many of them offer speeds which landline modem users can only dream of. TAPR and others are working on bringing this type of SS technology into the amateur service, where it can be used on different bands, and without the Effective Radiated Power (ERP) restrictions which exist for the unlicenced service. This technology will be the ticket to developing high-speed wireless LANs and MANs which, using the Internet as a backbone, could finally realize the dream of a high-performance wide-area AMPRnet which can support the applications (WWW, audio and video conferencing, etc.) that get people excited about computer networking these days.

Although the dream as stated above is somewhat controversial, the author believes it represents the best hope of attracting new people to the hobby, providing a basis for experimentation and training in state-of-the-art wireless techniques and networking, and, ultimately, retaining spectrum for the amateur radio service. One problem is that most of the people attracted to using digital wireless techniques have little or no background in RF. When it comes to setting up wireless links which will work over some distance, they
tend to lack the necessary knowledge about antennas, transmission lines and, especially, the subtleties of radio propagation. This paper deals with the latter area, in the hopes of providing this new crop of digital experimenters with some tools to help them build wireless links which work.

The main emphasis of this paper is on predicting the path loss of a link, so that one can approach the installation of the antennas and other RF equipment with some degree of confidence that the link will work. The focus is on acquiring a feel for radio propagation, and pointing the way towards recognizing the alternatives that may exist and the instances in which experimentation may be fruitful. We’ll also look at some propagation aspects which are of particular relevance to digital signaling.

2.3 Estimating Path Loss

The fundamental aim of a radio link is to deliver sufficient signal power to the receiver at the far end of the link to achieve some performance objective. For a data transmission system, this objective is usually specified as a minimum bit error rate (BER). In the receiver demodulator, the BER is a function of the signal to noise ratio (SNR). At the frequencies under consideration here, the noise power is often dominated by the internal receiver noise; however, this is not always the case, especially at the lower (VHF) end of the range. In addition, the “noise” may also include significant power from interfering signals, necessitating the delivery of higher signal power to the receiver than would be the case under more ideal circumstances (i.e., back-to-back through an attenuator). If the channel contains multipath, this may also have a major impact on the BER. We will consider multipath in more detail later - for now, we will focus on predicting the signal power which will be available to the receiver.
2.4 Free Space Propagation

The benchmark by which we measure the loss in a transmission link is the loss that would be expected in free space - in other words, the loss that would occur in a region which is free of all objects that might absorb or reflect radio energy. This represents the ideal case which we hope to approach in our real world radio link (in fact, it is possible to have path loss which is less than the “free space” case, as we shall see later, but it is far more common to fall short of this goal).

Calculating free space transmission loss is quite simple. Consider a transmitter with power $P_t$ coupled to an antenna which radiates equally in all directions (everyone’s favorite mythical antenna, the isotropic antenna). At a distance $d$ from the transmitter, the radiated power is distributed uniformly over an area of $4\pi d^2$ (i.e. the surface area of a sphere of radius $d$), so that the power flux density is:

$$S = \frac{P_t}{4d^2}$$ (1)

The transmission loss then depends on how much of this power is captured by the receiving antenna. If the capture area, or effective aperture of this antenna is $A_r$, then the power which can be delivered to the receiver (assuming no mismatch or feedline losses) is simply $P_r = S A_r$ (2)

The free space path loss between isotropic antennas is $P_t / P_r$. Since we usually are dealing with frequency rather than wavelength, we can make the substitution $\lambda = \frac{c}{f}$ to get $L_p = \left(\frac{4}{c}\right)^2 f^2 d^2$ (3)

This shows the classic square-law dependence of signal level versus distance. What troubles some people when they see this equation is that the path loss
also increases as the square of the frequency. Does this mean that the transmission medium is inherently more lossy at higher frequencies? While it is true that absorption of RF by various materials (buildings, trees, water vapor, etc.) tends to increase with frequency, remember we are talking about “free space” here. The frequency dependence in this case is solely due to the decreasing effective aperture of the receiving antenna as the frequency increases. This is intuitively reasonable, since the physical size of a given antenna type is inversely proportional to frequency. If we double the frequency, the linear dimensions of the antenna decrease by a factor of one half, and the capture area by a factor of one-quarter. The antenna therefore captures only one-quarter of the power flux density at the higher frequency versus the lower one, and delivers 6 dB less signal to the receiver. However, in most cases we can easily get this 6 dB back by increasing the effective aperture, and hence the gain, of the receiving antenna. For example, suppose we are using a parabolic dish antenna at the lower frequency. When we double the frequency, instead of allowing the dish to be scaled down in size so as to produce the same gain as before, we can maintain the same reflector size. This gives us the same effective aperture as before (assuming that the feed is properly redesigned for the new frequency, etc.), and 6 dB more gain (remembering that the gain is with respect to an isotropic or dipole reference antenna at the same frequency). Thus the free space path loss is now the same at both frequencies; moreover, if we maintained the same physical aperture at both ends of the link, we would actually have 6 dB less path loss at the higher frequency. You can picture this in terms of being able to focus the energy more tightly at the frequency with the shorter wavelength. It has the added benefit of providing greater discrimination against multipath - more about this later.

The free space path loss equation is more usefully expressed logarithmically:
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\[ L_p = 32.4 + 20 \log f + 20 \log d \text{ dB (} f \text{ in MHz, } d \text{ in Km)} \]  

(4)

or \[ L_p = 36.6 + 20 \log f = 20 \log d \text{ dB (} f \text{ in MHz, } d \text{ in Miles)} \]  

(5)

This shows more clearly the relationship between path loss and distance: path loss increases by 20 dB/decade or 6 dB/octave, so each time you double the distance, you lose another 6 dB of signal under free space conditions.

Of course, in looking at a real system, we must consider the actual antenna gains and cable losses in calculating the signal power \( P_r \) which is available at the receiver input:

\[ P_r = P_t - L_p + G_t + G_r - L_t - L_r \text{ (6)} \]  

where \( P_t \) = transmitter power output (dBm or dBW, same units as \( P_r \))

\( L_p \) = free space path loss between isotropic antennas (dB)

\( G_t \) = transmit antenna gain (dBi)

\( G_r \) = receive antenna gain (dBi)

\( L_t \) = transmission line loss between transmitter and transmit antenna (dB)

\( L_r \) = transmission line loss between receive antenna and receiver input (dB)

A table of transmission line losses for various bands and popular cable types can be found in the Appendix.

Example 1. Suppose you have a pair of 915 MHz WaveLAN cards, and want to use them on a 10 km link on which you believe free space path loss conditions will apply. The transmitter power is 0.25 W, or +24 dBm. You also have a pair of yagi antennas with 10 dBi gain, and at each end of the link, you need about 50 ft (15 m) of transmission line to the antenna. Let’s say you’re using LMR-400 coaxial cable, which will give you about 2 dB loss at 915
MHz for each run. Finally, the path loss from equation (6a) is calculated, and this gives 111.6 dB, which we’ll round off to 112 dB. The expected signal power at the receiver is then, from (7):

\[ Pr = 24 - 112 + 10 + 10 - 2 - 2 = -72 \text{ dBm} \]

According to the WaveLAN specifications, the receivers require -78 dBm signal level in order to deliver a low bit error rate (BER). So, we should be in good shape, as we have 6 dB of margin over the minimum requirement. However, this will only be true if the path really is equivalent to the free space case, and this is a big if! We’ll look at means of predicting whether the free space assumption holds in the next section.

Path Loss on Line of Sight Links

The term Line of Sight (LOS) as applied to radio links has a pretty obvious meaning: the antennas at the ends of the link can “see” each other, at least in a radio sense. In many cases, radio LOS equates to optical LOS: you’re at the location of the antenna at one end of the link, and with the unaided eye or binoculars, you can see the antenna (or its future site) at the other end of the link. In other cases, we may still have an LOS path even though we can’t see the other end visually. This is because the radio horizon extends beyond the optical horizon. Radio waves follow slightly curved paths in the atmosphere, but if there is a direct path between the antennas which doesn’t pass through any obstacles, then we still have radio LOS. Does having LOS mean that the path loss will be equal to the free space case which we have just considered? In some cases, the answer is yes, but it is definitely not a sure thing. There are three mechanisms which may cause the path loss to differ from the free space case:

- \textit{refraction} in the earth’s atmosphere, which alters the trajectory of radio waves, and which can change with time.
- diffraction effects resulting from objects near the direct path.
- reflections from objects, which may be either near or far from the direct path.

We examine these mechanisms in the next three sections.

Atmospheric Refraction

As mentioned previously, radio waves near the earth’s surface do not usually propagate in precisely straight lines, but follow slightly curved paths. The reason is well-known to VHF/UHF DXers: refraction in the earth’s atmosphere. Under normal circumstances, the index of refraction decreases monotonically with increasing height, which causes the radio waves emanating from the transmitter to bend slightly downwards towards the earth’s surface instead of following a straight line. The effect is more pronounced at radio frequencies than at the wavelength of visible light, and the result is that the radio waves can propagate beyond the optical horizon, with no additional loss other than the free space distance loss. There is a convenient artifice which is used to account for this phenomenon: when the path profile is plotted, we reduce the curvature of the earth’s surface. If we choose the curvature properly, the paths of the radio waves can be plotted as straight lines. Under normal conditions, the gradient in refractivity index is such that real world propagation is equivalent to straight-line propagation over an earth whose radius is greater than the real one by a factor of 4/3 - thus the often-heard term “4/3 earth radius” in discussions of terrestrial propagation. However, this is just an approximation that applies under typical conditions - as VHF/UHF experimenters well know, unusual weather conditions can change the refractivity profile dramatically. This can lead to several different conditions. In super refraction, the rays bend more than normal and the radio horizon is extended; in extreme cases, it
leads to the phenomenon known as *ducting*, where the signal can propagate over enormous distances beyond the normal horizon. This is exciting for DXers, but of little practical use for people who want to run data links. The main consequence for digital experimenters is that they may occasionally experience interference from unexpected sources. A more serious concern is *subrefraction*, in which the bending of the rays is less than normal, thus shortening the radio horizon and reducing the clearance over obstacles along the path. This may lead to increased path loss, and possibly even an outage. In commercial radio link planning, the statistical probability of these events is calculated and allowed for in the link design (distance, path clearance, fading margin, etc.). We won’t get into all of the details here; suffice it to say that reliability of your link will tend to be higher if you back off the distance from the maximum which is dictated by the normal radio horizon. Not that you shouldn’t try and stretch the limits when the need arises, but a link which has optical clearance is preferable to one which doesn’t. It’s also a good idea to build in some margin to allow for fading due to unusual propagation situations, and to allow as much clearance from obstacles along the path as possible. For short-range links, the effects of refraction can usually be ignored.

**Diffraction and Fresnel Zones**

Refraction and reflection of radio waves are mechanisms which are fairly easy to picture, but diffraction is much less intuitive. To understand diffraction, and radio propagation in general, it is very helpful to have some feeling for how radio waves behave in an environment which is not strictly “free space”. Consider Fig.(2-1), in which a wavefront is traveling from left to right, and encountering an obstacle which absorbs or reflects all of the incident radio energy. Assume that the incident wavefront is uniform; i.e., if we measure the field strength along the line A-A’, it is the same at all
points. Now, what will be the field strength along a line B-B’ on the other side of the obstacle? To quantify this, we provide an axis in which zero coincides with the top of the obstacle, and negative and positive numbers denote positions above and below this, respectively (we’ll define the parameter \( \nu \) used on this axis a bit later). Figure (2-1) Shadowing of Radio Waves by an Object

![Diagram of shadowing](image)

Figure (2-1) Shadowing of Radio by an Object
Figure (2-2) Signal Levels on the Far Side of the Shadowing Object

Figure (3-3) Fresnel Zone for a Radio Link
The two-dimensional representation of a Fresnel zone is shown in Fig. (2-3). The surface of the ellipsoid is defined by the path ACB, which exceeds the length of the direct path AB by some fixed amount. This amount is \( n\lambda/2 \), where \( n \) is a positive integer. For the first Fresnel zone, \( n = 1 \) and the path length differs by \( \lambda/2 \) (i.e., a 180° phase reversal with respect to the direct path). For most practical purposes, only the first Fresnel zone need be considered. A radio path has first Fresnel zone clearance if, as shown in Fig. (3-3), no objects capable of causing significant diffraction penetrate the corresponding ellipsoid. What does this mean in terms of path loss? Recall how we constructed the wave front behind an object by vector addition of the wavelets comprising the wave front in front of the object, and apply this to the case where we have exactly first Fresnel zone clearance. We wish to find the strength of the direct path signal after it passes the object. Assuming there is only one such object near the Fresnel zone, we can look at the resultant wave front at the destination point B. In terms of the Cornu spiral, the upper half of the spiral is intact, but part of the lower half is absent, due to blockage by the object. Since we have exactly first Fresnel clearance, the final vector which we add to the bottom of the spiral is 180° out of phase with the direct-path vector - i.e., it is pointing downwards. This means that we have passed the bottom of the spiral and are on the way back up, and the resultant vector is near the free space magnitude (a line between X and Y). In fact, it is sufficient to have 60% of the first Fresnel clearance, since this will still give a resultant which is very close to the free space value.

In order to quantify diffraction losses, they are usually expressed in terms of a dimensionless parameter \( V \), given by:

\[
V = 2 \sqrt{\frac{\Delta d}{\lambda}} \quad (7)
\]

Figure (3-6) Fresnel Zone for a Radio Link where \( \Delta d \) is the difference in lengths of the straight-line path between the endpoints of the link.
and the path which just touches the tip of the diffracting object (see Fig. (2-7), where \( \Delta d = d1 + d2 - d \)). By convention, \( v \) is positive when the direct path is blocked (i.e., the obstacle has positive height), and negative when the direct path has some clearance ("negative height"). When the direct path just grazes the object, \( v = 0 \). This is the parameter shown in Figures (3-1) and (3-2). Since in this section we are considering LOS paths, this corresponds to specifying that \( v \geq 0 \). For first Fresnel zone clearance, we have \( \Delta d = \lambda/2 \), so from equation (8), \( v = -1.4 \). From Figure (3-2), we can see that this is more clearance than necessary - in fact, we get slightly higher signal level (and path loss less than the free space value) if we reduce the clearance to \( v = -1 \), which corresponds to \( \Delta d = \lambda/4 \). The \( v = -1 \) point is also shown on the Cornu spiral in Fig. (3-3). Since \( \Delta d = \lambda/4 \), the last vector added to the summation is rotated 90° from the direct-path vector, which brings us to the lowest point on the spiral. The resultant vector then runs from this point to the upper end of the spiral at point Y. It’s easy to see that this vector is a bit longer than the distance from X to Y, so we have a slight gain (about 1.2 dB) over the free space case. We can also see how we can back off to 60% of first Fresnel zone clearance (\( v \approx -0.85 \)) without suffering significant loss. But how do we calculate whether we have the required clearance? The geometry for Fresnel zone calculations is shown in Fig. (2-4). Keep in mind that this is only a two-dimensional representation, but Fresnel zones are three-dimensional. The same considerations apply when the objects limiting path clearance are to the side or even above the radio path. Since we are considering LOS paths in this section, we are dealing only with the “negative height” case, shown in the lower part of the figure. We will look at the case where \( h \) is positive later, when we consider non-LOS paths. For first Fresnel zone clearance, the distance \( h \) from the nearest point of the obstacle to the direct path must be at least...
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\[ h = 2 \sqrt{\frac{d_1 d_2}{d_1 + d_2}} \]  
\hspace{1cm} (8)

where \( d_1 \) and \( d_2 \) are the distances from the tip of the obstacle to the two ends of the radio circuit. This formula is an approximation which is not valid very close to the endpoints of the circuit. For convenience, the clearance can be expressed in terms of frequency:

\[ h = 17.3 \sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}} \]  
\hspace{1cm} (9)

where \( f \) is the frequency in GHz, \( d_1 \) and \( d_2 \) are in km, and \( h \) is in meters. Or:

\[ h = 72.1 \sqrt{\frac{d_1 d_2}{f(d_1 + d_2)}} \]  
\hspace{1cm} (10)

where \( f \) is in GHz, \( d_1 \) and \( d_2 \) in statute miles, and \( h \) is in feet.

![Figure (2-4) Fresnel Zone Geometry](image-url)

Figure (2-4) Fresnel Zone Geometry
Example 2. We have a 10 km LOS path over which we wish to establish a link in the 915 MHz band.

The path profile indicates that the high point on the path is 3 km from one end, and the direct path clears it by about 18 meters (60 ft.) - do we have adequate Fresnel zone clearance? From equation (10a), with \( d_1 = 3 \text{ km} \), \( d_2 = 7 \text{ km} \), and \( f = 0.915 \text{ GHz} \), we have \( h = 26.2 \text{ m} \) for first Fresnel zone clearance (strictly speaking, \( h = -26.2 \text{ m} \)). A clearance of 18 m is about 70% of this, so it is sufficient to allow negligible diffraction loss.

Fresnel zone clearance may not seem all that important - after all, we said previously that for the zero clearance (grazing) case, we have 6 dB of additional path loss. If necessary, this could be overcome with, for example, an additional 3 dB of antenna gain at each end of the circuit. Now it’s time to confess that the situation depicted in Figures (2-1) and (2-2) is a special case, known as “knife edge” diffraction. Basically, this means that the top of the obstacle is small in terms of wavelengths. This is \textit{sometimes} a reasonable approximation of an object in the real world, but more often than not, the obstacle will be rounded (such as a hilltop) or have a large flat surface (like the top of a building), or otherwise depart from the knife edge assumption. In such cases, the path loss for the grazing case can be considerably more than 6 dB - in fact, 20 dB would be a better estimate in many cases. So, Fresnel zone clearance can be pretty important on real-world paths. And, again, keep in mind that the Fresnel zone is three-dimensional, so clearance must also be maintained from the sides of buildings, etc. if path loss is to be minimized.

Another point to consider is the effect on Fresnel zone clearance of changes in atmospheric refraction, as discussed in the last section. We may have adequate clearance on a longer path under normal conditions (i.e., 4/3 earth radius), but lose the clearance when unusual refraction conditions prevail. On
longer paths, therefore, it is common in commercial radio links to do the Fresnel zone analysis on something Figure (2-4) Fresnel Zone Geometry close to “worst case” rather than typical refraction conditions, but this may be less of a concern in amateur applications.

Most of the material in this section was based on Ref. [2], which is highly recommended for further reading.

Ground Reflections

An LOS path may have adequate Fresnel zone clearance, and yet still have a path loss which differs significantly from free space under normal refraction conditions. If this is the case, the cause is probably multipath propagation resulting from reflections (multipath also poses particular problems for digital transmission systems - we’ll look at this a bit later, but here we are only considering path loss).

One common source of reflections is the ground. It tends to be more of a factor on paths in rural areas; in urban settings, the ground reflection path will often be blocked by the clutter of buildings, trees, etc. In paths over relatively smooth ground or bodies of water, however, ground reflections can be a major determinant of path loss. For any radio link, it is worthwhile to look at the path profile and see if the ground reflection has the potential to be significant. It should also be kept in mind that the reflection point is not at the midpoint of the path unless the antennas are at the same height and the ground is not sloped in the reflection region - just the remember the old maxim from optics that the angle of incidence equals the angle of reflection.

Ground reflections can be good news or bad news, but are more often the latter. In a radio path consisting of a direct path plus a ground-reflected path, the path loss depends on the relative amplitude and phase relationship of the signals propagated by the two paths. In extreme cases, where the ground
reflected path has Fresnel clearance and suffers little loss from the reflection itself (or attenuation from trees, etc.), then its amplitude may approach that of the direct path. Then, depending on the relative phase shift of the two paths, we may have an enhancement of up to 6 dB over the direct path alone, or cancellation resulting in additional path loss of 20 dB or more. If you are acquainted with Mr. Murphy, you know which to expect! The difference in path lengths can be estimated from the path profile, and then translated into wavelengths to give the phase relationship. Then we have to account for the reflection itself, and this is where things get interesting. The amplitude and phase of the reflected wave depend on a number of variables, including conductivity and permittivity of the reflecting surface, frequency, angle of incidence, and polarization.

It is difficult to summarize the effects of all of the variables which affect ground reflections, but a typical case is shown in Fig. (2-5) [2]. This particular figure is for typical ground conditions at 100 MHz, but the same behavior is seen over a wide range of ground constants and frequencies. Notice that there is a large difference in reflection amplitudes between horizontal and vertical polarization (denoted on the curves with “h” and “v”, respectively), and that vertical polarization in general gives rise to a much smaller reflected wave. However, the difference is large only for angles of incidence greater than a few degrees (note that, unlike in optics, in radio transmission the angle of incidence is normally measured with respect to a tangent to the reflecting surface rather than a normal to it); in practice, these angles will only occur on very short paths, or paths with extraordinarily high antennas. For typical paths, the angle of incidence tends to be of the order of one degree or less - for example, for a 10 km path over smooth earth with 10 m antenna heights, the angle of incidence of the ground reflection would only be about 0.11 degrees. In such a case, both polarizations will give reflection amplitudes near
unity (i.e., no reflection loss). Perhaps more surprisingly, there will also be a phase reversal in both cases. Horizontally-polarized waves always undergo a phase reversal upon reflection, but for vertically-polarized waves, the phase change is a function of the angle of incidence and the ground characteristics.

The upshot of all this is that for most paths in which the ground reflection is significant (and no other reflections are present), there will be very little difference in performance between horizontal and vertical polarization. For very short paths, horizontal polarization will generally give rise to a stronger reflection.

If it turns out that this causes cancellation rather than enhancement, switching to vertical polarization may provide a solution. In other words, for shorter paths, it is usually worthwhile to try both polarizations to see which works better (of course, other factors such as mounting constraints and rejection of other sources of multipath and interference also enter into the choice of polarization).

As stated above, for either polarization, as the path gets longer we approach the case where the ground reflection produces a phase reversal and very little attenuation. At the same time, the direct and reflected paths are becoming more nearly equal. The path loss ripples up and down as we increase the distance, until we reach the point where the path lengths differ by just one-half
wavelength. Combined with the $180^\circ$ phase shift caused by the ground reflection, this brings the direct and reflected signals into phase, resulting in an enhancement over the free space path loss (theoretically 6 dB, but this will seldom be realized in practice).

Thereafter, it’s all downhill as the distance is further increased, since phase difference between the two paths approaches in the limit the $180^\circ$ phase shift of the ground reflection. It can be shown that, in this region, the received power follows an inverse fourth-power law as a function of distance instead of the usual square law (i.e., 12 dB more attenuation when you double the distance, instead of 6 dB). The distance at which the path loss starts to increase at the fourth-power rate is reached when the ellipsoid corresponding to the first Fresnel zone just touches the ground.
where \( h_1 \) and \( h_2 \) are the antenna heights above the ground reflection point. For example, for antenna heights of 10 m, at 915 MHz (\( \lambda = 33 \) cm) we will be into the fourth-law loss region for links longer than about 1.2 km.

So, for longer-range paths, ground reflections are always bad news. Serious problems with ground reflections are most commonly encountered with radio links across bodies of water. Spread spectrum techniques and diversity antenna arrangements usually can’t overcome the problems - the solution lies in siting the antennas (e.g., away from the shore of the body of water) such that the reflected path is cut off by natural obstacles, while the direct path is unimpaired. In other cases, it may be possible to adjust the antenna locations so as to move the reflection point to a rough area of land which scatters the signal rather than creating a strong specular reflection.

Other Sources of Reflections

Much of what has been said about ground reflections applies to reflections from other objects as well.

The “ground reflection” on a particular path may be from a building rooftop rather than the ground itself, but the effect is much the same. On long links, reflections from objects near the line of the direct path will almost always cause increased path loss - in essence, you have a permanent “flat fade” over a very wide bandwidth. Reflections from objects which are well off to the side of the direct path are a different story, however. This is a frequent occurrence in urban areas, where the sides of buildings can cause strong reflections. In such cases, the angle of incidence may be much larger than zero, unlike the ground reflection case. This means that horizontal and vertical polarization may behave quite differently - as we saw in Fig. (2-5), vertically polarized signals tend to produce lower-amplitude reflections than horizontally polarized signals when the angle of incidence exceeds a few degrees. When
the reflecting surface is vertical, like the side of a building, a signal which is transmitted with horizontal polarization effectively has vertical polarization as far as the reflection is concerned. Therefore, horizontal polarization will generally result in weaker reflections and less multipath than vertical polarization in these cases. Effects of Rain, Snow and Fog

The loss of LOS paths may sometimes be affected by weather conditions (other than the refraction effects which have already been mentioned). Rain and fog (clouds) become a significant source of attenuation only when we get well into the microwave region. Attenuation from fog only becomes noticeable (i.e., attenuation of the order of 1 dB or more) above about 30 GHz. Snow is in this category as well. Rain attenuation becomes significant at around 10 GHz, where a heavy rainfall may cause additional path loss of the order of 1 dB/km.

Path Loss on Non-Line of Sight Paths

We have spent quite a bit of time looking at LOS paths, and described the mechanisms which often cause them to have path loss which differs from the “free space” assumption. We’ve seen that the path loss isn’t always easy to predict. When we have a path which is not LOS, it becomes even more difficult to predict how well signals will propagate over it. Unfortunately, non-LOS situations are sometimes unavoidable, particularly in urban areas. The following sections deal with some of the major factors which must be considered.

Diffraction Losses

In some special cases, such as diffraction over a single obstacle which can be modeled as a knife edge, the loss of a non-LOS path can be predicted fairly readily. In fact, this is the same situation that we saw in Figures 1 and 2, with the diffraction parameter v.
To get $\Delta d$, measure the straight-line distance between the endpoints of the link. Then measure the length of the actual path, which includes the two endpoints and the tip of the knife edge, and take the difference between the two, the “positive h” case. A good approximation to the knife-edge diffraction loss in dB can then be calculated from:

$$L(v) = 6.9 + 20 \log \left[ \sqrt{v^2 + 1} + v \right]$$

(11)

Example 3. We want to run a 915 MHz link between two points which are a straight-line distance of 25 km apart. However, 5 km from one end of the link, there is a ridge which is 100 meters higher than the two endpoints. Assuming that the ridge can be modeled as a knife edge, and that the paths from the endpoints to the top of ridge are LOS with adequate Fresnel zone clearance, what is the expected path loss? From simple geometry, we find that length of the path over the ridge is 25,001.25 meters, so that $\Delta d = 1.25$ m. Since $\lambda = 0.33$ m, the parameter $v$, from (7), is 3.89. Substituting this into (12), we find that the expected diffusion loss is 24.9 dB. The free space path loss for a 25 km path at 915 MHz is, from equation (4), 119.6 dB, so the total predicted path loss for this path is 144.5 dB. This is too lossy a path for many WLAN devices. For example, suppose we are using WaveLAN cards with 13 dBi gain antennas, which (disregarding feedline losses) brings them up to the maximum allowable EIRP of $+36$ dBm. This will produce, at the antenna terminals at the other end of the link, a received power of $(36 - 144.5 + 13) = -95.5$ dBm. This falls well short of the -78 dBm requirement of the WaveLAN cards. On the other hand, a lower-speed system may be quite usable over this path. For instance, the FreeWave 115 Kbps modems require only about -108 dBm for reliable operation, which is a comfortable margin below our predicted signal levels.
To see the effect of operating frequency on diffraction losses, we can repeat the calculation, this time using 144 MHz, and find the predicted diffraction loss to be 17.5 dB, or 7.4 dB less than at 915 MHz. At 2.4 GHz, the predicted loss is 29.0 dB, an increase of 4.1 dB over the 915 MHz case (these differences are for the diffraction losses only, not the only total path loss).

Unfortunately, the paths which digital experimenters are faced with are seldom this simple. They will frequently involve diffraction over multiple rooftops or other obstacles, many of which don’t resemble knife edges. The path losses will generally be substantially greater in these cases than predicted by the single knife edge model. The paths will also often pass through objects such as trees and wood-frame buildings which are semi-transparent at radio frequencies. Many models have been developed to try and predict path losses in these more complex cases. The most successful are those which deal with restricted scenarios rather than trying to cover all of the possibilities. One
common scenario is diffraction over a single obstacle which is too rounded to be considered a knife edge. There are different ways of treating this problem; the one described here is from Ref. [3]. The top of the object is modeled as a cylinder of radius \( r \), as shown in Fig. (3-6). To calculate the loss, you need to plot the profile of the actual object, and then draw straight lines from the link endpoints such that they just graze the highest part of the object as seen from their individual perspectives. Then the parameters \( D_s, d_1, d_2 \) and \( r \) are estimated, and an estimate of the radius \( r \) can then be calculated from

\[
r = \frac{2D_s d_1 d_2}{(d_1^2 + d_2^2)}
\] (12)

Note that the angle \( \alpha \) is measured in radians. The procedure then is to calculate the knife edge diffraction loss for this path as outlined above, and then add to it an excess loss factor \( L_{\text{ex}} \), calculated from

\[
L_{\alpha} = 11.7 \sqrt{\frac{r}{\lambda}}
\] (13)

Figure (3-9) Diffraction by a Rounded Obstacle

There is also a correction factor for roughness: if the object is, for example, a hill which is tree-covered rather than smooth at the top, the excess diffraction loss is said to be about 65% of that predicted in (13). In general, smoother objects produce greater diffraction losses. Example 4. We revisit the scenario in Example 3, but let’s suppose that we’ve now decided that the ridge blocking our path doesn’t cut it as a knife edge (ouch!). From a plot of the profile, we estimate that \( D_s = 10 \) meters. As before, \( d_1 = 20 \) km, \( d_2 = 5 \) km and the height of the ridge is 100 meters. Dusting off our high school trigonometry, we can work out that \( \alpha = 1.43^\circ \), or 0.025 radians. Now,
plugging these numbers into (12), we get \( r = 188 \) meters. Then, with \( \lambda = 0.33 \) m, we can calculate the excess loss from (13):

So, summed with the knife edge loss calculated previously, we have an estimated total diffraction loss of 37.3 dB (assuming the ridge is “smooth” rather than “rough”). This is a lot, but you can easily imagine scenarios where the losses are much greater: just look at the direct dependence on the angle \( r \) in (13) and picture from Fig. (3-6) what happens when the obstacle is closer to one of the link endpoints.

Amateurs doing weak signal work are accustomed to dealing with large path losses in non-LOS propagation, but such losses are usually intolerable in high-speed digital links.

Attenuation from Trees and Forests

Trees can be a significant source of path loss, and there are a number of variables involved, such as the specific type of tree, whether it is wet or dry, and in the case of deciduous trees, whether the leaves are present or not. Isolated trees are not usually a major problem, but a dense forest is another story. The attenuation depends on the distance the signal must penetrate through the forest, and it increases with frequency. According to a CCIR report [10], the attenuation is of the order of 0.05 dB/m at 200 MHz, 0.1 dB/m at 500 MHz, 0.2 dB/m at 1 GHz, 0.3 dB/m at 2 GHz and 0.4 dB/m at 3 GHz. At lower frequencies, the attenuation is somewhat lower for horizontal polarization than for vertical, but the difference disappears above about 1 GHz. This adds up to a lot of excess path loss if your signal must penetrate several hundred meters of forest! Fortunately, there is also significant propagation by diffraction over the treetops, especially if you can get your antennas up near treetop level or keep them a good distance from the edge of the forest, so all is not lost if you live near a forest.
General Non-LOS Propagation Models:

There are many more general models and empirical techniques for predicting non-LOS path losses, but the details are beyond the scope of this paper. Most of them are aimed at prediction of the paths between elevated base stations and mobile or portable stations near ground level, and they typically have restrictions on the frequency range and distances for which they are valid; thus they may be of limited usefulness in the planning of amateur high-speed digital links. Nevertheless, they are well worth studying to gain further insight into the nature of non-LOS propagation. The details are available in many texts - Ref. [3] has a particularly good treatment. One crude, but useful, approximation will be mentioned here: the loss on many non-LOS paths in urban areas can be modeled quite well by a fourth-power distance law. In other words, we substitute $d^4$ for $d^2$ in equation (3). In equation (4), we can substitute $40\log(d)$ for the $20\log(d)$ term, which would correspond to the assumption of square-law distance loss for distances up to 1 km (or 1 mile, for the non-metric version of the equation), and fourth-law loss thereafter. This is probably an overly optimistic assumption for heavily built-up areas, but is at least a useful starting point.

The propagation losses on non-LOS paths can be discouragingly high, particularly in urban areas.

Antenna height becomes a critical factor, and getting your antennas up above rooftop heights will often spell the difference between success and failure. Due to the great variability of propagation in cluttered urban environments, accurate path loss predictions can be difficult. If a preliminary analysis of the path indicates that you are at least in the ballpark (say within 10 or 15 dB) of
having a usable link, then it will generally be worthwhile to give it a try and hope to be pleasantly surprised (but be prepared to be disappointed!).

Software Tools for Propagation Prediction

Although there is no substitute for experience and acquiring a “feel” for radio propagation, computer programs can make the job of predicting radio link performance a lot easier. They are particularly handy for exploring “what if” scenarios with different paths, antenna heights, etc. Unfortunately, they also tend to cost money! If you’re lucky, you may have access to one of the sophisticated prediction programs which includes the most complex propagation models, terrain databases, etc. If not, you can still find some free software utilities that will make it easier to do some of the calculations discussed above, such as knife edge diffraction losses. One very useful freeware program which was developed specifically for short-range VHF/UHF applications is RFProp, by Colin Seymour, G4NNA. Check Colin’s Web page at:

http://www.users.dircon.co.uk/~netking/freesw.htm for more information and downloading instructions.

This is a Windows (3.1, 95 or NT) program which can calculate path loss in free space and simple diffraction scenarios. In addition to calculating knife edge diffraction loss, it provides some correction factors for estimating the loss caused by more rounded objects, such as hills. It also allows changing the distance loss exponent from square-law to fourth-law (or anything else, for that matter) to simulate long paths with ground reflections or obstructed urban paths. There is also some provision for estimating the loss caused when the signals must penetrate buildings. The program has a graphical user interface in which the major path parameters can be entered and the result (in terms of
receiver SNR margin) seen immediately. There is also a tabular output which lists the detailed results along with all of the assumed parameters.

Special Considerations for Digital Systems:

We have previously looked at the effect of multipath on path loss. When reflections occur from objects which are very close to the direct path, then paths have very similar lengths and nearly the same time delay. Depending on the relative phase shifts of the paths, the signals traversing them at a given frequency can add constructively to provide a gain with respect to a single path, or destructively to provide a loss. On longer paths in particular, the effect is usually a loss. Since the path lengths are nearly equal, the loss occurs over a wide frequency range, producing a “flat” fade.

In many cases, however, reflections from objects well away from the direct path can give rise to significant multipath. The most common reflectors are buildings and other manmade structures, but many natural features can also be good reflectors. In such cases, the propagation delays of the paths from one end of the link to the other can differ considerably. The extent of this time spreading of the signal is commonly measured by a parameter known as the \textit{delay spread} of the path. One consequence of having a larger delay spread is that the reinforcement and cancellation effects will now vary more rapidly with frequency. For example, suppose we have two paths with equal attenuation and which differ in length by 300 meters, corresponding to a delay difference of 1 μsec. In the frequency domain, this link will have deep nulls at intervals of 1 MHz, with maxima in between. With a narrowband system, you may be lucky and be operating at a frequency near a maximum, or you may be unlucky and be near a null, in which case you lose most of your signal (techniques such as space diversity reception may help, though). The path loss in this case is highly frequency-dependent. On the other hand, a wideband
signal which is, say, several MHz wide, would be subject to only partial cancellation or selective fading. Depending on the nature of the signal and how information is encoded into it, it may be quite tolerant of having part of its energy notched out by the multipath channel. Tolerance of multipath-induced signal cancellation is one of the major benefits of spread spectrum transmission techniques.

Longer multipath delay spreads have another consequence where digital signals are concerned, however: overlap of received data symbols with adjacent symbols, known as intersymbol interference or ISI.

Suppose we try to transmit a 1 Mbps data stream over the two-path multipath channel mentioned above.

Assuming a modulation scheme with 1 µsec symbol length is used, then the signals arriving over the two paths will be offset by exactly one symbol period. Each received symbol arriving over the shorter path will be overlaid by a copy of the previous symbol from the longer path, making it impossible to decode with standard demodulation techniques. This problem can be solved by using an adaptive equalizer in the receiver, but this level of sophistication is not commonly found in amateur or WLAN modems (but it will certainly become more common as speeds continue to increase). Another way to attack this problem is to increase the symbol length while maintaining a high bit rate by using a multicarrier modulation scheme such as OFDM (Orthogonal Frequency Division Multiplex), but again, such techniques are seldom found in the wireless modem equipment available to hobbyists. For unequalized multipath channels, the delay spread must be much less than the symbol length, or the link performance will suffer greatly. The effect of multipath-induced ISI is to establish an irreducible error rate - beyond a certain point, increasing transmitter power will cause no improvement in BER, since the
BER vs Eb/N0 curve has gone flat. A common rule of thumb prescribes that the multipath delay spread should be no more than about 10% of the symbol length. This will generally keep the irreducible error rate down to the order of 10⁻³ or less.

Thus, in our two-path example above, a system running at 100K symbols/s or less may work satisfactorily. The actual raw BER requirements for a particular system will of course depend on the error-control coding technique used.

Delay spreads of several microseconds are not uncommon, especially in urban areas. Mountainous areas can produce much longer delay spreads, sometimes tens of microseconds. This spells big trouble for doing high-speed data transmission in these areas. The best way to mitigate multipath in these situations is to use highly directional antennas, preferably at both ends of the link. The higher the data rate, the more critical it becomes to use high-gain antennas. This is one advantage to going higher in frequency.

The delay spread for a given link will usually not exhibit much frequency dependence - for example, there will be similar amounts of multipath whether you operate at 450 MHz or 2.4 GHz, if you use the same antenna gain and type. However, you can get more directivity at the higher frequencies, which often will result in significantly reduced multipath delay spread and hence lower BER. It may seem strange that high-speed WLAN products are often supplied with omnidirectional antennas which do nothing to combat multipath, but this is because the antennas are intended for indoor use. The attenuation provided by the building structure will usually cause a drastic reduction in the amplitude of reflections from outside the building, as well as from distant areas inside the building. Delay spreads therefore tend to be much smaller inside buildings - typically of the order of 0.1µsec or less.
However, as WLAN products with data rates of 10 Mbps and beyond are now appearing, even delay spreads of this magnitude are problematic and must be dealt with by such measures as equalizers, high-level modulation schemes and sectorized antennas.

2.5 Conclusions

Radio propagation is a vast topic, and we’ve only scratched the surface here. We haven’t considered, for example, the interesting area of data transmission involving mobile stations - maybe next year! Hopefully, this paper has provided some insight into the problems and solutions associated with setting up digital links in the VHF to microwave spectrum. To sum up, here are a few guidelines and principles: Always strive for LOS conditions. Even with LOS, you must pay attention to details regarding variability of refractivity, Fresnel zone clearance and avoiding reflections from the ground and other surfaces. Non-LOS paths will often lead to disappointment unless they are very short, especially with the high-speed unlicensed WLAN devices. Their low ERP limits and high receive signal power requirements (due to large noise bandwidths, high noise figures and sometimes, significant modem implementation losses) leave little margin for higher-than-LOS path losses. Hams are not encumbered by the low ERP limits, but it can be very expensive to overcome excessive path losses with higher transmitter powers.

Use as much antenna gain as is practical. It is always worthwhile to try both polarizations, but horizontal polarization will often be superior to vertical. It will generally provide less multipath in urban areas, and may provide lower path loss in some non-LOS situations (e.g., attenuation from trees at VHF and lower UHF). Also, interfering signals from pagers and the like tend to be vertically polarized, so using the opposite polarization can often provide some protection from them. There are advantages to going higher in frequency, into
the microwave bands, due to the higher antenna gains which can be achieved. The tighter focusing of energy which can be achieved may result in lower overall path loss on LOS paths (providing that you can keep the feedline losses under control), and less multipath. Higher frequencies also have smaller Fresnel zones, and thus require less clearance over obstacles to avoid diffraction losses. And, of course, the higher bands have more bandwidth available for high-speed data, and less probability of interference. However, the advantage may be lost in non-LOS situations, since diffraction losses, and attenuation from natural objects such as trees, increase with frequency.

Radio propagation is seldom 100% predictable, and one should never hesitate to experiment. It’s very useful, though, to be equipped with enough knowledge to know what techniques to try, and when there is little probability of success. This paper was intended to help fill some gaps in that knowledge. Good luck with your radio links!

2.6 Acknowledgements

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Appendix

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<th>144 MHz (20.3)</th>
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<th>450 MHz (34.8)</th>
<th>915 MHz (54.1)</th>
<th>1.2 GHz (69.2)</th>
<th>2.4 GHz (105.6)</th>
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<td>RG-58</td>
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<td>8.6 (28.2)</td>
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<td>1 5/8” LDF</td>
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<td>0.96 (3.1)</td>
<td>1.4 (4.6)</td>
<td>2.5 (8.2)</td>
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1 Attenuation of Various Transmission Lines in Amateur and ISM Bands in dB/ (dB/ 100 m)
Chapter 3: Microwave Antenna System

Aim of study

Properties and Definitions of Microwave Antenna Systems and Applications, Return loss/voltage-standing-wave-ratio (VSWR), Solid parabolic Microwave Antennas, Flanges, Antenna Options.

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Chapter 3
Microwave Antenna Systems
Systems and Applications

3.1 Introduction

Over the past decade microwave links have proven a popular solution for the telecommunication industry. The relative ease and economy of installation has been them deployed in an increasing number of point-to-point applications – from communications backbones (blue), to branch links (white) and distribution networks (light blue), not to mention applications in the broadcast industry and private enterprises. With the rise of new cellular operators and technologies, overall microwave network density is undeniably escalating. Backbone systems are built country wide in a majority of case using a ring structure. In the very seldom case that a link is down the service will remain full operational. The frequencies in use are below 10 GHz allowing link distances up to 50 km with antennas up to 4.5m diameter. Branch links are connected to the backbone towers providing the signal to main areas and towns. The frequencies in use are up to 20 GHz providing links up to 20 km with medium size antennas. Distribution links using frequencies above 22 GHz with small antennas are completing the network. Yet this intensification of microwave communications brings added challenge. The greater the number of point-to-point links in a given area, the greater the potential for these to interact with one another and cause interference. Since any distortion of the signal reduces the quality of service, controlling interferences is now the mandate of any radio network operator and national authority. The key issue for consideration is the design and location of the source of the signal – the antenna.
3.2 Minimizing Interference by antenna design

The radiated power of a microwave antenna apart the main beam at 0 deg is significant up to 90 deg from the main beam. It is these side lobes that can cause interference with adjacent point-to-point links, and it is these side lobes that must be minimized through careful antenna design and installation.
RFS is taking care on this fact using advanced antenna designs and extensive quality control during production. In addition the antenna mounts as well as fine adjustments means provide an easy and quick antenna installation.

Figure (4-2)
3.3 Microwave Antenna Systems

3.3.1 Systems and Applications

a- Radio Link Applications

In the field of telecommunications, recent years have been marked by the rapid construction of radio link networks for different applications.

b- Radio Link Backbone Systems

Backbone or back haul systems have been built for mobile operators who want to be independent from Telcos and fixed wire operators. It saves cost for leasing a fixed line and allows a simple upgrade of the network if higher capacity is required.

In addition traditional and new telcom's, utilities as well as broadcast organizations are upgrading their networks to offer higher capacities to clients or to upgrade their system from analogue to digital service.

Backbone systems usually use large size antennas in frequency bands below 10 GHz. Due to the distance from the antenna to the radio a flexible elliptical waveguide is used for connection.RFS antennas .

c- Radio link systems for base station connectivity

Mobile operators use microwave in about 70% of cases for the connection of base station to base station and base station to switching centers. A very quick and cost effective deployment is mandatory to be successful in a rapidly growing market.

This construction process is still a long way from completion. The central issues are higher and more secure network coverage as well as expansion of capacity. Radio link stations can be erected in a large variety of locations, and
these all have specific structural and electrical requirements which must be fulfilled by the antenna/waveguide system. It is now common practice to install new base stations on existing radio link towers for backhaul applications to share the cost of a site. Maximum use is made of existing infrastructure. The disadvantage in such cases is the high level of radiated interference caused by existing telecommunication equipment.

These problems can however be overcome by careful frequency planning together with the use of antennas with high side lobe suppression and high crosspolarization discrimination.
Chapter 3: Microwave Antenna Systems

Figure (4-3)
• **Systems and Applications**

The number of available radio link towers is no way near enough to achieve satisfactory network coverage for mobile applications, as the distance between adjacent towers can be 20 to 50 km depending on the frequency range in use. For this reason network operators are forced to use other sites in unusual locations. On account of their height industrial chimneys can be ideal. However large concentration of emitted gases, which are caused by turbulence and are potentially highly corrosive, are encountered in such locations. This means that the antenna system must be manufactured from corrosion-resistant materials. Furthermore, any combination of different materials must also be able to resist corrosion. In urban environments radio links can be installed on multi-story buildings. This however does not always have a positive effect on the overall visual impression created by the building. The number of installation options is restricted, especially if preservation orders have to be taken into account as well. In such cases the planner's work can be made easier by incorporating antennas which either blend with the background or are at least to a large degree inconspicuous. RFS Compact Line and Lens antennas meet perfectly these requirements offering a very small shape.
A way of reducing the cost for erecting new towers is the use of high-voltage masts. Large numbers of these masts and pylons already exist and providing the necessary height. The disadvantage here is that it is not possible to switch-off the high-voltage supply in order to undertake repairs and maintenance or to replace the transmission equipment.

It follows therefore that the radio equipment can only be mounted on the mast at a point below the high-voltage cables. RFS low attenuation FLEXWELL® Elliptical waveguide can be used for transferring the RF signal to and from the antenna. In frequency bands above 10 GHz RFS overmoded FLEXWELL® Elliptical waveguide provides an extremely low attenuation. This could lead to the use of a smaller antenna size on top of the mast or to a
reduced power of the radio which is enlarging the lifetime of the electronic equipment. In locations where there is no possibility of installing the antenna on an existing structure, it will be necessary to erect a new tower. In order to keep the size and associated costs of the new tower within manageable proportions, the antennas should offer minimum wind loading while at the same time assuring high mechanical stability. Simple and fast installation is also a standard requirement. Especially RFS small and medium size antennas with their advanced casting mounts meet these requirements perfectly.

Figure (3-5)
• Systems and Applications

a- Antennas with waveguide installation

Small antennas (1 and 2 ft) operating in the frequency range above 10 GHz are, as a rule, connected directly to the transmission equipment.

Special mechanical and electrical matching ensure that the RF signal passes directly into the radio equipment with the minimum loss.

It is not always possible to integrate the antenna and radio equipment due to structural restrictions at the installation site. In this case, as with larger antennas,

use is made of flexible waveguide. Long connections lead to increased losses. These losses can only be offset in the overall link calculations by using larger antennas or additional amplifier stages in the transmission equipment.

An alternative solution is the use of overmoded waveguide. The attenuation with this type of waveguide is particularly low, as it no longer operates in the singl-mode frequency range.
High order modes are suppressed by means of appropriate filter units in the waveguide connectors.

There are significant advantages to be gained by using overmoded waveguide whenever a frequency range above 18 GHz is used in a mobile communication network.

**b- RFS end-to-end philosophy**

RFS offers for all installation scenarios the right products:

**c- Radio integrated with antenna**

The radio unit is directly mounted onto the back of the antenna. This is a very common type of installation providing a quick and cost effective solution. RFS is providing a variety of integrated antennas in different sizes. All interfaces meet highest electrical as well as mechanical specification to secure a stable operation in the field. Please contact RFS for more detail.

**d- Radio near to the antenna**

In cases where the radio can not be attached directly to the antenna, an additional section of a Twistflex waveguide provides the connection to the radio. The radio is installed on the pipe or tower near to the antenna. Twistflex waveguides are also used to connect antennas to waveguide runs providing the necessary flexibility during installation.

RFS provides Twistflex waveguides in all frequency bands with different lengths. Necessary fixing hardware can be ordered separately.
Figure (3-7)
Antenna integrated with ODU

Figure (3-8)

Antenna with Twistflex installation

Figure (3-9)
• **Systems and Applications**

  **a- Radio in a shelter**

  In traditional backbone systems as well as in configurations where quick and easy maintenance is required, the radio is installed in a shelter at ground level. In such cases FLEXWELL® Elliptical Waveguide provides a low-loss connection to the antenna. RFS is providing all necessary tools and accessories to install the antenna/waveguide system with best electrical and mechanical performance. This includes hoisting stockings, flanging tools, bending tools and fast earthing components.

  As waveguide runs have to be filled with dry air, suitable equipment for manual as well as automatic dehydration is part of the RFS product portfolio.

  **b- The bottom line**

  RFS antenna/waveguide systems provide a high mechanical stability and corrosion resistance and are easy to install. Antennas and waveguides are matched offering highest system performance and stability.

  Mechanical features are outstanding to secure the radio link even under severe environmental conditions.

  Small size antennas are offered with a very small shape to minimize the environmental impact. This is required in rural areas to get the permission for a radio link much easier.

  Electrical characteristics comply and even exceed with national and international standards to minimize interference and to simplify network planning.
Low-Loss waveguides and simple means of dehydrating short waveguide runs make planning and maintenance easier.

Optimized logistic and state-of-the-art manufacturing respond to the request for short delivery times.

### 3.4 Properties and Definitions

**Half Power Beam Width (HPBW)** The angle, relative to the main beam axis, between the two directions at which the co-polar pattern is 3 dB below...
the value on the main beam axis. The values are nominal and stated as the minimum for the frequency band.

3.4.1 Gain

The ratio of the radiation intensity, in the main beam axis to the radiation intensity that would be obtained if the power accepted by the antenna were radiated isotropically. Value measured in dBi. The values are stated for the three frequencies at mid-band as well as at bottom and top of the frequency band. The tolerance for antenna gain is ± 0.2 dB for single polarized antennas. In the case of dual polarized antennas, tolerance is also ± 0.2 dB for the average value of both ports and ± 0.3 dB for each port alone.

3.4.2 Front-to-back-ratio (F/B)

Denotes the highest level of radiation relative to the main beam in an angular zone of 180° ± 40° for all antennas. Tolerance on stated values is 2 dB.

3.4.3 Cross-polar discrimination (XPD)

The difference in dB between the co-polarized main beam gain and the cross-polarized signal measured within an angular zone in azimuth of twice the maximum half power beam width of the frequency band. The value is 30 dB minimum for all antennas except where noted.

3.4.4 Antenna inter-port isolation (IPI)

Denotes the ratio in dB of the power level applied to one port of a dual polarized antenna to the power level received in the other input port of the
same antenna. The value is 35 dB minimum for all antennas (40 dB respectively 45 dB for UXA antennas).

### 3.5 Return loss / voltage-standing-wave-ratio (VSWR)

The stated values are guaranteed across the frequency band of operation.

#### 3.5.1 Radiation pattern

A diagram relating power flux density at a constant distance from an antenna to direction relative to the antenna main beam axis.

![Half-power beamwidth (3 dB-width)](image)

Figure (3-11)
Figure (4-12)

Figure (4-13)
• **Properties and Definitions**
  
  **a- Radiation pattern envelopes (RPE’s)**
  
  The envelope represent the worst values of measurements taken on the pattern test range at the three frequencies mid-band, bottom and top of the band, in both copolar and cross polar condition, horizontal and vertical polarized, over the full 360° of azimuth. Since the envelope is drawn over the highest peaks out of all measurements actual interference radiation in an operation system will be generally smaller than calculated from the RPE. Tolerance on given values is 3 dB in an angular region of ±100° and 2 dB from 100° to 180°.

  **b- Mechanical Properties and Definitions**
  
  In addition to the electrical performance RFS designs antennas with outstanding mechanical features. This assures a high link stability as well as a long lifetime. Key mechanical features are Survival and Operational windspeed.

  **c- Survival windspeed**
  
  The antenna sub-system will survive the specified survival windspeed without any permanent deformation or changes of shape. The value is 250 km/h (70 m/sec) for the 1 ft and 2 ft antennas and 200 km/h (56 m/sec) for all other antennas. An additional load of an ice layer of 30 mm radial ice is taken into account. Special ‘Windload kits’ are available to improve the survival windspeed of all antennas up to 250 km/h.
D- Operational windspeed

The antenna axis deflection is less than one third the half power beam width at the highest frequency which occurs. The drop in signal is only approximately 1 dB; the radio link will therefore continue to operate. The value is 190 km/h (53 m/sec) for all antennas. Antennas with windload kit offer an operational windspeed of 200 km/h all types.
All RFS designs are based on advanced methods of calculation (Finite Element Method) providing state of the art results. In addition there are numerous possibilities for simulation based on recognized standards and regulations. Results have been approved by independent stress analysts. The proof of mechanical stability is determined on the basis of EIA Standards RS-195-* and RS-222-* which are recognized world-wide.

* Current Version These standards prescribe the wind resistance coefficients (Cw values) to be used for calculating the equivalent forces caused by wind loading. The values are the result of numerous trials in a wind tunnel and calculations of aerodynamic properties. Amongst other things they also take into account the physical shape of the antenna, e.g.
reflector only (standard antenna) or reflector with shroud and radome (high performance antenna).

A wind force $F_{wind}$ acting on the antenna leads to a load on the mounting pipe. This load can be divided into an axial force $F_{AT}$, a lateral force $F_{ST}$ and a torque (turning moment) $M_t$.

![2ft M-Mount Complete](image)

Figure (4-16)
Chapter 3: Microwave Antenna Systems

Figure (4-17)

Figure (4-18)
3.7 Mechanical Tests

In addition to calculation RFS has proven the design with extensive physical testing. Small size antennas have been put on a shock and vibration test facility. The applied test conditions exceed the requirement of the European standard EN 300 019, class 4M5. Wind tunnel tests including 4 ft (1.2m) antennas and equivalent windload tests complete the mechanical testing. Windspeeds have been applied exceeding the mechanical design wind speeds to prove the design even under extreme conditions.

Figure (4-19)
Vibration Test

Figure (4-20)
Figure (3-21)
Mechanical Tests

Large size antennas are difficult to be tested in a standard wind tunnel due to a missing rigid mounting structure. Therefore RFS has designed an equivalent windload test rig. The job of the test rig is to apply different forces to the antenna in such a way that it simulates the wind force, split into an axial component Fa, a lateral component Fs and the torque Mv that develops in the vertex of the antenna. For this purpose the test rig has different independent hydraulic systems, which employ hydraulic cylinders and a band to apply forces to the antenna. The contour of the antenna is checked with a template before and after the load is applied. According to the definition of survival windspeed no
permanent deformation or changes of shape has to occur on the antenna sub-system. Dial gauges register the flexible change of shape of the antenna and the mast mounting during the test. This system enables antennas with a diameter of up to 4.5 m to be measured at a wind load of up to 250 km/h. Forces acting on the mounting pipe can be up to 150 kN axially and 40 kN laterally, together with a torque of 90 kNm. The hydraulic pressure required to create these measurement conditions is approx. 65 bar.

**Bottom Line:** RFS antennas provide secure operations under all standard environmental conditions. This is assured by the use of corrosion resistant materials as well as selected material combinations. Continuous proving in environmental chambers and salt fog spray test facilities guarantee an outstanding long lifetime.

![Figure (4-23)](image)
3.8 Solid Parabolic Microwave Antennas

3.8.1 Introduction and Antenna Descriptions

Radio Frequency Systems offers the most comprehensive line of highest quality microwave antennas in the industry. Antennas are available in all the common frequency bands ranging from 3GHz to 60GHz. They are available in diameters from 1 ft (0.3 m) to 15 ft (4.60 m). System design becomes easy and efficient with such a comprehensive antenna offering.

The antennas are available in four performance classes offering complete flexibility when designing a network. The antennas meet the pattern requirements according to EN 300 631, EN 300 833 and FCC depending on the frequency range. In addition to the different electrical classes of antennas Radio Frequency Systems offers the system design engineers different options of survival wind speeds. This allows the use of antennas in areas where extreme wind conditions are normal.

3.8.2 Standard Performance Antennas

Standard Performance Antennas are economical solutions for systems where side lobe suppression is of less importance. The antennas consist of a reflector, feed and tower mount. Low VSWR versions are available for low echo distortion.

<table>
<thead>
<tr>
<th>STANDARD PERFORMANCE ANTENNAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single polarized</td>
</tr>
<tr>
<td>Single polarized, spread spectrum</td>
</tr>
<tr>
<td>Dual polarized</td>
</tr>
</tbody>
</table>
3.8.3 Improved Performance Antennas

Improved Performance Antennas are unshrouded and offer an economic solution for systems requiring good radiation performance particularly in the back region. The improved F/B ratio is achieved by use of an efficient feed design together with a deep dish reflector. These features result in an improved front to back ratio, and were specially designed to meet FCC category A standards.

<table>
<thead>
<tr>
<th>IMPROVED PERFORMANCE ANTENNAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single polarized</td>
</tr>
<tr>
<td>Dual polarized</td>
</tr>
</tbody>
</table>

3.8.4 High Performance Antennas

High Performance Antennas are similar to Ultra High Performance Antennas in construction. They are ideally suited for systems where a good level of side lobe suppression is required.

<table>
<thead>
<tr>
<th>HIGH PERFORMANCE ANTENNAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single polarized</td>
</tr>
<tr>
<td>Dual polarized</td>
</tr>
</tbody>
</table>

3.8.5 Ultra High Performance Antennas

Ultra High Performance Antennas are the optimum choice for systems where a high level of pattern performance is required because of high local radio congestion. The antennas are supplied with low VSWR feed, planar radome, tower mount and shroud with RF absorber.
3.8.6 High Cross Polar Discrimination Antennas

UXA series of antennas are based on Ultra High Performance Antennas. These antennas offer high side lobe suppression. In addition UXA antennas offer extremely high cross-polar discrimination. They are therefore ideally suited for very high capacity systems utilizing extensive frequency reuse in highly congested environments. This outstanding performance is achieved by use of a special corrugated illuminator, a rigid torsion box back structure which ensures the reflector maintains its shape in the field and strict quality control during manufacture. The cross-polar characteristics for radiation angles close to bore sight meet the highest XPD requirements according to EN 300 833 and FCC. High cross-polar discrimination antennas are available for frequencies from 4 GHz to 23 GHz.
### 3.8.7 Introduction and Antenna Descriptions

**Reflectors**

Antennas with diameters up to 10ft (3.0m) are supplied with reflectors in one piece.

Antennas with diameters 12ft (3.7m) are supplied with a two piece reflector (except UXA-types). Antennas with diameters of 15ft (4.6m) are supplied with a 3 piece reflector, 8ft and 10ft antennas are available in 2 pieces.
Standard color for RFS Microwave Antennas is white. Custom colors are available upon request. Molded fiberglass radomes are white. High Performance, Ultra High Performance and High Cross Polarization Discrimination antenna are supplied with planar white radome Custom colors are available upon request.
3.8.8 Slim Line and Compact Line Antennas

Radio Frequency Systems recognizes that mobile operators and private microwave users have requirements for cost effective solutions for their microwave antenna systems. These needs include products, which are easy and quick to install while maintaining good electrical performance. In response to these needs Radio Frequency Systems developed the Slim Line and Compact Line series of antennas.

The Slim Line series of antennas utilize a conventional feed system and are available in Standard, High and Ultra High performance versions. The Slim Line series of antennas are available in diameters from 1ft (0.3m) to 6 ft (1.8 m).
The Compact Line series of antennas use a special feed system which results in a reduced shroud length and consequently a lower profile antenna. These antennas are lighter in weight than standard antennas for reduced tower loading and shipping costs.
Furthermore Compact Line antennas up to 2ft (0.6m) diameter are very rugged, with a wind loading rating of 250 km/h (155mph). Their type designation is SB for single polarization and SBX for dual polarization.

Compact Line antennas are available in 1ft (0.3 m), 2 ft (0.6 m), 3ft (0.9 m) and 4ft (1.2 m) diameters.

### 3.9 RFS Compact Line Antennas

Single polarized Ultra High Performance SB Dual Polarized Ultra High Performance SBX 1ft and 2 ft antennas consist of an integrated reflector/shroud system avoiding any RF-leakage. This is a further contribution offering excellent radiation performance especially in the back direction.

![Image of Compact Line Antenna](image)

Figure (4-28)

<table>
<thead>
<tr>
<th>RFS COMPACTLINE® ANTENNAS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single polarized</td>
</tr>
<tr>
<td>Dual Polarized</td>
</tr>
</tbody>
</table>
1ft and 2 ft antennas consist of an integrated reflector/shroud system avoiding any RF-leakage. This is a further contribution offering excellent radiation performance especially in the back direction.

![Antenna Image](image)

Figure (4-29)

### 3.10 Solid Parabolic Microwave Antennas

#### 3.10.1 Lens Antennas

RFS lens antennas are an economical solution for short haul radio links. The antennas are based on conventional horn antenna design. A dielectric lens is used to correct the phase difference at the aperture, which occurs due to the large ratio of wavelength to aperture diameter. Lens antennas have no metallic parts blocking the radiating aperture. This results in a very high antenna efficiency of nearly 70%.

An additional advantage is the visual impression. To a certain extent a lens antenna looks like a lamp. This solution is highly suited to installations where environmental restrictions limit the choice of antenna type, such as in the proximity of listed buildings or monuments.

Lens antennas are available with a diameter of 0.5ft (0.15m) offering an ultra high radiation performance.
Customized Antennas

RFS Slim Line and especially RFS Compact Line antennas can be provided with a custom designed adaption for the outdoor unit of the radio equipment. This allows the outdoor unit of the radio to be mounted directly the antenna, removing the need for an additional twist flex or elliptical waveguide connection between the radio and the antenna. The antenna is normally mounted to a vertical pole. The equipment box can be replaced without the need for a realignment the antenna system. RFS is taken special care to meet highest electrical as well as mechanical requirements of the interface. In
addition to wind tunnel tests, shock and vibration tests with radios as well as water spray tests are performed demonstrating a leakage free interface.

RFS is continuously increasing the product portfolio of customized antennas. For more details please contact RFS.

Figure (4-31)

Figure (4-32)
3.10.3 Antenna Types, Overview

<table>
<thead>
<tr>
<th>STANDARD PERFORMANCE</th>
<th>HIGH PERFORMANCE</th>
<th>ULTRA HIGH PERFORMANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAD</td>
<td>DA, SD, SDF</td>
<td>UA, SU</td>
</tr>
<tr>
<td>Single polarized, standard, (FCC part 101, category “A” compliant)</td>
<td>Single polarized</td>
<td></td>
</tr>
<tr>
<td>PADX</td>
<td>DAX, SDX</td>
<td>UDA, SUX</td>
</tr>
<tr>
<td>Dual polarized, standard, (FCC part 101, category “A” compliant)</td>
<td>Dual polarized</td>
<td></td>
</tr>
<tr>
<td>PA, SP</td>
<td></td>
<td>UXA</td>
</tr>
<tr>
<td>Single polarized</td>
<td></td>
<td>Dual polarized, high XPD</td>
</tr>
<tr>
<td>PAL</td>
<td></td>
<td>SB</td>
</tr>
<tr>
<td>Single polarized, low VSWR</td>
<td></td>
<td>CompactLine, single polarized</td>
</tr>
<tr>
<td>PAX, SPX</td>
<td></td>
<td>SBX</td>
</tr>
<tr>
<td>Dual polarized</td>
<td></td>
<td>Lens, single polarized</td>
</tr>
<tr>
<td>PSF, SPF</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single polarized, non-pressurized, Spread Spectrum</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.10.4 Ordering Information & Antenna Options

In order to easily identify an antenna model RFS utilizes a model numbering system which clearly identifies the antenna type, diameter, frequency, revision and antenna input.

In addition to the standard products Radio Frequency Systems offers, products with increased wind rating, improved environmental ratings, planar radome colors and radome types. For these options please contact your local RFS sales office.
Different flange types are available for the whole antenna range. The flange sizes, profiles and dimensions are in accordance with specifications 154 IEC and EIA (Electronic Industry Association) which classifies the flange types in the following coding systems:

### 3.11.1 IEC-flanges

1st digit pressurizable or unpressurizable etc. 2nd digit flange type-A, B, D etc. 3rd digit waveguide profile, rectangular, etc. secondary numbers Waveguide size according to 154-IEC.
**Chapter 3: Microwave Antenna Systems**

**DESCRIPTION OF FLANGE TYPES:**

<table>
<thead>
<tr>
<th>Type</th>
<th>Flange Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Round</td>
</tr>
<tr>
<td>B</td>
<td>Square</td>
</tr>
<tr>
<td>D</td>
<td>Rectangular</td>
</tr>
</tbody>
</table>

**Typical coding examples**

- P D R 70
  - waveguide size 70
  - rectangular
  - type D, flange profile rectangular
  - pressurizable

- U B R 140
  - waveguide size 140
  - rectangular
  - type B, flange profile square
  - unpressurizable

Figure (3-34)
3.12 EIA Flange Identification

3.12.1 CPRG Flanges

CPRG, pressurizable contact flanges, are flat faced with a gasket groove and secured with nuts and bolts. One full thickness gasket is used when mating two CPRG flanges.

![CPR G Flange](image)

Figure (4-35)

3.12.2 Choke Flanges

Choke flanges include a choke groove, gasket groove and threaded bolt holes for mating to a cover flange. One O-ring is used when mating a choke flange to a cover flange without gasket groove. Use an O-ring and half gasket when mating a choke flange to a cover/gasket flange. Two choke flanges cannot be mated.
3.12.3 Cover Flanges

Cover flanges are flat faced without any choke or gasket grooves, and have clear bolt holes for mating to a choke or cover flange. A conductive gasket is required when mating two cover flanges. One O-ring is used when mating a cover flange to a cover/gasket flange.
3.12.4 Cover/Gasket

Cover/gasket flanges are flat faced with a gasket groove only, and have clear bolt holes for mating with a choke, cover, or cover/gasket flange. One O-ring and a half gasket are used when mating two cover/gasket flanges or when mating a cover/gasket flange to a choke flange. One O-ring is used when mating a cover/gasket flange to a cover flange without gasket groove.

![Cover/Gasket](image)

Figure (4-38)
### 3.13 Mounting Information

#### 3.13.1 Solid Parabolic Microwave Antennas

- **Multi-purpose mount (M-mount) for 1 and 2 ft**

**Antennas** The mounting hardware – called the M-mount – has been especially designed for the installation of small antennas (1 and 2 ft). The M-mount provides ± 30 deg fine adjustment of both azimuth and elevation. This is especially important for small antennas used in short radio links. The mount is made primarily from cast aluminum parts, which provide outstanding stability together with a very low weight. The basic material of the mount is seawater-resistant aluminum alloy.
The M-mount enables small antennas (1 and 2 ft) to be mounted on pipe diameters of 48-114 mm (2-4.5 in).

The mount is standard for all 2 ft antennas. It can be ordered optional for 1 ft antennas.

- **Oversized Mounting Hardware**

  The Oversized Mounting Hardware has been specially designed for the installation of small antennas on larger diameter pipes which are already in place on radio link towers. These pipes are often larger than the standard 114 mm. Therefore RFS has designed an alternative mounting bracket which makes it unnecessary for the installation team to provide a special mechanical interface. The Oversized Mounting Hardware enables small antennas to be mounted on pipe diameters of 120-219 mm (4.8-9 in).

  The easy and fast installation saves time and cost because no additional steel work has to be prepared.

  In addition the Oversized Mounting Hardware provides more flexibility and higher stability to secure the link.

  For more details contact RFS.
Chapter 3: Microwave Antenna Systems

Figure (4-39)

1ft M-Mount, optional

Figure (3-40)

2ft M-Mount
3.14 Antenna Options

3.14.1 Increased Wind Load Kit

Large RFS antennas, 6 to 12 ft (1.8 to 3.7m) diameter, already incorporate a strong back ring structure to support the reflector. The hot dip galvanized steel mount is fixed to the back ring. This configuration allows a simple upgrade of one of the antenna’s most important mechanical features. The Increased Wind Load Kit consists of additional struts for mounting between the back ring and the reflector rim. Thus enables the wind forces to be directed to the most rigid part of the antenna mount.

The 3 and 4 ft antennas can simply be upgraded by an additional side strut due to basic strong casting mount. The kit can be installed on site before lifting the antenna onto the tower. Antennas with a wind load kit provide a survival wind speed of 250 km/h (155mph), 200 km/h (125mph) without kit, and an operational wind speed of 200 km/h (125mph), 190 km/h (118mph) without kit.

3.14.2 Sway Bars

For protection against antenna shifting and deflection, 6, 8, 10 and 12 ft (1.8, 2.4, 3.0 and 3.7m) antennas contain one sway bar and 15 ft (4.6m) antennas have four (4) sway bars. Additional sway bars are available as an option for all 6ft (1.8 m) to 12ft (3.7m) antennas.

3.14.3 Harsh Environment Antennas

For increased protection within extreme corrosive and humid environments, harsh environment antennas are offered as an option. These antennas come with special corrosion resistant components and finishes, and are designed to
withstand corrosive weathering environments typical of industrial, shoreline and offshore environments.

Figure (4-41)

Figure (3-42)
Chapter 3: Microwave Antenna Systems

Figure (4-42)

Figure (3-43)

Figure (4-44)
3.15 Radomes

3.15.1 Solid Parabolic Microwave Antennas

- Molded Radomes

Optional molded radomes are available for Standard Performance antennas 2 to 12 ft. The radomes are made of fiberglass reinforced polyester resin covered with a gel coat. The 2 ft radome is manufactured from ABS material. The shape minimizes the influence of the radome upon antenna gain, return loss and radiation characteristic.

Radomes with a special flat shape are available for all 4 and 6 ft antennas above 5.6 GHz. These radomes provide reduced packing volume and therefore are ideal for transportation. The radomes are identified by 'SH' in the model name. Moulded radomes protect against the accumulation of snow, ice and dirt, and reduce windload. The surface is protected against ultraviolet degradation. The standard colour is white.
Flexible Planar Radomes

Flexible Planar radomes manufactured from Complan are supplied with all shrouded antennas > 2ft with the exception of 3 and 4 ft CompactLine antennas. For Teflon coated fiberglass radomes please contact RFS.

3.15.2 Replacement Planar Radomes

Replacement radomes are available. Please contact RFS.
- **Parabolic Point to Point Antennas 2.3 - 2.5 GHz**

1 ft Antenna with Standard Mount
SB, SBX, SUX

1 ft Antenna with M-mount, optional
SB, SBX, SUX

<table>
<thead>
<tr>
<th>ANT TYPE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D PIPE Ø 114</th>
<th>D PIPE Ø 51</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB, SBX</td>
<td>380(15)</td>
<td>170(6.7)</td>
<td>85(3.3)</td>
<td>287(11.3)</td>
<td>242(9.5)</td>
<td>133(5.2)</td>
</tr>
<tr>
<td>SUX</td>
<td>380(15)</td>
<td>250(9.8)</td>
<td>85(3.3)</td>
<td>287(11.3)</td>
<td>242(9.5)</td>
<td>133(5.2)</td>
</tr>
</tbody>
</table>

All dimensions in mm (inch)
Figure (3-46)
3 ft Antenna
SD, SDX, SU, SUX

All dimensions in mm (inch)

<table>
<thead>
<tr>
<th>ANT TYPE</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD, SDX, SU, SUX</td>
<td>970(38.3)</td>
<td>620(24.5)</td>
<td>165(6.5)</td>
<td>273(10.8)</td>
<td>67(2.6)</td>
<td>350(13.8)</td>
</tr>
<tr>
<td>SP, SPX</td>
<td>970(38.3)</td>
<td>165(6.5)</td>
<td>273(10.8)</td>
<td>67(2.6)</td>
<td>350(13.8)</td>
<td></td>
</tr>
<tr>
<td>SB</td>
<td>970(38.3)</td>
<td>500(19.8)</td>
<td>170(6.8)</td>
<td>273(10.8)</td>
<td>65(2.5)</td>
<td>350(13.8)</td>
</tr>
</tbody>
</table>

Figure (4-47)
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Figure (4-48)
Figure (4-49)
6 ft Antenna
UA, UDA, UXA, DA, DAX, SD, SDX, SU, SUX

PA, PAL, PAX, SP, SPX

All dimensions in cm (inch):

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D Ø114</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000(79)</td>
<td>1242(48.9)*</td>
<td>364(14.3)</td>
<td>175(6.9)</td>
<td>283(11.1)</td>
<td>590(23.2)</td>
</tr>
</tbody>
</table>

*3.6-4.2 GHz = 1342(52.8)

Figure (4-50)
Figure (4-51)
10 ft Antenna
UA, UDA, UXA, DA, DAX

PA, PAL, PAX

All dimensions in mm (inch)

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D Ø114</th>
<th>E</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>3170(125.3)</td>
<td>1655(65)*</td>
<td>550(21.7)</td>
<td>190(7.5)</td>
<td>370(14.6)</td>
<td>1440(56.9)</td>
</tr>
</tbody>
</table>

*3.6-4.2 GHz = 1845(72.9)

Figure (4-52)
Figure (3-53)
Figure (3-54)