

MICROWAVE COMMUNICATION BASICS

THE THEORY, PRACTICES AND
TECHNOLOGIES THAT LINK THE
WIRELESS WORLD

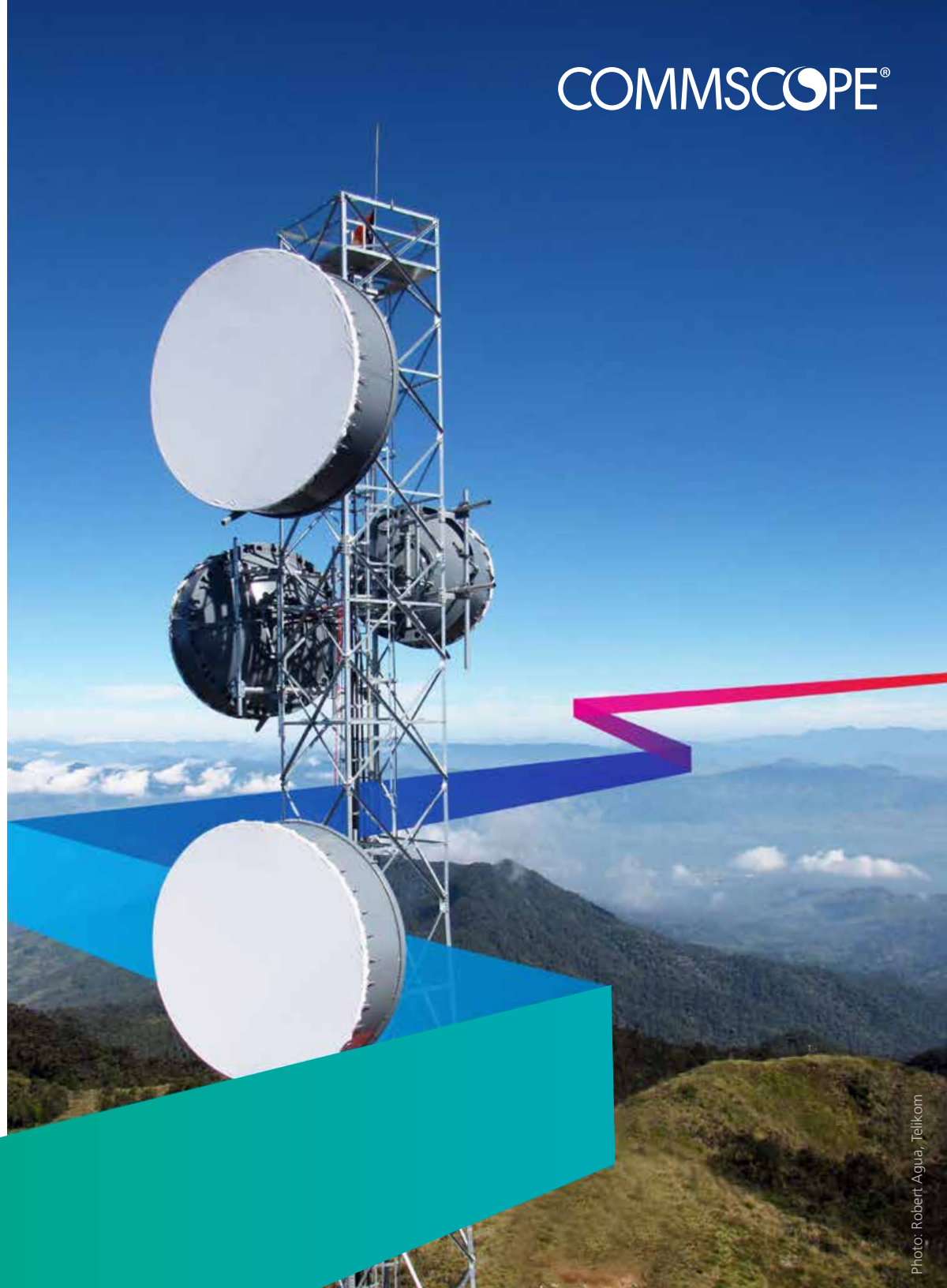


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COUNT ON COMMSCOPE TO HELP YOU OVERCOME TODAY'S MOST PRESSING NETWORK CHALLENGES

Authored by CommScope experts, this book explains how the fundamentals of microwave communications impact the capacity and reliability of your wireless network.

A modern wireless network depends on multiple systems, meshing together, to provide the customer with a positive experience—one that's transparent, fast and most of all, dependable. Microwave communications, used for backhaul applications that move site traffic on and off of the core network, can make or break that positive customer experience.

This book offers an accessible yet meaningful look into the components, systems and practices that go into an efficient, reliable microwave communications network. "As an industry leader, CommScope is sharing what we've learned to help you overcome every network challenge—even if it's just simple curiosity about the science of microwave communications," said Morgan Kurk, chief technology officer.

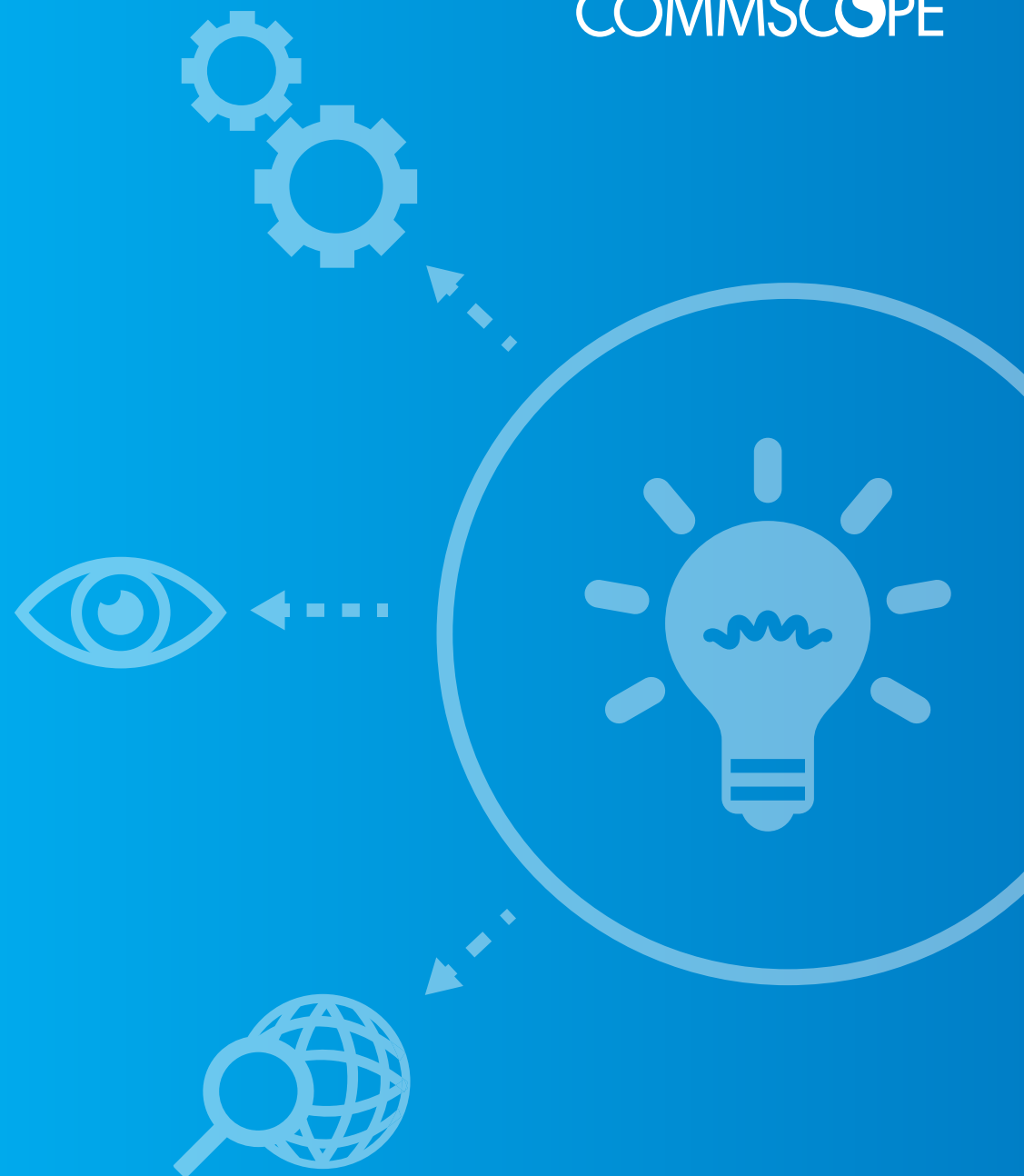


*Morgan Kurk,
chief technology officer*

CHAPTER

1

Introduction:
Microwave networks and
the insight that builds them



JOIN US AS WE TAKE THE NEXT LEAP FORWARD IN EFFICIENCY AND COST

This book is released at an exciting time in the field, as new advances are pushing back the boundaries of performance, efficiency and cost in microwave communication networks.

CommScope has been at the forefront in development of new microwave antenna designs that feature low side lobes that vastly improve interference resistance, which in turn boosts capacity and quality of service—all while reducing total cost of ownership for the operator.

You'll learn more about side lobes in Chapter 4 and elsewhere in this book—and you can always rely on your partners at CommScope for innovative thinking and industry leadership.

Microwave backhaul

The use of microwave communications to aggregate and transmit cellular voice and data to and from the main network.

WHAT ARE MICROWAVES AND HOW ARE THEY USED?

Within the broader spectrum of radio frequency (RF) communications, point-to-point communications are usually carried out using microwave frequencies between 1 GHz and 100 GHz along line-of-sight (LOS) paths called links.

These frequencies and their propagation characteristics allow the transmission of vast amounts of data between remote communication sites without the need to lay cables between them.

The characteristics of the antennas used in point-to-point communication allow the same frequencies to be used throughout a system—that is, the system can employ high frequency reuse. Careful link planning and management make this possible without interference becoming a problem.

These advantages give microwaves a special place in the world of RF engineering, where they are used in point-to-point wireless communications networks, satellite communications, radar systems and even radio astronomy.



Line of sight (LOS)

A clear path—free of any obstructions—between points of microwave signal transmission and reception.

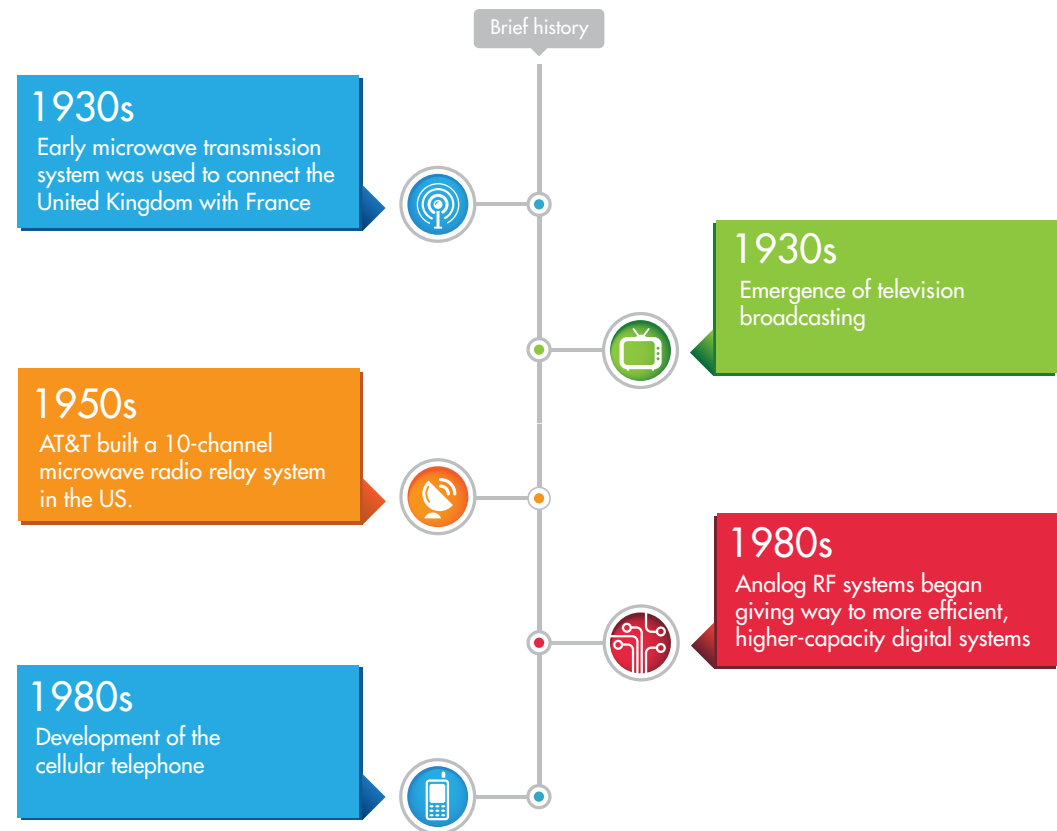
Link

The connection of two fixed microwave sites via a line-of-sight (LOS) path. Also referred to as a “hop.”

A BRIEF HISTORY OF MICROWAVES

The first practical application of microwaves in a communication system took place more than 80 years ago. In the 1930s, an experimental microwave transmission system was used to connect the United Kingdom with France—bridging the English Channel without cables. In the 1950s, AT&T built a 10-channel microwave radio relay system in the United States that was capable of carrying 5,400 long-distance calls per channel, supporting a total of 54,000 simultaneous callers. The emergence of television provided another opportunity, as network broadcasting was relayed to local affiliates across the country.

In the 1980s, analog RF systems began giving way to more efficient, higher-capacity digital systems to accommodate rising traffic demand. Even then, microwave networks typically provided long-haul communications—but all that was to change with the development of another ubiquitous consumer RF technology: the cellular telephone.



THE CELLULAR REVOLUTION

The worldwide proliferation of cellular networks introduced a critical demand for new microwave backhaul infrastructure; after all, a cell site could only generate revenue if it could move its traffic to and from the rest of the network. Connecting individual sites to the main network called for a reliable, affordable and powerful means of transmitting large amounts of aggregated data over the span of a few kilometers—and its infrastructure would have to be quickly deployed to keep up with rising demand.

The telecommunications industry adopted a small, single-channel microwave radio system mounted directly onto the back of a smaller antenna. This solution provided the capacity the industry needed, but without the complex installation required by traditional long-haul microwave systems.

Since those early days, the wireless industry has continued to grow exponentially—moving data as

well as voice and creating a consumer experience that has led to nearly universal expectations of constant, reliable connectivity all over the world. As new network technologies and standards emerged, point-to-point microwave communication has remained the backbone of the entire model, connecting millions of users to their networks in a seamless tapestry covering the planet.

Microwave backhaul

The use of microwave communications to aggregate and transmit cellular voice and data to and from the main network.



TRUST A PROVEN PARTNER TO PUT IT ALL TOGETHER

Beyond the basic theory and simplest applications, building microwave communication infrastructure into wireless networks is a complicated task requiring broad expertise across a number of technologies and disciplines.

CommScope has been involved in microwave networks since the early 1950s. Our microwave antenna solutions connect the world's networks, much as the early railways connected cities and nations. Throughout the development of microwave communication, our innovative approach to product design and manufacturing—together with our unwavering commitment to quality—has made CommScope a leader in the communications revolution.

We provide innovative solutions and practical guidance for:

- Link planning
- Antennas
- Elliptical waveguide and connectivity solutions
- Pressurization
- Environmental considerations
- Installation and alignment



THE BUSINESS CASE FOR TECHNICAL EXPERTISE

Network operators continually monitor key performance indicators (KPIs) within their networks to identify performance problems and ensure customer satisfaction. These indicators include quality of service (QoS), link failures, lost traffic, and other criteria.

To keep up with constantly growing traffic, engineers, designers and technicians are constantly required to optimize network performance. While there are sophisticated tools available to help stay ahead of growing demand, true network optimization requires a solid physical foundation of components and solutions across the network. After all, even the best network design cannot deliver performance if the physical infrastructure performs below expectations. This can lead to both operational and business challenges as customers notice poor network performance—and look to competitors for something better.

Since taking a link down for maintenance is costly and disruptive, it's even more important to put one's best thinking and strategy into the initial link design and selection of components. That forethought can prevent network downtime and, ultimately, lost customers. It all begins with a thorough understanding of the site's specific requirements and the components available to help meet those requirements.

Key performance indicators (KPI)

Critical measurements of network function related to reliability and performance.

BEGIN THE JOURNEY WITH US

With the understanding that foresight in planning and component selection is vital to the long-term performance and profitability of a microwave network, let's explore how the many parts of such a network come together.



The scope of this book

While we will cover many aspects of microwave communication networks, we will not address microwave radio technology itself, which is a complex, technical subject worthy of its own book.

CHAPTER

2

Microwave basics and
all about antennas



MEASURING THE WAVE

In theory, electromagnetic (EM) waves may exist with frequencies from zero to infinity.

However—in practice—the generation, transmission, detection and processing of EM waves requires frequencies within a certain range called the EM spectrum. Microwave (MW) is a part of this spectrum, comprising the bands between 1 GHz and 300 GHz.

Sending and receiving information via microwaves is collectively called microwave transmission, and it could be composed of voice, data, television, telephony or radio signals. Microwaves are also emitted by natural objects, as well as from space.

Because microwaves cover a substantial part of the EM spectrum, they can be used in many different applications. Some of these bands and their uses are shown in Table 2.1, which illustrates the whole of the EM spectrum.

Hertz (Hz)

A measurement of a signal’s electromagnetic frequency, expressed as the number of cycles per second.

kHz: kilohertz
(x1,000)

MHz: Megahertz
(x1,000,000)

GHz: Gigahertz
(x1,000,000,000)

THz: Terahertz
(x1,000,000,000,000)

Frequency	Wavelength	Application
50–60 Hz	6000–5000 km	AC electricity transmission
3–30 kHz	100–10 km	Sub-marine communication
30–300 kHz	10–1 km	Long-wave radio broadcast
180–1600 kHz	1.7 km–188 m	AM radio broadcast
1.8–30 MHz	167–10 m	Shortwave radio
88–108 MHz	3.4–2.7 m	FM broadcast
300–3000 MHz	1–0.1 m	UHF point to point
800–2200 MHz	0.375–0.136 m	Mobile base station
1–60 GHz	0.3–0.005 m	Microwave links
60–300 GHz	0.005–0.001 m	Millimeter-wave links
352, 230, 193 THz	1550, 1300, 850 nm	Fiber-optic links
420–750 THz	714–400 nm	Visible light

Table 2.1: *Applications within the electromagnetic spectrum, arranged by frequency*

Antennas are devices that radiate or receive EM waves of certain frequencies. The antenna is a transition structure between a guided structure (that is, a cable or waveguide) and the open air. An antenna designed to radiate and receive microwave frequencies, therefore, is called a microwave antenna. We will discuss these in more detail later in the chapter.

Antennas must be engineered to suit the key parameters of EM waves:

Frequency: The rate of the wave's oscillation, measured in Hertz (Hz).

Amplitude: The strength or power level of the wave.

Phase: The particular point in the cycle of a waveform, measured in degrees.

Polarization: The orientation of the electric field driving the wave.

MICROWAVE TRANSMISSION

Microwaves can propagate through a guided medium, such as a transmission line, which could be cable or waveguide. They can also propagate through an unguided medium as plane waves in free space and through the atmosphere.

In all networks, selecting a physical medium is generally a matter of budget, capacity needs, availability, reliability and how quickly the solution can be deployed. Common options include twisted-pair copper cable, coaxial cable and fiber-optic cable.

In some instances, however, conflicting requirements defeat all these options; for instance, capacity requirements may demand a fiber-optic backhaul link, but the budget may not allow for the time and cost needed to install it. MW transmission holds a unique position as a solution where cost, capacity, flexibility and timing all intersect.



Figure 2.1: Coaxial cable examples



Figure 2.2: Example of hybrid fiber optic cable



Figure 2.3: Example of fiber optic cable installation

WAVEGUIDE

Microwave energy travels through guided media in different modes. A microwave waveguide with a single conductor is a high pass filter; these structures have a cutoff frequency.

Single-conductor options include:

- Rectangular waveguide
- Circular waveguide
- Elliptical waveguide
- Ridged waveguide
- Corrugated waveguide

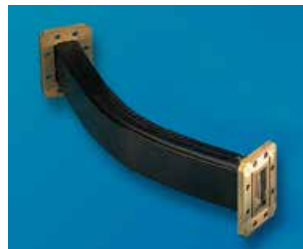
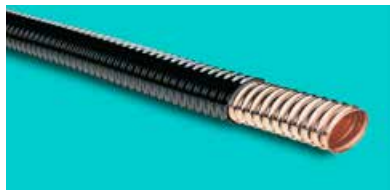


Figure 2.4: Examples of waveguide

Attenuation in waveguide can be caused by dielectric loss, if the waveguide is full of dielectric, or by conductor loss due to the metal structure's finite conductivity. The various modes of operation available depend on the desired frequency, as well as the size and shape of the waveguide itself.

The maximum attenuation values—measured in decibels per meter (dB/m)—are published by the International Electrotechnical Commission based in Switzerland (IEC). Waveguide attenuation is published by manufacturer.

For example, an EWP52 elliptical waveguide (attenuation: 3.93 dB/100 m (1.2 dB/100 ft) @ 6.175 GHz will attenuate 2.4 dB over a 61 m (200 ft) length. Microwave waveguides are maintained under dry air or dry nitrogen pressure to avoid moisture condensation that would impede their performance.

We will explore waveguide in greater detail in Chapter 8.

Waveguide

A metallic-sheathed physical transmission medium; unlike a cable, waves propagate along it without an inner conductor.

GOING TO THE AIR

Microwaves display some interesting propagation characteristics that make them ideal for radio transmission. Point-to-point radio links are often the most cost-effective method of transporting large volumes of data in a location without existing copper or fiber-optic infrastructure. Low in cost and easily installed, network operators don't have to rely on third-party vendors to deploy expensive cables.

Highly directional antennas such as parabolic dishes facilitate point-to-point radio links. Lower frequencies (≤ 11 GHz) can propagate over long distances with larger long-haul antennas, enabling connections to the core network from remote locations. Higher frequencies above 11 GHz propagate over lesser distances via smaller short-haul antennas, providing connectivity better suited to urban environments where fiber-optic "point of presence" is closer and more accessible.

In all cases, a microwave transmission's highly-focused line of sight (LOS) beam path allows the reuse of the same frequencies systemwide without concern that adjacent links will interfere with each other.



Figure 2.5: *Example of a traditional parabolic microwave antenna*

AGGREGATING THE SIGNAL

The wireless network's traffic is extracted from the mobile telephone frequency band carrier and coded, aggregated and compressed into a relatively small radio channel. This is aided by a technique called modulation.

The radio channel is up-converted to the correct microwave frequency and transmitted across a link to a receiver station, which then down-converts and demodulates the signal to extract its aggregated information so it can be sent along to its final destination.

A channel's capacity is directly proportional to the width of the channel and the type of signal modulation scheme used. Microwave backhaul generally uses a frequency-division duplex (FDD) system, whereby each hop is allocated a frequency channel pair known as a go/return pair. This facilitates simultaneous transmission in both directions across the link (See Figure 2.6). Today, FDD is the dominant mode of operation.

Modulation

The practice of encoding large amounts of data onto a carrier signal to allow transmission.

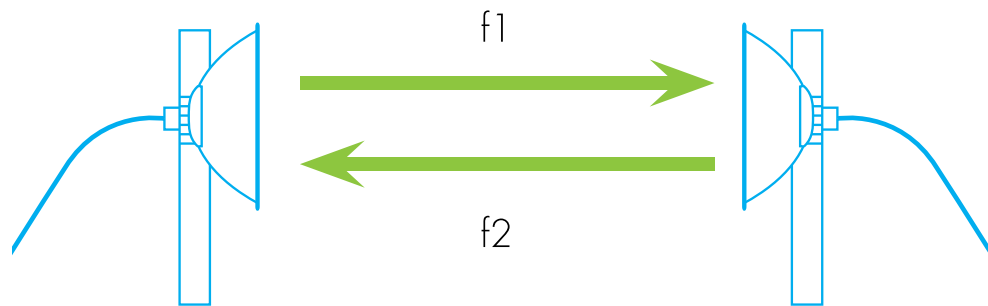


Figure 2.6: Frequency-division duplex (FDD) system using separate go/return frequencies ($f1$ and $f2$)

Time-division duplex (TDD) is another way of achieving two-way communication, whereby only one channel achieves two-way communication by synchronized selection of which direction the transmission is moving at any given moment (See Figure 2.7). Although this is a more efficient mode of operation in regard to spectrum use, careful timing control is required—limiting its application in microwave backhaul.

Of course, because all microwave links require clear LOS, antennas must be installed high up. For the longest links, even the curvature of the Earth's surface presents a design challenge in maintaining clear LOS.

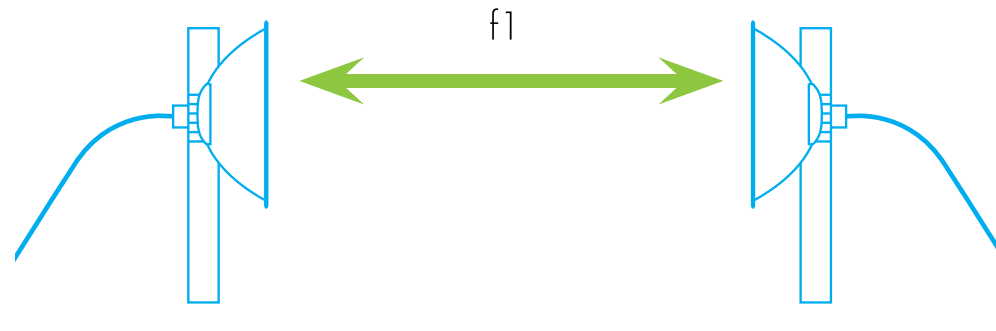


Figure 2.7: Time-division duplex (TDD) system using one go/return frequency in synchronicity

ALL ABOUT ANTENNAS

In technical terms, an antenna is a transducer between guided and unguided media. That means it transforms electromagnetic energy between free space and a guide medium such as a cable or waveguide. Antennas can radiate and receive electromagnetic energy.

An antenna's performance can be measured many different ways, with varying degrees of relevance to any particular application. These are the most important parameters:

- **Frequency of operation**

Refers to the operating frequency band—all antenna specifications are guaranteed within the frequency of operations. These frequency bands and channel arrangements are defined by ITU-R recommendations and/or ECC (or CEPT/ERC).

- **Radiation pattern**

Radiation pattern determines an antenna's ability to discriminate against unwanted signals under conditions of radio congestion from +180 degrees to -180 degrees of its axis. Radiation patterns are dependent on antenna series, size and frequency. This includes co-polar and cross-polar radiation patterns.

- **Half-power beamwidth**

It is the nominal total width of the main beam at the -3 dB points, expressing the focus of the strongest part of the beam.

- **Gain**

A measurement combining an antenna's directivity and electrical efficiency. Gain is primarily a function of antenna size. The gain of CommScope MW antennas is determined by gain by comparison. It is stated in dBi (decibels over an isotropic radiator) at three frequencies: bottom, middle and top of band.

- **Return loss or voltage standing wave ratio (VSWR)**

The VSWR maximum is the guaranteed peak VSWR within the operating band. It determines how effectively the power transfer between radio and antenna will be within the operating band.

ALL ABOUT ANTENNAS CONTINUED

- **Polarization**

The orientation of electric field driving the signal—either vertical or horizontal. Most CommScope antennas are available in both single- and dual-polarized versions. All can be used horizontally or vertically polarized, and most have polarization adjustment capabilities.

- **Cross-polar discrimination (XPD)**

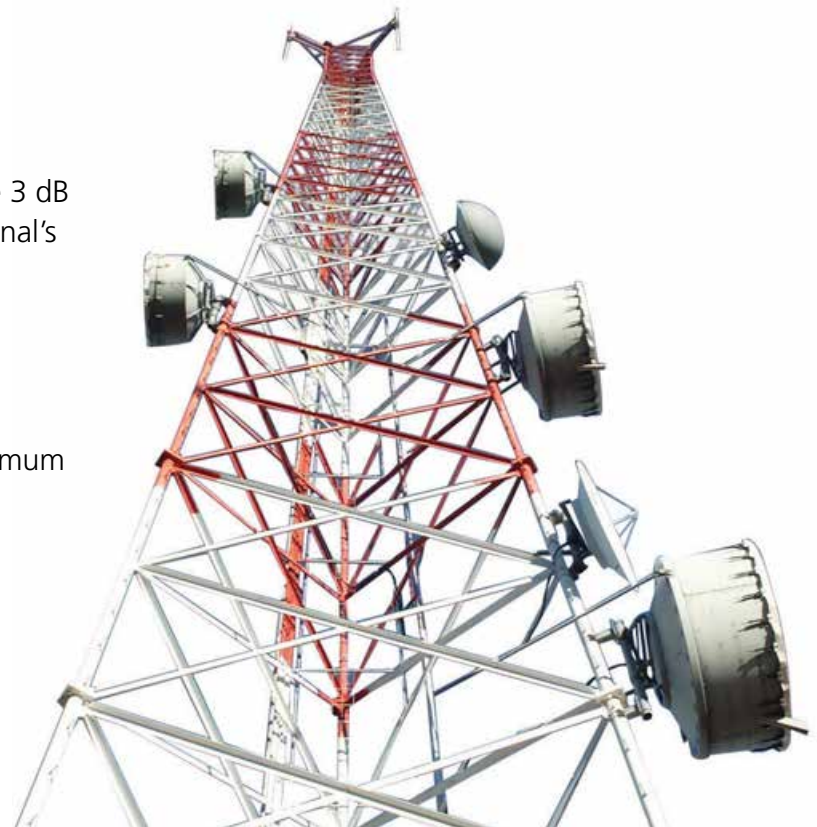
Expressed in dB, XPD is the difference between the peak of the co-polarized main beam and the maximum cross-polarized signal over an angle twice the 3 dB beamwidth of the co-polarized main beam—signifying how much of the signal's energy is transmitted in the correct polarization.

- **Inter-port isolation (IPI)**

The isolation, or electromagnetic separation, between input ports of a dual-polarized antennas. The IPI of a CommScope antenna is typically 35 dB minimum unless otherwise specified.

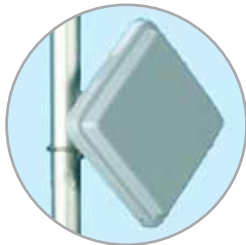
- **Front to back ratio (F/B)**

Expressed in dB, this ratio denotes how much radiation is emitted behind the main beam, at 180 degrees \pm 40 degrees, across the band.



MICROWAVE ANTENNAS

Aperture antennas are used mostly at microwave frequencies. The defining feature of this design is a large physical area, or aperture. Reflector antennas are used mostly at microwave and millimeter wave (MMV) frequencies; however, other antennas typically used at MW and MMW frequencies include:



Array antenna



Horn antenna



Lens antenna

The radiation characteristics of an aperture antenna depend upon the energy distribution over the aperture.

There are two ways to measure this:

Amplitude distribution

- **Uniform distribution:** More efficiency but higher side lobes
- **Tapered distribution:** Less efficiency but wider and lower side lobes

Phase distribution

- **Planar distribution:** Focused at infinity, like a camera
- **Spherical distribution:** Focused at a finite point
- **Other distribution:** Create symmetry in radiation characteristics

MICROWAVE FREQUENCIES AND REGULATIONS

The frequency bands available for microwave backhaul are defined by the International Telecommunications Union (ITU-R Radio Regulations 2008) with a global region dependency. Table 2.2 summarizes the global bands (subject to regional variations), together with typical maximum link lengths.

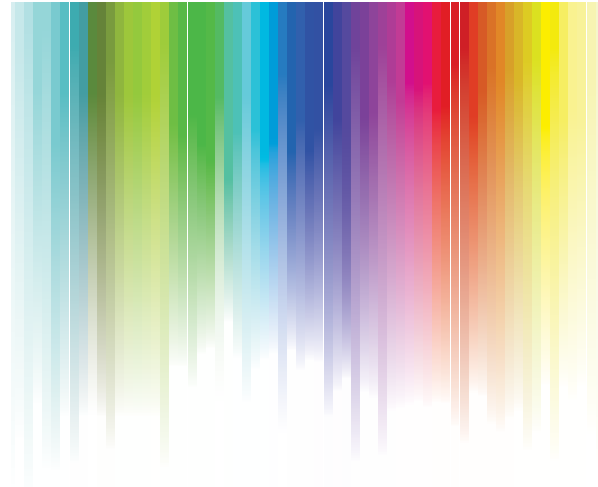
Frequency band	Frequencies, GHz	Typical maximum link length, km	Typical minimum link length, km
0.9 (unlicensed)	0.902–0.928	100	-
2.4 (unlicensed)	2.4–2.5	100	-
4	3.6–4.2	70	24
5	4.4–5.0	60	16
5 (unlicensed)	5.3, 5.4 and 5.8	50	-
L6	5.925–6.425	50	16
U6	6.425–7.125	50	16
L7	7.1–7.75	50	10
U8	7.75–8.5	50	10
10	10–10.7	20	10
11	10.7–11.7	20	10
13	12.7–13.25	20	6
15	14.4–15.35	20	6
18	17.7–19.7	20	2
23	21.2–23.6	20	2
26	24.25–26.5	20	2
28	27.5–29.5	15	2
32	31.0–33.4	10	1.5
38	37.0–40.0	10	1
42	40.5–43.5	10	1
60 (unlicensed)	57.0–66.0	1	-
80	71–76/81–86	5	-

Table 2.2: Typical hop length for different frequency bands, defined by ITU-R Radio Regulations

In addition to these regulations, a link's design is also determined by availability targets, local geography, climate, and cost of deployment—including tower leasing and channel bandwidth. It will also depend on the local frequency coordinator, who will have a responsibility to maximize spectrum efficiency while preventing interference between adjacent link paths. Indeed, minimum link lengths are often specified by regulators precisely to ensure that the most appropriate frequency band is selected.

You will note that Table 2.4 also references “unlicensed” frequency bands. While most microwave bands are subject to local licensing regimes in order to promote frequency coordination, unlicensed bands have no such requirements—and responsibility for controlling interference is left to the link provider. In unlicensed bands, “spread spectrum” is one way to encode data and avoid interference.

Lastly, the 60 GHz and 80 GHz bands—the previously mentioned MMW bands—are also included in Table 2.2. These possess unique propagation characteristics and will be discussed in Chapter 11.



Microwave backhaul systems require availability reliability between 99.99 percent and 99.999 percent of the time.

Unlicensed microwave bands

Frequencies not subject to regulatory oversight and hence more susceptible to interference problems. cellular voice and data to and from the main network.

MICROWAVE PROPAGATION THROUGH ATMOSPHERE

By its nature, microwave transmission is exposed to environmental and weather variables. Depending on its location, an antenna may be subjected to rain, hail, snow, fog, temperature extremes and dangerously high winds—not to mention exposure to lightning strikes.

Poor environmental conditions can disrupt microwave links, as signal reflection or refraction can greatly reduce the power levels of received signals. This is true particularly of higher-frequency transmissions, which are more susceptible to weather effects. In addition, adjacent-link interference can be a problem if there is not sufficient LOS clearance.

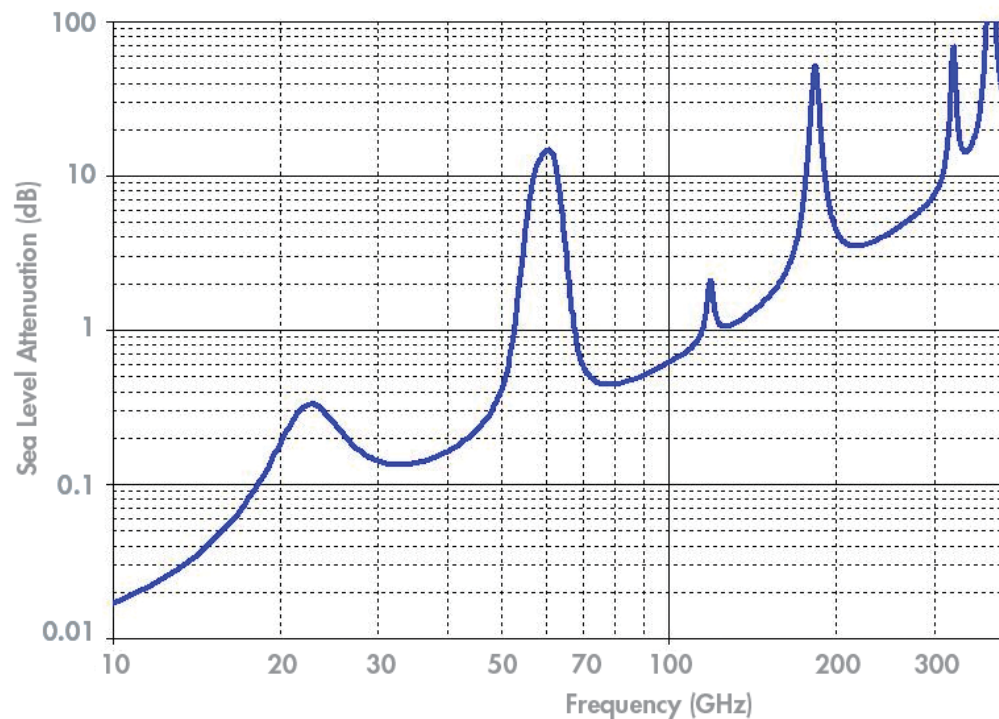
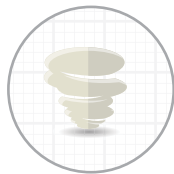
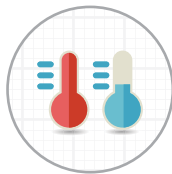
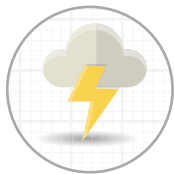


Figure 2.9 Atmospheric attenuation relative to frequency



MAKING A LONG HOP WITH A LOW FREQUENCY

The lower-frequency microwave bands offer the greatest possible distance—theoretically allowing for links in excess of 50 km (31 miles). The actual, practical link length is determined by the traffic fidelity that can be achieved, even in the worst of weather conditions.

For example, consider something as simple and frequent as rainfall. Even a little rain adds losses to the signal path, creating an effect known as “fade”—reduced signal strength across the link’s channel.

The exact amount of fade can be computed using established “rain outage models” that accurately predict how much attenuation, or signal loss, can be expected for a certain rate of rainfall.

With this information in hand, the link designers can then anticipate these losses and build in a performance safety margin that guarantees the link will operate within specification even in rainy weather. This margin usually takes the shape of additional power budget, allowing the signal to maintain fidelity over the link—a system known as adaptive transmit power control (ATPC). ATPC dynamically adjusts power levels to compensate for any link impediments.



Fade

Loss in signal strength across a link caused by atmospheric disturbances like rain or snow that can scatter microwave signals.

HIGHER FREQUENCIES, HIGHER ATTENUATION

For frequencies above 11 GHz, rain and other weather phenomena are an even bigger problem. For these bands, increasing signal power is not enough by itself, and changes in the link's length may be required. Scattering of the signal caused by rain or (to a lesser extent) snow can be counteracted by using ATPC and limiting the link's length, but another method is the use of signal polarization, the orientation of the signal's wave relative to the ground.

Polarization can be either vertical or horizontal; horizontally polarized signals are more susceptible to rain due to the shape of the falling raindrops—making vertical polarization the better choice for link planning. However, raindrops can also cause polarization rotation as they fall, skewing a signal's polarization out of alignment and potentially causing interference with other polarized signals in the channel. This problem can be mitigated with cross-polar interference cancellers (XPICs), which sample signals in both polarizations to create a canceling routine for any interference.

Adaptive modulation also helps counteract atmospheric attenuation. As mentioned earlier, modulation compresses the data stream over the link. Adaptive modulation, as its name suggests, allows the signal to become more or less modulated to adapt to changing conditions—reducing modulation to improve fidelity in poor conditions, and increasing it to maximize capacity in clear conditions.

A more strategic solution is to employ a multi-hop topology—or arrangements of links in the network. Mesh and ring topologies provide alternative paths that help maintain optimal connectivity; a storm affecting one link can be bypassed by routing through another (Figure 2.10).

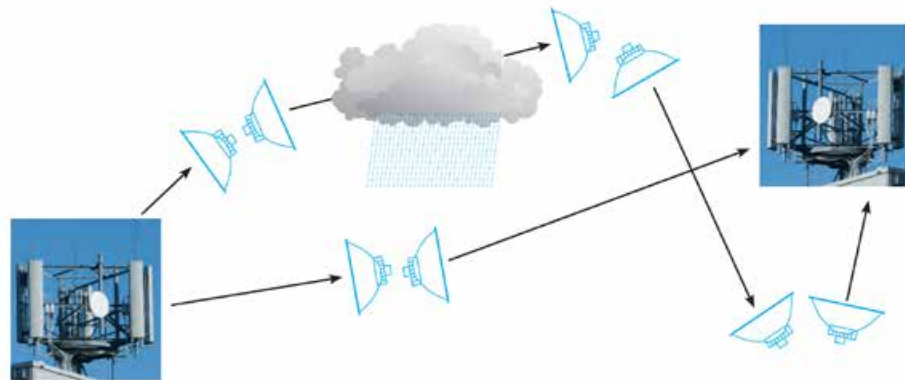


Figure 2.10: Typical network topology providing redundant paths that mitigate localized impediments

OTHER ATMOSPHERIC CHALLENGES

Fog generally causes negligible loss in microwave links, but the attenuation does become more pronounced as we proceed into higher frequencies. In the millimeter bands above 60 GHz, fog does start to become a factor worth consideration.

Likewise, air temperature has little impact on microwave links. However, it does introduce an indirect threat in the form of condensation if any water vapor is present in transmission lines. Sudden temperature drops can cause liquid water to form in waveguides, introducing the same effects as rain in a link. To counteract this possibility, waveguides are often pressurized with dry air or nitrogen to keep moisture out.



THE HARDWARE FACTOR

The climate takes a toll on signal strength and fidelity, but it also takes a toll on the physical microwave infrastructure and its mechanical integrity. Snow and ice can easily build up on exposed antenna structures, increasing the weight on the mounts. Therefore, the total weight of antennas and equipment must also account for likely accumulations of snow and ice.

Antennas can be fitted with protective covers, or radomes, that prevent the buildup of snow and ice in front of the antenna while also reducing its wind load. Radomes are particularly useful for large, long-haul microwave antennas that are already heavy and prone to high wind loads. Ice shields can also be applied, preventing antenna damage from ice falling from above.



Radome

A protective plastic or fabric cover fitted to the front of a microwave antenna. Some feature hydrophobic designs that repel water, snow and ice, and can reduce the antenna's wind load.

MICROWAVE BASICS AND ALL ABOUT ANTENNAS

Decades after the first microwave communications across the English Channel, hundreds of channels of focused microwave beams now carry words, videos, music and more.

There seems to be no end in sight to wireless demand, so microwave backhaul is under constant pressure to expand capacity, improve reliability, and drive down capital and operating costs—and keep our world more connected than ever.

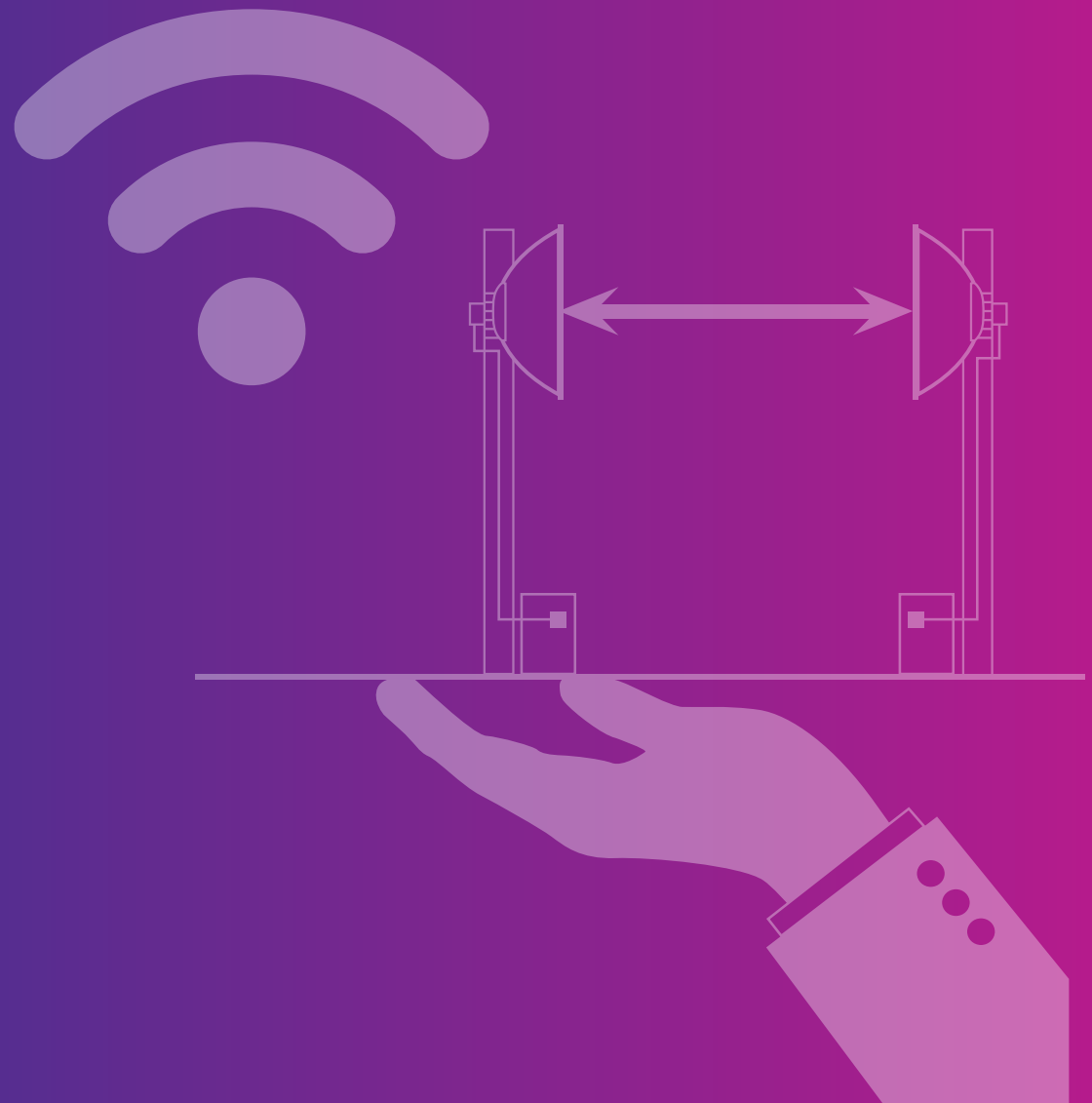


Chapter 2 summary

- Return on Investment (ROI) is realized in a balance between cost and performance
- Smart antenna decisions take a deep understanding of the link's needs
- A wide choice of antennas exists to suit specific applications, needs and conditions
- Up to 70 percent of antenna Total Cost of Ownership (TCO) comes after the initial investment
- Class 4 antennas represent a major advance in capacity and efficiency over Class 3 antennas—potentially, greatly reducing TCO, See Chapter 4 for detailed explanations of Class 3 and Class 4 antennas

CHAPTER

3

Microwave communication
and path design

Attenuation

The gradual loss of intensity in propagating waves due to disruption or loss in its medium.

MAPPING THE CONNECTIONS

As we explored in Chapter 2, microwave communications are accomplished by LOS links between two microwave antennas—generally operating within the 1 GHz to 100 GHz range of the EM spectrum.

The length of these links can vary greatly depending on the size of the antennas, their heights and the frequency they use; in practice, links tend to range between 1 km (about 0.6 miles) and 100 km (about 60 miles) in length.

Because any obstacle in the link's path can attenuate or completely block the signal, the length of a link is also determined by the presence of any such obstacles, such as buildings, trees, mountains or other tall objects.

However, the narrowly focused energy beam in LOS links used in microwave communications also has an upside: the ability to reuse the same frequency more often through the system—if the path design and network layout play to this strength. This chapter will explore various aspects of microwave path and network design and how a strategic approach to the selection of components, frequency planning and licensing can help deliver an efficient, reliable and cost-effective microwave backhaul network.

THE FUNDAMENTAL COMPONENTS

The basic building blocks of a microwave communication system are shown in Figure 3.1. They include a microwave radio transmitter connected to a directional antenna via a transmission line. The directional antenna's outbound signal is aligned to a distant receiving antenna, which is connected to a radio receiver. We discuss the fine points of antenna alignment in Chapter 10.

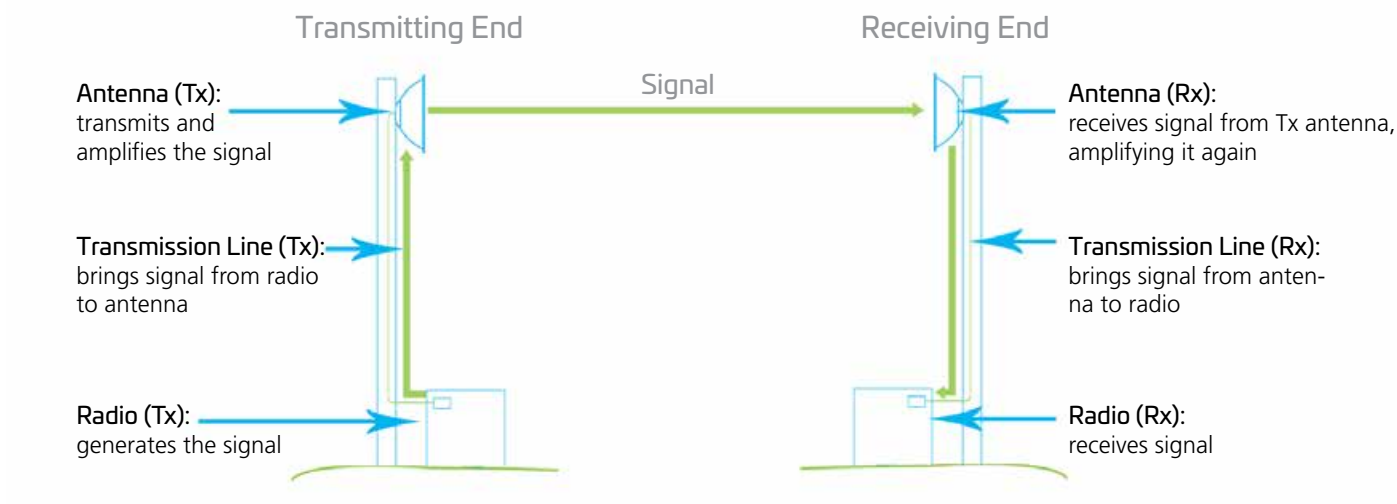


Figure 3.1: The basic components that allow LOS microwave communications

Let’s look more closely at the three building blocks of this link: the radios, the transmission lines and the antennas.

The radio

Each end of the link has its own radio unit, typically with both transmission (TX) and receiving (RX) capabilities. A typical microwave radio uses about 1 watt of power or less (30 dBm). A radio’s throughput usually ranges between 100 and 300 Mbps within a 50 MHz bandwidth, depending on the kind of modulation used. Throughput can be increased either by adding more data channels used or by increasing the modulation scheme employed. Modulation schemes can range from low-order QPSK to higher-order 2048 QAM or more. However, increased modulation reduces overall system gain, which has the practical effect of increasing susceptibility to interference and lowering overall reliability of the link in less-than-ideal conditions. Adaptive modulation is gaining popularity as a means to find the best balance between reliability and throughput in

variable conditions, since it can dynamically adjust modulation in response to changing weather or other limiting factors. You can learn more about adaptive modulation in Chapter 7.

There are three basic radio configurations used in microwave communications systems:

ALL INDOOR

All active components are located inside a building or shelter, allowing easy maintenance and upgrades—without requiring tower climbs, for instance. Being farther from the antenna may introduce higher transmission line losses than other configurations, however.

ALL OUTDOOR

All electronics are mounted outside, eliminating the need and cost for indoor space. However, because they are located on the tower, they can be difficult to access for maintenance or upgrades, requiring tower climbs. In some cases, rooftop access mitigates this challenge.

SPLIT-MOUNT

Electronics are split into an outdoor unit (ODU) and indoor unit (IDU), eliminating transmission line losses with easy maintenance of the IDU. However, it also combines the disadvantages of the other two configurations by requiring indoor storage and tower climbs for the ODU.

Transmission lines

These are the physical media connecting the radio and directional antenna, and may be coaxial cable or waveguide as explored in Chapter 2. Because of the amount of signal loss they can introduce, the choice of transmission line type is determined largely by the frequencies in use.

COAXIAL CABLE

is suitable in applications using frequencies up to—or just above—2 GHz. Above this range, most lengths become too lossy to be of practical use.

WAVEGUIDE

is suitable for higher frequencies. Elliptical waveguide features an elliptical cross section and can support frequencies up to around 40 GHz, however it is rarely used in applications above 13 GHz.

Frequently, a split-mount radio with an ODU is mounted directly to the antenna with a special interface plate eliminating the need for transmission line all together.



Example of coaxial cable



Example of waveguide cable

The antenna

A microwave system's directional antenna is typically parabolic in shape, as this permits the greatest focus of energy possible in a single beam. They are usually polarized, vertical or horizontal, based on the location of their feed connection.

The size of the antenna's dish is a key part of its design, function and role within the network. Bigger antenna dishes yield greater power, but they are more difficult to install and introduce limitations regarding tower space, tower loading, leasing costs and local zoning regulations.

Even though parabolic microwave antennas are highly directional, some of the signal energy is still lost to either side and behind the antenna. Higher-quality antennas reduce this lost energy and mitigate interference, making them a worthwhile investment in spite of the incremental cost.

To learn more about selecting the right antenna, see Chapter 7.



Better quality, better ROI

Purchase price represents only 30 percent of an antenna's TCO over its lifetime.

For instance, CommScope's Ultra High Performance series or ETSI Class 4-compliant Sentinel® antennas allow for greater frequency reuse in a given area, reducing spectrum costs and improving ROI.

PROPAGATION AND PATH LOSS

As the signal propagates, even a tightly directional LOS link's beam experiences losses in transmission—known as path loss. This is due to several factors, including:

- **Free space path loss (FSPL).** This is the effect of a signal spreading out as it propagates from the transmitting antenna. This is typically the greatest portion of path loss, accounting for 130 dB or more of losses. Its effects are directly proportional to the link's distance and the signal's frequency—as either increases, so does path loss.
- **Atmospheric absorption.** Both oxygen and water vapor in the air attenuate microwave signals—and the effect is more pronounced as the link length increases. It also depends on frequencies, with loss spikes at 22 GHz due to oxygen absorption and again at 63 GHz due to water vapor.

- **Diffraction.** Microwave rays follow multiple paths as they arrive at the same end point (see Figure 3.2). Rays with odd half-wavelengths travel longer than the direct ray and enhance the direct signal, while even half-wavelengths degrade the direct signal. When drawn, these odd—and even multi-half wavelength—signals form ellipsoids around the direct ray. When the received ray is exactly one half wavelength longer, the elliptical path it travels is called the first Fresnel Zone (F1). Designing the path such that the clearance is 0.6 F1 minimizes the diffraction loss.

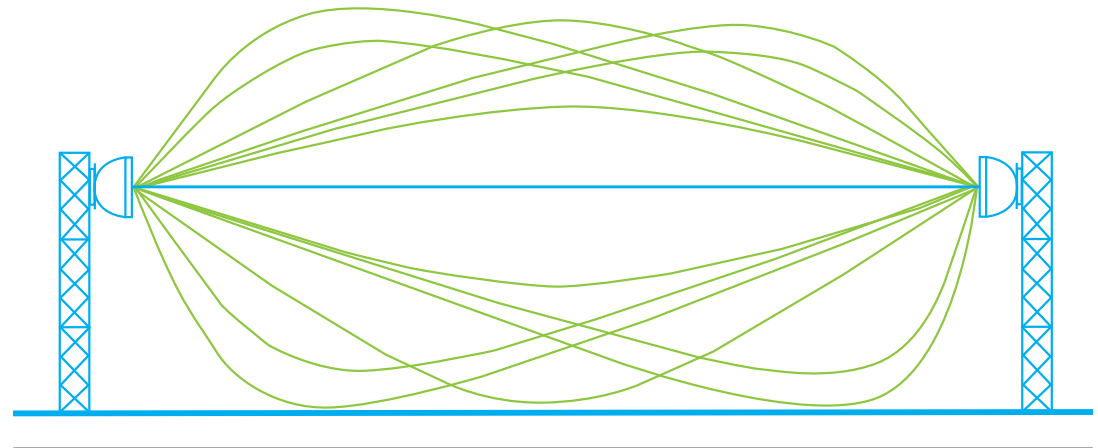


Figure 3.2: Diffraction. Odd and even multi-half wavelength signals form ellipsoids around the direct ray

PATH RELIABILITY

Taking all the path loss factors into account allows one to quantify path reliability—also known as path availability. Simply put, a path fails to perform when data transmitted from one end is not successfully received at the other. This can be caused by poor propagation conditions (such as those given above), by reflective or refractive multipath fading, or rain attenuation.

Path availability is a measurement of the path's ability to reliably transmit data over the course of a year, expressed as a percentage of time it is available. As we will learn in Chapter 7, the carrier-grade availability is typically “five nines”—that is, 99.999 percent availability.

Path performance can typically be improved by increasing overall system gain by increasing power, reducing losses in transmission lines, or increasing the size of the antenna itself.



Reflective and refractive multipath fading

The result of part of a signal being reflected or refracted in the atmosphere, causing it to travel a different path from the direct ray and arrive at the receiving point slightly after the direct ray does.

Demanding digital standards

In modern digital system, path reliability is measured in terms of bit error rate (BER).

The typical wireless carrier defines unacceptable performance at one error per million bits transmitted or 1×10^{-6} bit error rate.

PATH RELIABILITY CONTINUED

Other factors that adversely affect path reliability are longer link lengths, areas of flat terrain, hot climates and frequent rainfalls. Rain has a particularly detrimental effect on higher-frequency links.

This brings us back to the issue of frequency and the role it plays in link performance and reliability. As in most areas of technology, there are tradeoffs to consider with each option. Higher frequency bands offer greater capacity but reduced reliability.

Frequencies above 10 GHz can be attenuated by rain—particularly heavy rain—because the size of a typical raindrop more closely approximates the size of the signal's wavelength, creating a formidable attenuating obstacle.



ASSESSING AVAILABILITY REQUIREMENTS

Regardless of the availability model used, the first factor to consider in path design is the reliability a link must provide for a particular need.

While five nines is the standard for most wireless operators, some applications demand even greater availability: six nines, or 99.9999 percent availability—allowing for a mere 30 seconds of downtime per year. These criteria are common for public safety or utility applications.

On the other hand, more forgiving applications such as email or web page downloads may only require 99.995 percent availability, with the leeway of accepting up to 53 minutes of downtime per year.

99.999%



99.999% availability ("5 nines" in carrier jargon) amounts to just five minutes of downtime per year.

Building a better availability model

Years of measured data have informed the development and improvement of path reliability prediction models.

In the United States, the prevailing model is called Vigants or Barnett-Vigants.

Other parts of the world generally use the model developed by the International Telecommunications Union (ITU), referred to as ITU-R P.530.

DESIGNING THE LINK

At a high level, a microwave link design can be broken into several elements listed below. The process is somewhat iterative—especially the nominal design phase—and may involve the evaluation of several different connectivity options.

1. Nominal (preliminary) design. This step involves setting design guidelines and getting preliminary site candidate information to start. Maximum antenna heights for each site should be noted, as this will be a controlling factor for connectivity.

The next task is to lay out the network routing and determine the capacity requirements for the link. Once an initial routing is determined, the designer must select the most suitable frequency band based on path length and the design guidelines. Then—using a link design tool in conjunction with high-resolution terrain, morphology and possibly even building data—the designer can confirm clear LOS along the path.

In this process, options will begin to eliminate themselves and alternatives must be constructed. Some sites will prove impractical, some bands will prove unavailable, and some paths will prove too congested or obstructed to use. Eventually, the designer will arrive at the optimal solution for the given demands of the project.

Link design tools: iQ.link® XG

One of the tools available to link designers to model prospective link paths is iQ.link® XG from Comsearch®, a CommScope company.

It displays every detail of a proposed link and how it fits into the larger network, showing the effects of interference and other factors that may affect link availability.

DESIGNING THE LINK CONTINUED

2. Path survey. Once the link has been modeled in software, it's time to perform a physical verification of the proposed link path. This means visiting the site and confirming the link's endpoint coordinates, ground elevation and site parameters such as accessibility and the availability of electrical power.

At this stage, the site is photographed in detail to identify potential antenna space and to document the candidate structure. The designer creates an initial path profile and then verifies critical points along the proposed link path to confirm the dimensions of any obstacles so the antenna's proposed height is confirmed to offer clear LOS.



Photo credit: Robert Agua, Telikom

*Too much clearance?
It's possible.*

It may seem counterintuitive, but too much path clearance over obstacles is not necessarily a good thing.

If you recall from the diffraction discussion earlier, path clearance criteria is typically $0.6 F1$, so design engineers must be sure not to mount the antennas too high on the structure due to potential ground reflection issues.

DESIGNING THE LINK CONTINUED

3. Final design. Using data from both the nominal design and the path survey, all parameters are applied to the engineering that will bring the design to life. It is at this point that decisions regarding radio equipment, antenna size, mounting height, transmission lines and so forth are finalized. With these factors now included, the link design is checked again for reliability, clearance and capacity.

*Finding a place to fit in*

The interference analysis uses the technical parameters of a proposed link and compares them to what already exists in the operating environment. Some of these parameters include:

- Coordinates
- Ground elevations
- Antenna centerlines
- Radio transmit power
- Transmission losses
- Receive losses
- Antenna model and pattern information
- Radio model and filtering information
- Frequency(ies)
- Polarization

FREQUENCY PLANNING AND LICENSING

While the path design identifies the correct spectrum band to use for the link, frequency planning and licensing involve selecting the specific frequencies within that band—as well as antenna polarizations—and complete all regulatory licensing as needed.

This involves a detailed interference analysis that proves the link will not interfere with existing microwave paths. In the case of using unlicensed bands—or area-wide licensed bands—an intra-system interference analysis helps mitigate any interference from other links within one's own system.

You can learn more about unlicensed bands in Chapter 2.

The idea of frequency reuse is a simple one: microwave links may use the same frequencies so long as they do not interfere with each other. In practice, however, the density of these links requires a careful and thorough analysis of the microwave landscape, as you can see in Figure 3.3.

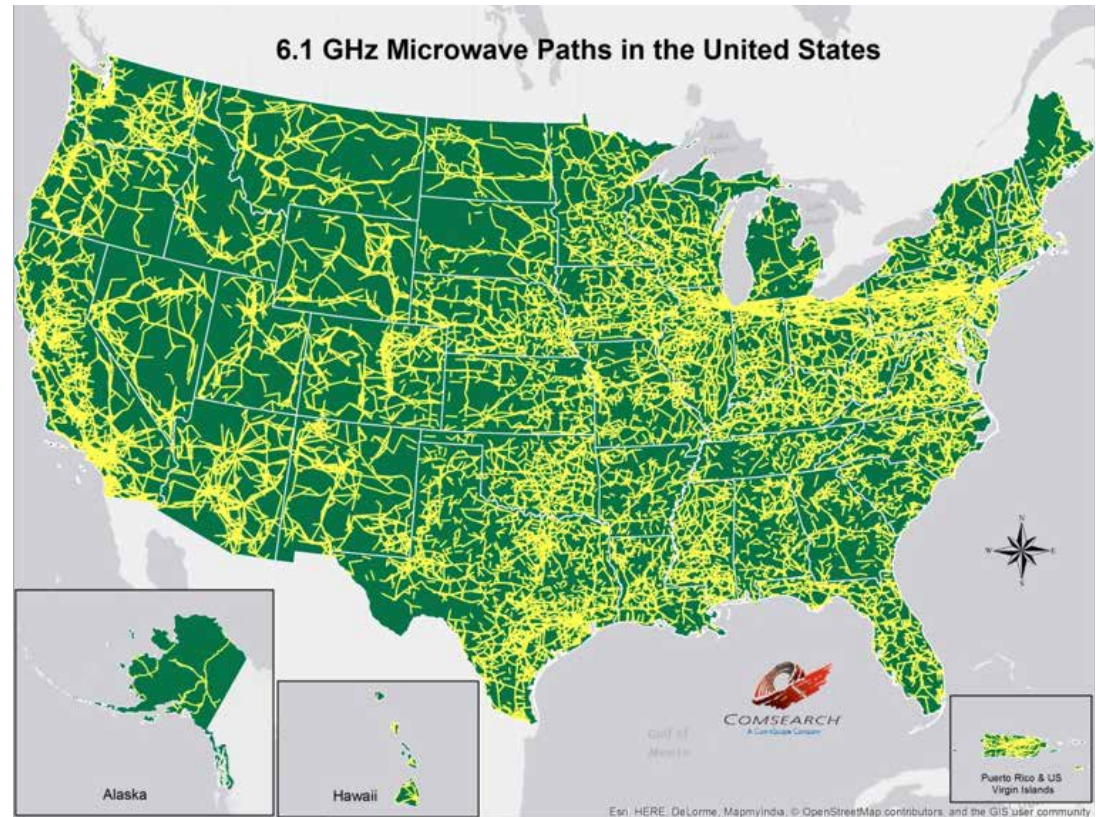


Figure 3.3: Microwave link paths in the United States. These all share the same 6.1 GHz frequency—primarily on just eight different channel pairs that are horizontally or vertically polarized.

PRIOR COORDINATION NOTICE (PCN)

In the United States and Canada, new links require notification of any incumbent entities with operating (or soon to be operating) paths within a 125 miles (200 km) radius if they use frequencies in the same band as the proposed link. This process typically allows them 30 days to review the plan and raise any concerns and have them addressed prior to the new link's deployment.

LICENSING

In the United States, microwave spectrum is licensed and leased by the FCC on a 10-year basis. In other countries, microwave spectrum may be auctioned or assigned to commercial or private enterprises.

Filing the paperwork— FAST

In the United States, frequency licensing requires electronic submission of the FCC's six-page Form 601. Some companies offer automated batch filing based off PCN data, such as Comsearch's ULS Express service.

iQ.link XG can also complete licensing paperwork for licensing in other countries.

MICROWAVE COMMUNICATION AND PATH DESIGN

When it comes to building an effective, efficient, reliable and cost-effective microwave network, the most advanced solutions and latest technology won't get you very far without solid planning and an informed strategy.

From the theoretical outline to personally visiting the path, link planning requires an insightful combination of skills to translate specifications on the page into performance in the field—and there's just no substitute for a good link planning tool to help keep all the loose ends together.



Chapter 3 summary

- Microwave links must be carefully planned to account for climate, terrain, frequency and capacity needs
- Path loss is the loss of signal strength across the link due to various factors
- Path reliability is a measure of uptime per year—generally 99.999 percent or even higher
- Four link planning steps: nominal design, path survey, final design, frequency planning and licensing
- A link planning tool like Comsearch's iQ.link® XG is vital to avoid pitfalls such as interference
- Coordination with other link owners is a necessity

CHAPTER

4

The importance of patterns and regulatory compliance



RADIATION PATTERN ENVELOPES

The way an antenna radiates signal energy in different directions is called its radiation pattern. The mask around the radiation pattern is called radiation pattern envelope (RPE).

These patterns take the shape of lobes—elongated areas of higher radiation—indicating what directions and distances a signal can most effectively propagate. RPE is a simpler way of showing radiation characteristics of the antenna.

A directional antenna like a microwave backhaul antenna will display an RPE featuring a main lobe, ideally aligned directly down the link's path; side lobes, smaller areas adjacent to the main lobe; and back lobes, describing signal energy lost to the rear of the antenna.

Antenna manufacturers publish RPE information for the products they sell because the precise characteristics of an antenna's radiation pattern are critical to the network planning process, particularly regarding matters of spectrum management and regulatory compliance.

Radiation pattern envelope (RPE)

The guaranteed electrical characteristics of the antenna. It is a line drawn over the peaks of the main lobe, side lobes and back lobes in horizontal and vertical polarization. It covers both co-and cross polarization performance.

Side lobes

Unwanted peaks in signal radiation off-axis to the main beam of the antenna. They are always lower than the main beam. Lower side lobes are indicative of better interference discrimination. Side lobes which breach the antenna RPE, i.e. a poorly performing antenna, provide an avenue for unwanted interference to enter the system.

WHAT GOES INTO A PUBLISHED RPE

A complete RPE comprises 12 measurements over the full, 360-degree azimuth, or horizontal plane, of the antenna under dry, still conditions. These measurements include horizontal and vertical polarizations for three frequencies representing the bottom, middle and top of the antenna's band.

The signals are also checked for parallel-polarized and cross-polarized responses. For more information on polarization and frequency bands, please refer to Chapter 2.

Turning these data points into a graphical representation of the RPE is accomplished by superimposing the left- and right-side patterns for all three test frequencies, then drawing an envelope of simple, straight lines to encompass each peak.

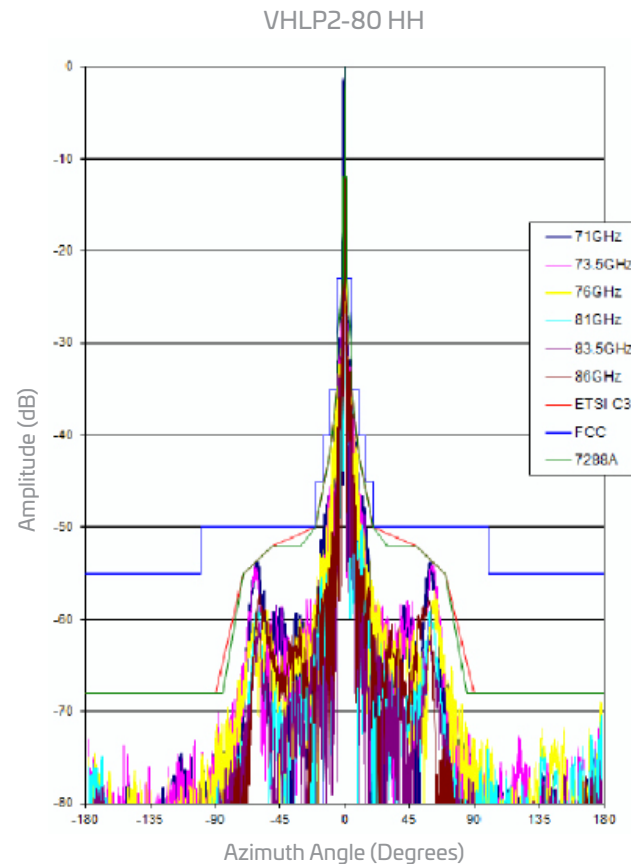


Figure 4.1 Typical antenna characterization showing test measurements against RPE and regulatory masks.

Co-Polarized

The orientation of a signal indicating it is within its intended polarization. Contrast with cross-polarized signals, which are transmitted outside their intended polarization.

WHAT GOES INTO A PUBLISHED RPE CONTINUED

Parallel-polarized and cross-polarized measurements are also included for both vertical and horizontal polarizations, yielding four curves describing performance. They are:

- HH—the response of a horizontally polarized port to a horizontally polarized signal
- HV—the response of a horizontally polarized port to a vertically polarized signal
- VV—the response of a vertically polarized port to a vertically polarized signal
- VH—the response of a vertically polarized port to a horizontally polarized signal

High-performance antennas feature asymmetrical patterns with lower side lobes on one or the other side of the main lobe. These antennas require full 360-degree RPEs because the superior side of their patterns can vary—being either on the left side or the right.

The boresight on such an antenna can be used to maximize interference discrimination during installation and alignment.

See Chapter 10 for more on the installation and alignment of microwave antennas.

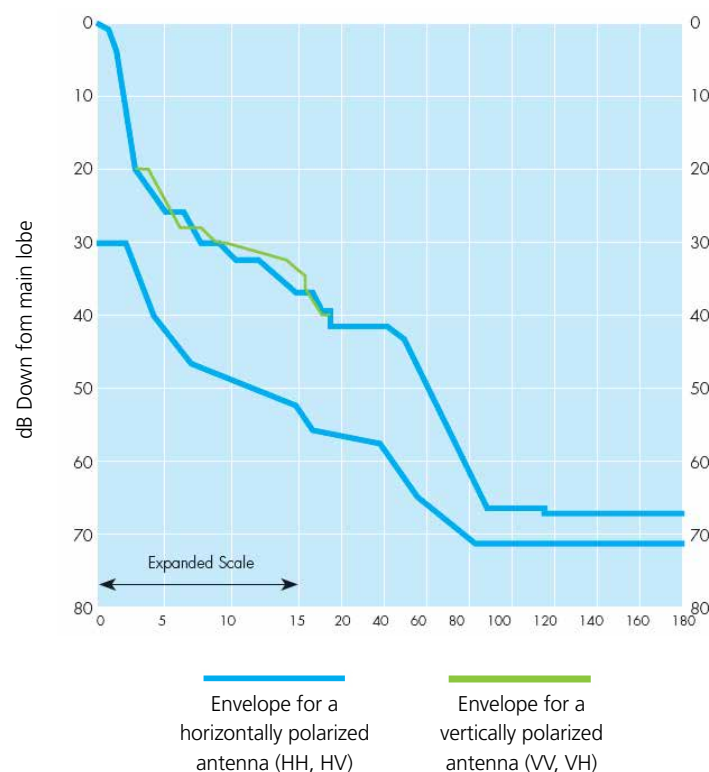


Figure 4.2 A typical radiation pattern envelope (RPE) document

Worst-case scenarios

In actual practice, an antenna should outperform its RPE value at any given angle and frequency. RPEs represent the “worst peaks” of radiation, making them a conservative measuring stick for actual performance.

CARRIER POWER, NOISE AND INTERFERENCE

For point-to-point communications to function reliably and efficiently, the energy directed from one antenna must arrive precisely at the receiving antenna. The amount of received energy is called the received signal level (RSL) or carrier power (C). Transmitted energy that is not received is called interference (I).

Shannon's Law describes the relationship between capacity and signal noise in this formula:

$$\text{Capacity} = B \times \text{Log}_2 (1 + C/N)$$

Where:

B = Channel bandwidth

C = Carrier power, or RSL

N = Signal noise

However, the contemporary reality of wireless communications has introduced a new variable—interference caused by operators adding more links to their networks. So, if we add the new variable (I) for interference and combine it with signal noise, we see that the equation now reads:

$$\text{Capacity} = B \times \text{Log}_2 (1 + C/(N + I))$$

This is why C/I ratios are so critical to link planning and design as a function of the business itself. Since a higher C/I ratio indicates an efficient and reliable link, the goal of the planner is to maximize its value—so that, in real-world operation, it yields greater capacity and, hence, greater revenue. Failure to deploy such a network not only reduces capacity, but also may result in higher levels of customer churn as subscribers experience poor service or reliability.

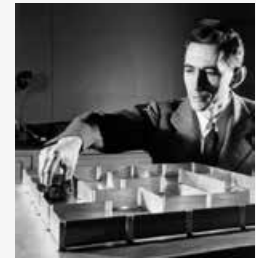


Photo credit: Bell Labs

Shannon's Law

American mathematician Claude Shannon (1946-2001) instructed that channel throughput is limited by its carrier-to-interference ratio (C/I); that is, controlling interference is the primary factor in evaluating data throughput.

THE COST/BENEFIT ANALYSIS

As in any business decision, capital expenditures are only one part of the financial decision. Considering the total cost of ownership (TCO) of a microwave system over its anticipated lifetime, the initial purchase represents less than a third of all costs associated with operating it.

One way to improve the broader cost picture is to explore the use of smaller but higher-quality and better-performing microwave antennas. While this may involve an incremental upfront cost, there are several operational advantages that can quickly erase the price differential and actually pay dividends over the longer term—cost centers such as more affordable shipping, easier installation, reduced power use and greater capacity.



Total cost of ownership (TCO)

In this instance, a holistic calculation of all costs involved in an antenna deployment, including purchase price, energy use, maintenance costs and time expenditure, among other factors.

IMPROVING THE C/I RATIO

To arrive at a better C/I ratio, it's intuitive that one must increase C or reduce I. There are several ways to accomplish each.

- **To increase C, one can:**

Boost transmission power. This is the most obvious way to increase carrier signal, but it comes with added energy costs and is limited by regulatory and interference constraints.

Increase gain with a bigger antenna. Bigger antennas mean more capacity, but they are expensive to ship, install and maintain—plus, tower space and loading allowances may not allow them at all in some places.

- **To decrease I, one can:**

Use a different frequency. This can help avoid specific interference problems, but spectrum is extremely limited and this is not always a viable option.

Use a different link path. Realigning an antenna to route signal around a problem is sometimes

possible, but overall cost factors prevent this from being a reliable large-scale solution.

Use an antenna with smaller side lobes. Since the RPE of an antenna determines its resistance to interference, the lower the side lobes, the less likely it is for interference to find its way into the signal.

From a TCO perspective, using an antenna with smaller side lobes is almost universally the best option when it comes to improving C/I ratio (Figure 4.3).

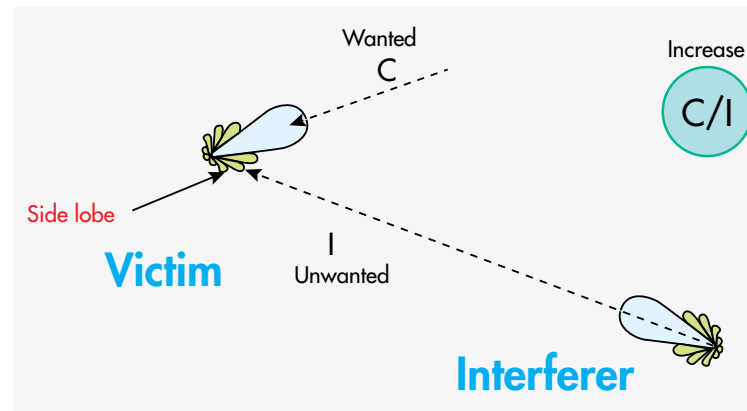


Figure 4.3: An illustration of lower side lobes improving interference discrimination in a link.

IMPROVING THE C/I RATIO CONTINUED

The lower side lobes of well-engineered antennas yield significant benefits with regard to capacity and corresponding advantages to the business side of the equation.

Low side lobes typically allow for:

- Efficient use of higher modulation schemes, increasing link capacity
- Smaller antenna sizes that reduce shipping, installation and tower lease costs
- Simplified coordination and planning
- Reduced site visits for maintenance
- Greater spectrum reuse, conserving expensive and limited spectrum resources



REGULATORY COMPLIANCE

Tighter control of an antenna's RPE means less likelihood of causing or receiving interference. Since the RF spectrum is regulated, there are specific classifications for antennas displaying different RPEs.

Bodies such as the European Telecommunications Standards Institute (ETSI) in the European Union and the Federal Communications Commission (FCC) in the United States publish standards that all antennas must meet in order to comply with regulatory requirements. For example, ETSI classifies four different microwave antenna standards, called Class 1, Class 2, Class 3 and Class 4, in order of ascending stringency of permissible RPE.

We will explore ETSI Class 3 and Class 4 distinctions in greater detail later on in Chapter 7.

In the United States, the FCC maintains its own RPE standards for directional antennas, called Category A and the less-stringent Category B. Other countries and regions have similar regulations.

In all cases, however, the conclusion is the same: higher-quality antennas with lower side lobes and tighter RPE characteristics yield better performance, better TCO, and better regulatory compliance.

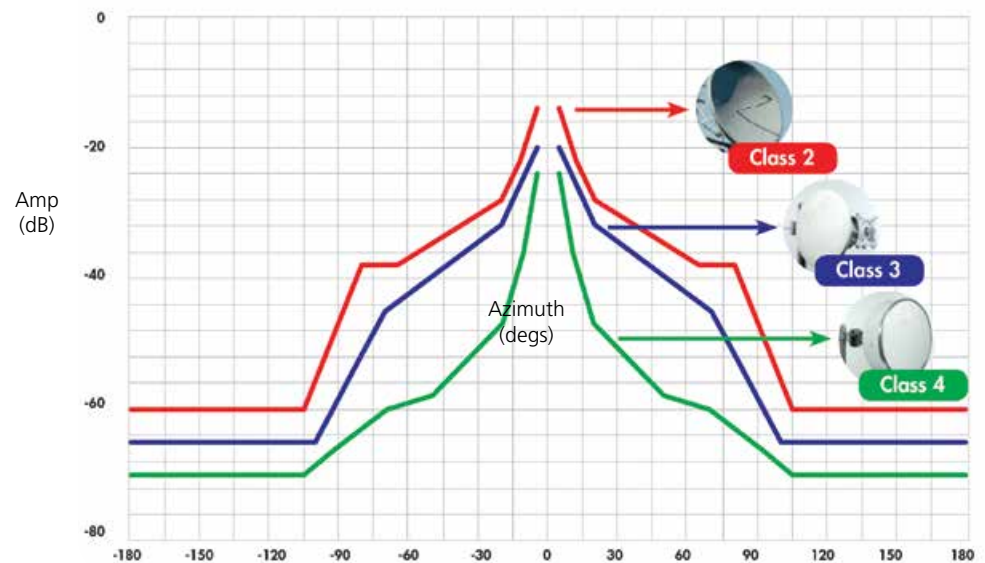


Figure 4.4: An overlay of three ETSI Class standards, showing the allowed side lobes of each. Class 1 is no longer used.

THE IMPORTANCE OF PATTERNS AND REGULATORY COMPLIANCE

The RPE of a microwave antenna is the key to understanding how it will operate in the real world under working conditions. The size of the RPE's side lobes can be an accurate predictor of how much of an issue interference will be—and what the corresponding capacity reduction will mean to the network and to the business itself.

A compliant, high-performance antenna with low side lobes offers significant advantages on both technological and financial levels. Because it reduces interference, it keeps network capacity optimized; and, because it also reduces TCO, it keeps an operator's balance sheet optimized.



Want to learn more about microwave antenna sidelobes? Watch the video.

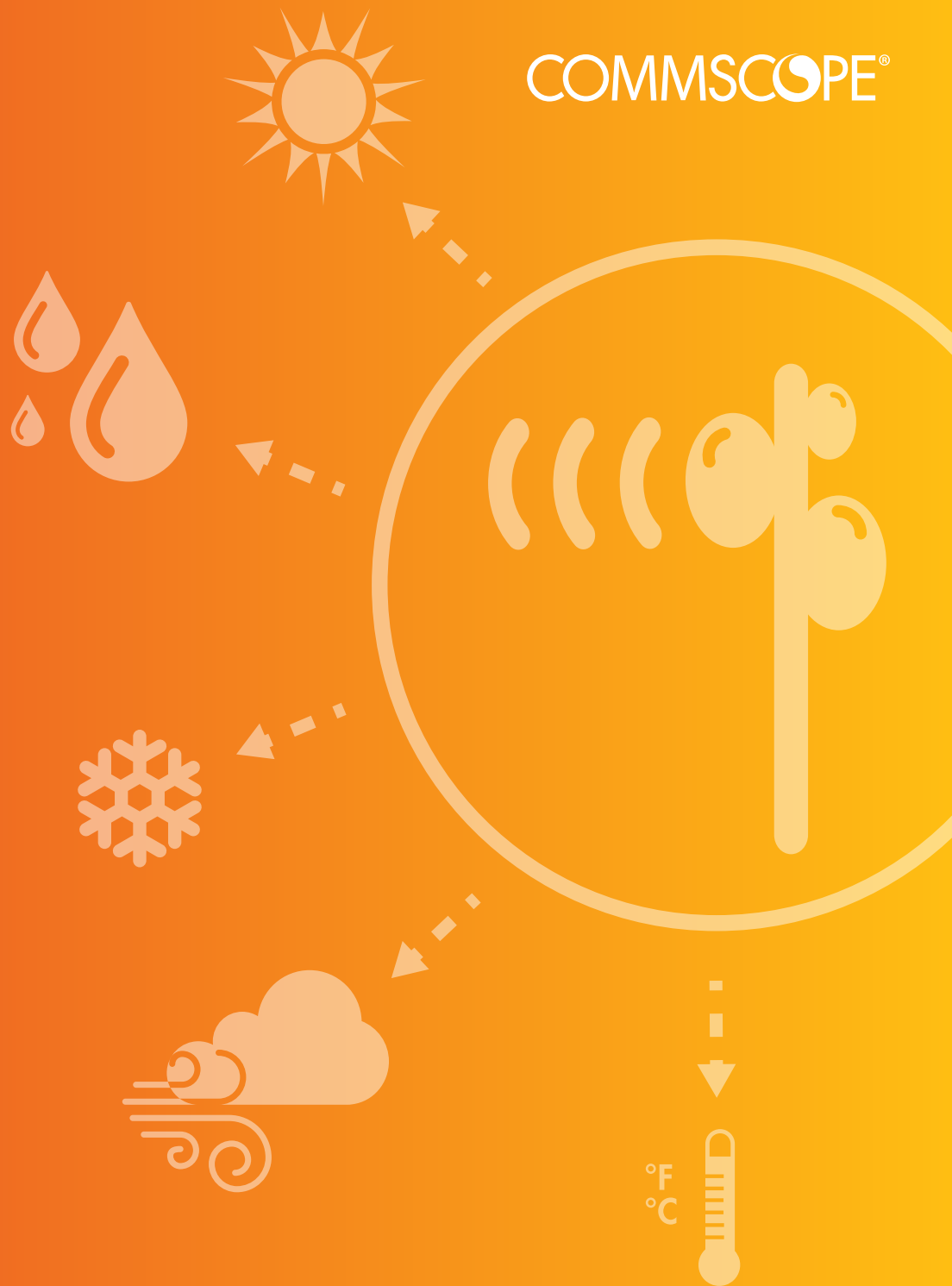
Chapter 4 summary

- A microwave antenna RPE is the envelope drawn over all the peaks of the measured radiation pattern to provide a guaranteed level of antenna performance
- Any energy exceeding the RPE can cause interference
- Shannon's Law dictates that capacity is limited by noise within the system
- Boosting capacity means increasing power or reducing interference
- Regulatory bodies specify different RPE requirements for different applications
- High-performance antennas yield significant capacity, reliability and TCO advantages

CHAPTER

5

Environmental considerations



TAKING ON NATURE

One of the biggest advantages of microwave point-to-point communications links is their high degree of reliability.

Operators expect near-flawless performance, up to 99.999 percent availability. But because these links are necessarily located outdoors—often in remote, difficult-to-access locations where other connectivity is too expensive or impossible to use—they are subject to enormous loads from the weather and the environment in general.

Even in more developed industrial areas, there exist unique environmental concerns that can affect antenna performance and reliability. In these areas, securing a microwave antenna site can mean long, detailed negotiation with land owners and regulatory authorities.

In this chapter, we will explore the key environmental factors that must be addressed in the design of microwave antennas if they are to fulfill their role as a reliable point-to-point means of communication.



WIND LOADS

It is tempting to assume that the gentle breezes one may feel at ground level are all that must be accommodated in antenna design, but the reality is more complicated.

Wind presents the single biggest and most constant stress on a microwave antenna installation. Because microwave antennas connect by LOS, they are generally located high above the ground in locations exposed to high winds. In addition, their size and position on towers make them particularly vulnerable to the effects of wind—which has structural implications not only for the antenna itself, but also the tower to which it is mounted.

When designing a structure to withstand the wind, it's critical to keep in mind that the antenna is not located at ground level. Winds blow much faster 50-100 meters (164-328 feet) up in the air (Figure 5.1).

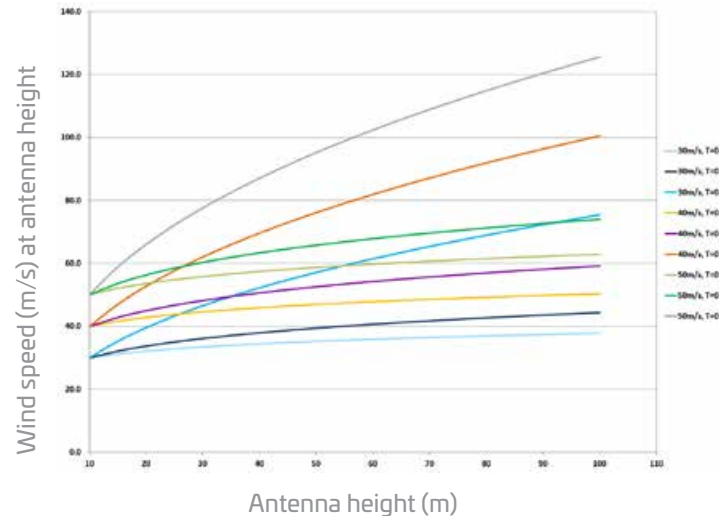


Figure 5.1: Height and terrain effects on windspeed. Wind speeds, and therefore windloads increase dramatically at greater heights.

Wind load

The amount of force experienced by an exposed structure due to winds common to its location. It is directly related to wind speed, which can be affected by the height and terrain of that location.

Calculating wind speeds at a given altitude

$$V_H = V_{10}(H/10)^T$$

H = Height of the antenna

V_{10} = Mean wind speed 10 m above ground level

T = Terrain factor (normally 0.17 but can vary between 0.1 and 0.4)

V_H = Mean wind speed at height H

VARIABLE WINDS

Note that these calculations deal with mean wind speeds—that is, normal, sustained winds. Of course, wind speed is never a constant. Gusts can briefly increase those winds up to 50 percent above their mean speeds. Topography and terrain play a significant role here. Mountain passes, cliff tops or even the spaces between tall buildings can create gust-prone environments that funnel high winds into specific locations. This means that a thorough understanding of the precise location where the site is to be built is required to determine the actual wind load of a site.

Since the microwave antennas represents only a small proportion of the capital cost of the entire system, it's an accepted practice to let a conservative estimate of the wind load requirements guide antenna selection. Any modest incremental cost for a higher-rated antenna is dwarfed by the potential costs involved in replacing an inadequate one.

CommScope, for instance, offers a full line of microwave antennas and mounts rated to withstand winds at most

conventional site locations, as well as a special line of antennas designed to survive even the most extreme of environments.

We will explore some of these extreme environments later in this chapter.



Anticipating wind loads at any given location requires a great deal of site-specific investigation from multiple sources, including:

- International climate bodies
- National meteorological agencies
- Local weather stations
- Experience of local residents in the community

WIND VIBRATION

Direct force is not the only threat winds pose to microwave antennas. There also exists the phenomenon of wind-induced vibration, which can be problematic even in light breezes.

Wind has a natural frequency of about 8 Hz. If an antenna or any equipment mounted to it has a similar natural frequency, then the wind can induce vibration—much like strumming a guitar string (Figure 5.2). Over time, this vibration can compromise the mechanical integrity of the installation through structural fatigue, shortening the operational life of the antenna.

Even light winds can have disastrous consequences

In 1940, the Tacoma Narrows bridge in Washington State collapsed four months after it was completed. Light winds blowing across it at a specific frequency caused the structure to resonate—twisting and buckling the bridge until the gyrations grew strong enough to tear it apart.



Figure 5.2: *The effect of wind-induced resonance on an ill-designed structure.*

CORROSION HAZARDS

In addition to wind, there are environmental chemical factors that can shorten the operational life of an exposed microwave antenna or its associated equipment. For instance, in coastal areas, airborne salt can cause corrosion. In developed urban areas, pollution from vehicle exhaust can have a similar effect. In industrial areas, there can be high concentrations of other corrosive chemicals vented by nearby factories, refineries or other sources. Often, more than one of these factors may be present (Figure 5.3).

To counter these effects, good microwave antenna design demands careful thought given to the materials—and the combinations of materials—used in their construction. An antenna should be expected to reach the end of its operational life without experiencing a failure of structural integrity, so—in corrosive environments like those described above—solutions should be considered that offer additional protection in the form of special coatings or different grades of materials.

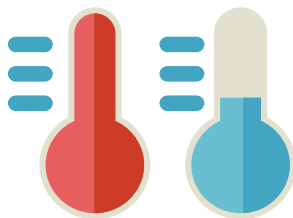


Figure 5.3: *Natural and man-made corrosion hazards.*

TEMPERATURE AND HUMIDITY

While temperature and humidity generally have very little effect on microwave operation, a challenge does exist in the installation of elliptical waveguide transmission line. To maintain efficient operation, the air inside the waveguide must be kept dry during installation and operation; otherwise, condensation can occur as temperatures drop. In addition, installing waveguide in extremely low temperatures makes it more likely that damage will occur to its outer jacket.

We discuss the installation and pressurization issues associated with elliptical waveguide in Chapters 8 and 9.



ICE BUILDUP AND RADOMES

As the temperature drops, the risk of ice buildup rises. Open and exposed, microwave antennas are prone to ice—particularly in areas where humidity levels are high. While antennas and their mounts are designed to bear the weight of this ice, a problem emerges when the ice obstructs the antenna’s LOS path.

Good practice in antenna selection can go a long way toward preventing problems. Radomes are one such measure. Flexible fabric radomes—used in larger high-performance antennas—are inherently self-shedding, meaning they deter water from sticking to their surface and attenuating the signal. Rigid planar radomes from reputable manufacturers are made of materials designed to avoid ice accretion on smaller antennas.

In exceptional circumstances, proprietary hydrophobic coatings can be applied to a radome in the field; however, great care must be taken in application to avoid degrading the electrical performance of the antenna.

Radome

A protective plastic or fabric cover fitted to the front of a microwave antenna.

LOOK OUT BELOW

Another threat posed by ice buildup is accumulation above the microwave antenna, as shown in Figure 5.4. In most cases, the microwave antenna shares its site with many other components and antennas. When these other components are mounted above the antenna, changing temperatures can cause ice buildup to fall and inflict significant damage on the microwave antenna—perhaps even destroying it altogether.

Ice shields are available to counteract this threat. While their inclusion in a design does add a modest cost, that cost is likely far less than would be the expense of an emergency antenna replacement and the cost of lost traffic while the site is compromised.



Figure 5.4: *Ice buildup can mean falling ice and damaged antennas.*

SOLAR RADIATION

Ultraviolet (UV) radiation from the sun damages more than sunbathers' backs. Over time, it also causes many plastics to become brittle and can even cause them to fail. Since microwave antennas are open and exposed to sunlight, any critical component made of non-UV-resistant plastic will experience this degradation. Reputable antenna manufacturers specify UV-resistant materials in their products and verify their performance through rigorous testing.



RAIN, HAIL AND SNOW

As explained in Chapter 2, the presence of water anywhere in the microwave path will attenuate, or weaken, the signal and reduce performance. This is true whether the water exists as condensation in the waveguide or as rain in the link path.

Since no location is fully immune to the effects of rain, good link design accounts for its effects. The radome also plays a role, as a good design will ensure that accumulated rain sheds quickly without being absorbed. This capability is a matter of the materials used in the radome's construction. Likewise, quality manufacturing and installation processes deliver a waveguide that sheds excess moisture that could also attenuate the signal (Figure 5.5).

While small hail pellets have no significant effect on microwave antennas, larger hailstones can cause damage. Ice shields offer some protection, but radomes should also be able to withstand any likely hail exposure.

Wet snow that falls at temperatures just above freezing can stick and accumulate on radomes and other structures, but a quality radome material and conscientious design practices can mitigate this possibility. Likewise, ice shields are a must for instances where the snow freezes into ice on the structure, creating the likelihood of falling ice.

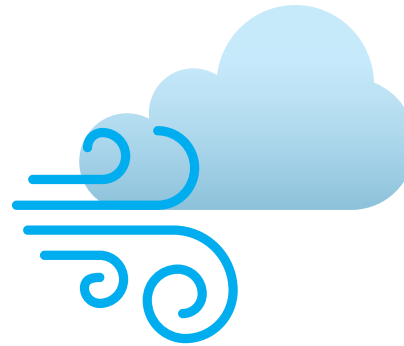


Figure 5.5: Waveguide must be kept dry internally to operate efficiently.

WIND LOAD AND ENVIRONMENT

It's a wild, unpredictable world out there. When something as sophisticated as a microwave antenna must operate flawlessly for years in the great outdoors, it takes a deep understanding of the specific location—and a good imagination for the worst-case scenarios.

Insightful design, reputable manufacturers and quality construction all go a long way toward ensuring that a microwave antenna continues to deliver up to 99.999 percent availability—because anything less just isn't acceptable.



Chapter 5 summary

- Wind load is determined by height, topography and climate
- Wind-induced vibration can be as great a threat as high-speed gusts
- Corrosion from sea air, pollution or industrial processes can shorten an antenna's operational life
- Radomes repel water, snow and ice to keep the link path clear
- Ice shields protect antennas from ice falling from other components
- Water anywhere in the microwave path will attenuate the signal

CHAPTER

6

Mechanical and
structural factors



BEARING THE LOADS

Now that we have explored the kind of environmental and weather-related loads microwave antennas and their structures must endure, let's examine how these forces affect the way a microwave link operates—and dig a bit deeper into how these loads can be mitigated.

OPERATIONAL WIND LOAD

Why would wind cause some of the signal to miss the target? Consider a ship crossing a great expanse of ocean. If it proceeds even a single degree off course, it will miss its destination port by a large margin. Likewise, in a microwave link, the targets are very small relative to the distance between them. Operational wind load is the amount of wind an antenna can experience without its beam going “off course” like the errant ship in our example.

The maximum value for allowed angular movement is normally calculated as $0.3 \times$ the “3 dB beamwidth of the antenna” (Figure 6.1). This means a low-frequency small antenna will have a higher angular movement allowance than a larger antenna, or one operating at a higher frequency.

Typically, the exact angular deflection at the operational wind load is not specified, but the wind speed at which the 0.3×3 dB beamwidth is.

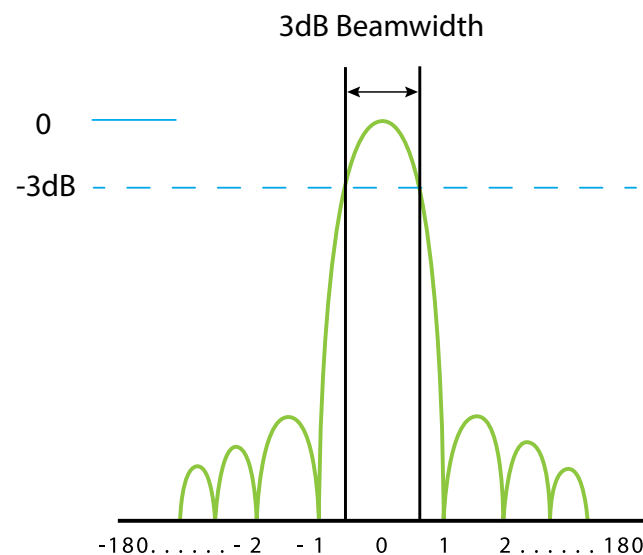


Figure 6.1: A graph representing 3 dB beamwidth, the strongest part of the signal used to measure angular movement.

Operational wind load

The maximum wind speed at which an antenna will continue to maintain the majority of the beam energy on the antenna at the other end of the link.

Angular movement

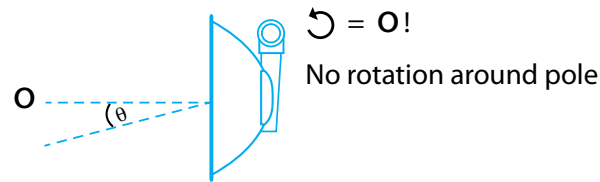
The shifting or twisting of a microwave antenna as a result of environmental conditions, which can result in lower signal strength or even total link failure.

SURVIVAL WIND LOAD

As its name implies, survival wind load is the maximum wind speed the antenna can withstand before experiencing mechanical failure, such as permanent damage or yielding of parts. At these speeds, the antenna may start to slip around the pole and some realignment may be required to restore the link to full operation (Figure 6.2 and 6.3).

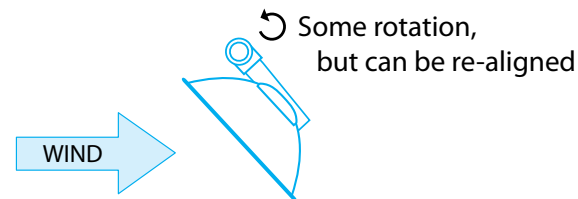
The addition of side struts can provide greater stability at wind speeds up to the survival rating, but this should be verified and recommended by the antenna supplier. In any case, environments with high-speed winds demand extra consideration and planning in the construction of microwave links.

The choice of antenna is crucial; it must be rated above the highest likely wind speed, including considerations for the antenna's mounting height and gusts that can briefly increase mean wind speeds by 50 percent. Refer to Chapter 5 for more information. Reputable manufacturers often market “extreme” antennas for the most demanding and windiest environments.



$\theta = \text{Max Operational deflection} = 0.3 \times \text{3dB Bandwidth}$
 Rated operational windspeed

Figure 6.2: Allowable antenna deflection at operational wind speed



Between rated operational and rated survival wind speed

Figure 6.3: Operational windspeed up to survival

Survival wind load

The maximum wind speed a microwave antenna can experience without permanent damage.

STRUCTURAL CONSIDERATIONS

As with any structure, the best results proceed from solid foundations. In the case of a microwave antenna, that foundation is the tower or mounting pole that supports it. These, too, must be tested and rated to withstand wind loads and minimize twist and sway.

For example, a 60 cm (2 ft) microwave antenna mounted to a long, thin-walled, small-diameter pipe attached at only one end would create enough movement to lose antenna alignment, even without the addition of wind. While this may be barely adequate for, say, a low-frequency antenna with large beamwidth, it would certainly result in total link failure for an antenna of higher frequency.

See Figure 6.4 and Figure 6.5—as well as the best practices in the sidebar—for proper mounting tips.

Best practices for a solid structural foundation

- Use large-diameter pipe up to 120 mm (4.7 in) for greater rigidity
- Shortest possible pole lengths to improve antenna access
- Rigid supports at both ends of the mounting pole, attached to tower leg, wall or similar
- Don't attach poles to tower cross braces
- Ensure interface steelwork design doesn't put excess stress on the tower structure

STRUCTURAL CONSIDERATIONS CONTINUED

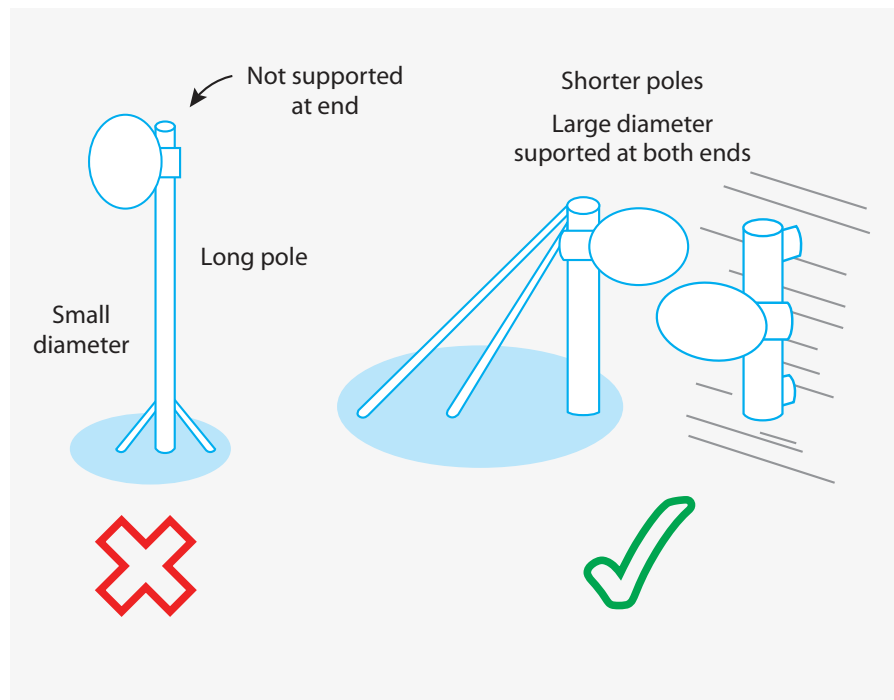


Figure 6.4: Cantilever (one support end) pole installation introduces sway, and is not recommended.

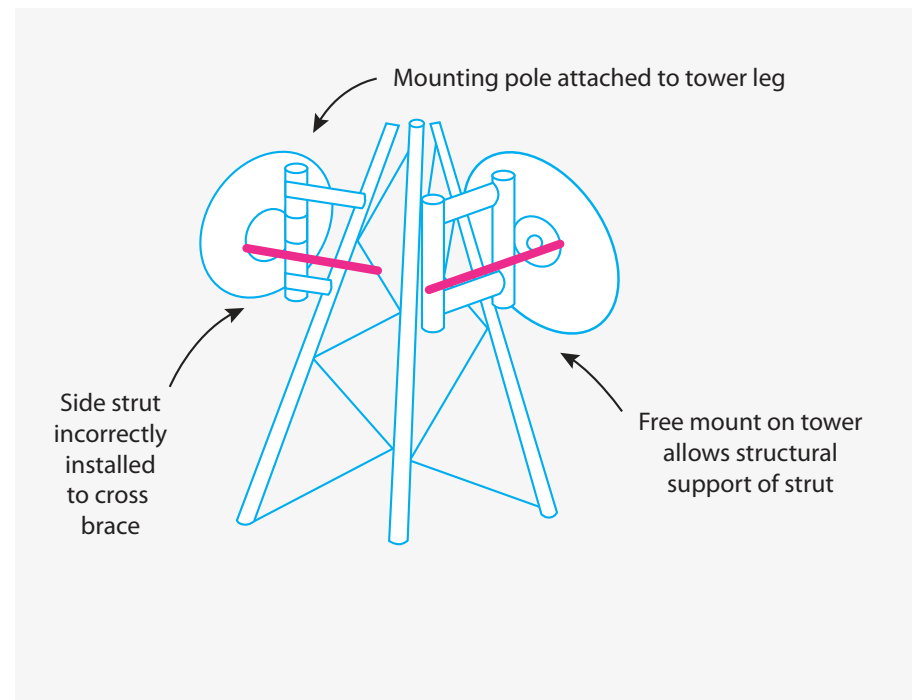


Figure 6.5: Tower mounting pole must be attached to the tower leg, not a cross brace.

STRUTS

In larger installations, the antenna will require the installation of one or more side struts. For the side strut to function effectively and be a benefit to the antenna stability, simple guidelines should be followed. Poorly or improperly installed struts may allow antennas to move under wind load and shorten their operational life through mechanical fatigue.

- The angle at which the strut is installed should be within guidelines specified by the manufacturer. Failure to do so can result in flexing or bending of the strut. Ideally, the strut will be most effective if mounted perpendicular to the antenna (Figure 6.6).
- The side strut must be attached according to the manufacturer's guidelines. Improvising the attachment to the tower or antenna will significantly reduce the strut's effectiveness and may invalidate its warranty.
- The side strut should be attached to an approved structural support designed to have such an attachment made. Cross braces do not meet this

requirement and drilling new attachment points on the tower should only be done with the permission of the tower owner. Tower face mounts are a better solution.

- Include the strut requirement in your installation plan.

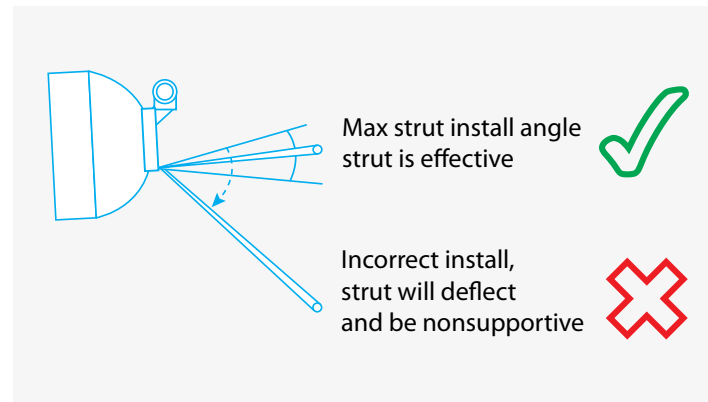


Figure 6.6: To provide adequate support, a strut must be angled within manufacturer guidelines.

Strut

A stiffening arm installed with a large antenna to improve its stability, accuracy and wind survivability.

VIBRATION AND FATIGUE

As explored in Chapter 5, wind-induced vibration is a serious design consideration because it can lead to fatigue and, eventually, link failure as alignment suffers. The solution is to choose antennas, mounts and struts from a manufacturer that performs extensive vibration and shock testing and rates their products accordingly.

The mounting pipe plays a particularly important role in reducing the effects of vibration. Since vibration is generally caused across the tower, the pipe's design will dictate how great an effect that vibration will have on the antenna.

Fatigue

Mechanical wear inflicted on plastics or metals by repeated variations in stress or load.

MATERIALS AND GALVANIC CORROSION

Several different kinds of chemical and environmental corrosion are covered in Chapter 5. However, there is another kind of corrosion that can compromise a microwave antenna installation, and that is the choice of materials combined in the manufacture of various components—the question of galvanic corrosion.

Aluminum has a natural resistance to corrosion due to the build-up of its own oxide layer, which protects the material. However, even with aluminum, care must be taken in material selection. Certain grades use alloying elements to enhance strength but can also degrade the corrosion resistance of the material. Aluminum components may be supplied with no coating, or painted for aesthetic reasons.

Galvanic corrosion

An electrochemical process in which one metal corrodes more readily when in contact with a different kind of metal.

MATERIALS AND GALVANIC CORROSION CONTINUED

All materials used in the design of these components must be certified compatible by their manufacturer, as well as suitable to the specific application. For instance, stainless steel and aluminum are both commonly found in the wireless industry, but they are not an ideal combination in terms of galvanic corrosion (Figure 6.7). Where these materials are used, the specific grades must be thoroughly tested in combination to validate their suitability for use over the life of the antenna.

Waveguide flanges are an area where different materials regularly come into contact with each other. Most waveguide flanges on the antennas are manufactured from brass, aluminum or nickel-plated brass, while the flanges on connectors are typically brass and are likely made by a different manufacturer. It's critical to know that these two materials are compatible and display suitable galvanic corrosion resistance.

Sourcing both flanges from a single manufacturer that has tested their compatibility is a great way to avoid the effects of galvanic corrosion.



Figure 6.7: *The effects of galvanic corrosion as a result of incompatible metals in contact.*

MECHANICAL AND STRUCTURAL FACTORS

For every challenge, there is a solution. That is particularly true in regard to countering the forces and stresses placed on a microwave antenna installation. With the right components, practices and materials, a site can deliver years of service in the environment for which it is designed.

The right answer is part engineering, part chemistry and part inspiration. Solid link design built on a strong foundation can help ensure the signal stays strong.

Chapter 6 summary

- Operation and survival wind loads determine antenna suitability
- Allowable movement is determined by how much signal reaches its target
- Structural design is fundamental to link integrity
- Choose manufacturers, antennas and materials carefully to avoid problems

CHAPTER

7

Antenna Selection
and maximizing ROI

GETTING THE MOST FROM YOUR INVESTMENT

What should be clear by now is that one's choice of microwave antenna has an enormous impact on how well—and how long—it performs in a real-world deployment.

While only a small part of the overall investment, antennas cover a range of costs that bear directly on their quality and reliability.

In this chapter, we will apply what we've learned so far to the process of selecting a microwave antenna that reduces TCO and maximizes performance and reliability—in other words, selecting an antenna that optimizes ROI.



SELECTION FACTORS

There are several factors to consider when choosing a microwave antenna and planning a link. They range from technological considerations to financial ones—each playing a part in calculating the value one can expect in return for the investment. These factors include:

- The electromagnetic environment and degree of radio congestion in the link area
- The link's capacity requirements, and whether they will need to be maximized
- Environmental conditions in the link area
- The nature of the available infrastructure for antenna installation
- Physical access to the site for installation, commissioning and maintenance
- Available installation budget and TCO targets over the life of the antenna

Other factors—such as the antenna type, size and operation frequency—are defined as part of the detailed RF analysis and the planning of the link. A wide variety of antenna types are available to suit virtually any requirements. They can range in size from a few centimeters to more than four meters in diameter; and they can support typical operation frequency bands from 3 GHz to 90 GHz.

What about 1 GHz to 3 GHz?

Microwave backhaul applications once included the lowest end of the microwave spectrum, but the frequencies between 1 GHz and 3 GHz have been generally redeployed for cellular applications.

FREQUENCY AND PROPAGATION

The study of radio wave propagation through the atmosphere is a vast topic all by itself. Generally speaking, the rules are that:

- Lower frequencies allow for longer links than higher frequencies
- Larger antennas transmit a signal farther than smaller antennas at the same frequency



These rules are limited by other practical considerations in the link, such as the degree of antenna alignment possible in a real-world deployment and the narrow beamwidths involved with larger antennas.

When selecting an antenna, the link planner must know:

- **How long the link must be.** That is, how far apart the two LOS endpoints are. This information can be obtained from map data.
- **The available frequency.** This may be determined by local regulators, a third-party coordination body, or based simply on which frequencies the operator owns.
- **Performance requirements.** This can be measured as link throughput (in mbs) and link availability, expressed as a percentage of uptime. If the radio supports it, the link's capacity and availability can be scaled dynamically—trading one for the other as needed.

With these parameters in hand, the planner can determine the amount of gain required from the antenna and, with reference to manufacturer literature, its approximate diameter. This is where the process begins, but there are several other important steps before a final antenna choice can be made.

Propagation

The way waves travel outward from a source. In this case, propagation refers to the direction, shape and strength of RF energy waves.

Five nines: that's carrier grade

Most wireless operators require five nines of availability—that is, availability 99.999 percent of the time. That equates to just five minutes of unavailability per year.

RADIATION PATTERN ENVELOPES (RPES)

Every antenna deployed in a point-to-point microwave network should have a published RPE, providing a measurement of the antenna's ability to discriminate against unwanted signals—that is, interference. This ability is measured over a plus/minus 180-degree azimuth angle relative to the antenna's boresight, or aimed direction.

Historically the best performing antennas (such as UHX antennas from CommScope) had asymmetrical RPEs. In these cases antennas had to be carefully installed to ensure that the feed orientation matched the path specification. Modern design tools have led to the development of even higher performing antennas such as the Sentinel and USX antennas from CommScope. These have symmetrical patterns that are better than the old asymmetrical ones. In all cases, quality antennas from responsible manufacturers will declare and demonstrate RPE compliance with regulatory standards published by such bodies at the FCC and ETSI.

You can refer to Chapter 4 for more information on RPEs.

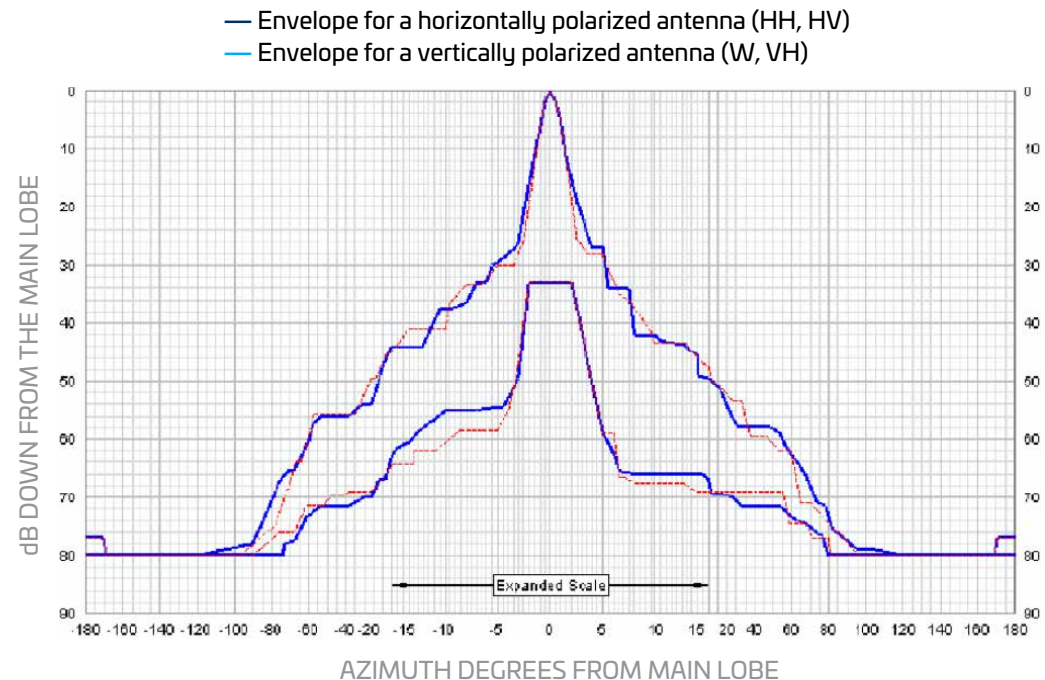


Figure 7.1: Asymmetric RPE for a CommScope UHX8-59 antenna

INTERFERENCE

Now that the link planner knows how much gain is needed—and has used that to calculate the approximate size of the antenna—it’s time to consider how the antenna will fit into the larger network. The main consideration now is one of avoiding interference with other links in the area. When working within regulated frequencies, it is not permissible to install a link that creates interference with existing users. Another challenge is avoiding any interference to the link from other users in the area. These are significant concerns, as potential interference sources will likely not even be visible from either end point of the proposed link.

Two options to beat interference

In congested networks, it can be extremely difficult to establish a path free of interference. In these cases, it’s time to consider the different classes of antennas available: The present industry-standard ETSI Class 3 antennas, and newer Class 4 antennas such as CommScope’s Sentinel® solution.

ETSI Class 3 antennas

In areas of limited congestion, high-performing Class 3 or FCC Category A antennas may be suitable, although local regulators may impose higher standards. Even in highly congested links, it may be possible to achieve performance goals with larger Class 3 antennas. However, as congestion increases in the future, a Class 3 solution that provides adequate performance today may not be adequate tomorrow—an important consideration in calculating ROI over the operational life of the antenna.

ETSI Class 4 antennas

Even in highly congested links, Class 4 antennas provide superior interference discrimination due to their much tighter RPEs. They are consequently more compliant with national and local regulations. Class 4 antennas provide higher immunity to interference with only a modest increase in capital cost. The potential, in some circumstances to use a smaller antenna reduces assembly, installation and tower lease costs as well as tower loading—offsetting some or all of the cost difference. Most importantly to TCO, Class 4 provides insurance against future interference issues.

THE CAPACITY QUESTION

The link's available capacity is determined by the available RF spectrum and the capacity of the radio itself. Intuitively, more spectrum means greater capacity, as it allows more radio channels to operate over the same link. The capacity of the radio is determined by the modulation scheme used, as described in Chapter 2.

Higher modulation schemes result in greater capacity, but this comes with the risk of an increase vulnerability to multipath fading and interference, which in turn can reduce availability—an unacceptable cost. One way to mitigate this problem is to employ an antenna with an RPE featuring lower side lobes. You can see more about side lobes and their role in reducing interference in Chapter 4.

In addition, opting for a dual-polarized antenna can double capacity simply by virtue of the fact that it can operate on both horizontal and vertical polarizations. Even if a link does not require such capacity, a dual-polarized antenna can be connected to just one polarization on the radio. Sealing the other polarization with an RF load banks that extra capacity for the future, where it can be deployed quickly and efficiently as needed.



Figure 7.2: *Integrated dual polarized antenna*

PLANNING FOR THE FUTURE

Turning to the financial and business aspects of link planning, the long-term view of the growing use of point-to-point microwave networks suggests that proactive future-proofing should be part of the strategy. In practical terms, this means choosing the best possible antenna based on its performance rather than simply on the basis of capital cost.

When assessing ROI in link planning, a key factor is the duration of the antenna's operational life. By opting for a premium antenna, the small additional capital investment is more than offset by a longer life, fewer problems and less maintenance—reducing TCO over that of a less expensive but inferior option.



ANTENNA DURABILITY AND SURVIVAL

As explored in Chapters 5 and 6, a keen understanding of the antenna's environment and climate is critical to its long-term survival. To recap, these factors include:

- **Wind.** This is the worst-case gusting wind speed, taking into account the terrain and the antenna's height. This is much greater than the winds experienced at ground level.
 - > **Operational wind speed** is the maximum wind load before most of the signal is lost, calculated as 0.3 multiplied by the 3 dB beamwidth of the antenna. Note that this is for the antenna only; the structure where it is mounted will have its own deflection ratings, which must be considered along with the antenna's rating. Any deflection at this wind speed is elastic, which means the antenna should return to its original position.
 - > **Survival wind speed** is the maximum wind load before physical damage and/or permanent misalignment occurs.



ANTENNA DURABILITY AND SURVIVAL CONTINUED

- **Water.** Because it severely attenuates microwave signals, the presence of water anywhere in the microwave path is an important factor. Radomes covering the antenna surface repel water to mitigate its effects on the link. All microwave antenna feeder systems are sealed and installations with longer lengths of microwave transmission line should be pressurized to avoid the ingress of moisture.
- **Snow and ice buildup.** While normally not a problem in extremely cold environments, snow and ice can accumulate when the temperatures hover near the freezing point. This buildup can interfere with the link's efficiency. Accumulations of snow and ice on other tower components above the antenna can also fall, making ice shields an important feature in temperate areas.

- **Corrosion.** Whether due to sea air, industrial pollution or dissimilar metals used in their construction or mounting, microwave antennas are expected to resist the effects of corrosion to provide years of trouble-free performance.
- **UV exposure.** Nonmetallic materials used in antennas must be tested and certified to be resistant to the damaging effects of the sun's ultraviolet radiation.

In all microwave antenna deployments, most (and often all) of these factors must be considered and confirmed against manufacturer specifications.



ANTENNA TYPES

Now that we have established the criteria of cost and performance that should inform the link planner's decision, let's look at some of the basic antenna solutions made by CommScope for microwave links.

- **Unshielded parabolic antennas.** These were historically used in areas of low radio congestion with little need for tightly engineered RPEs. These are now rarely deployed and are being slowly discontinued.
- **Enhanced performance standard parabolic antennas (PAR).** These unshielded antennas meet FCC Category A compliance for use in networks in the United States. With increasing radio congestion and the cost effective availability of better performing alternatives, the deployment of these antennas is diminishing.
- **High-performance antennas.** These meet or exceed ETSI Class 3 radiation pattern performance standards. They are available in single- and dual-polarized versions. They are typically provided with shields or shrouds, but recent advances in technology have made the same RPE possible

without shields. Low profile antennas have generally replaced shielded antennas of less than 1.3 m (4 ft) in diameter.

- **Ultra-high-performance antennas.** Providing high-gain, low-VSWR radiation patterns, these antennas minimize frequency congestion and simplify frequency coordination due to their highly-efficient beam-forming feed assembly. They are available in dual-polarized (UHX®) and single-polarized (UHP®) configurations.
- **High cross-polar discrimination antennas.** These antennas feature very high cross-polar discrimination, making them a good choice for co-channel transmission. CommScope's HSX antenna offers 40 dB of discrimination, tight RPE and low side lobes for high-capacity needs in congested areas.
- **Ultra-high-performance high cross-polar discrimination antennas.** The latest designs of antennas provide the best possible RPEs combined with very high cross-polar discrimination to maximise link availability and network density. Examples include CommScope's USX antenna range.



Figure 7.3: High performance antenna



Figure 7.4: Standard parabolic antenna

ANTENNA TYPES CONTINUED

- **ValuLine antennas.** Meeting and exceeding ETSI Class 3 standards, these small-diameter, high-performance antennas are used all over the world in short-haul backhaul applications. Available in single- or dual-polarized configurations, they are built in diameters up to 1.8 m (6 ft) and frequencies up to 80 GHz.
- **Sentinel® antennas.** Extremely low side lobe antennas meet ETSI Class 4 performance standards due to their superior RPE characteristics and high immunity to interference. This allows high levels of frequency reuse, amounting to 40 percent more than a comparably-sized Class 3 antennas. They also take advantage of advanced radio features like adaptive coding and modulation (ACM) that boosts capacity and availability. CommScope's Sentinel solution is a state-of-the-art Class 4 antenna; its small size makes it easy and inexpensive to ship and install.



Figure 7.5: Low side lobe Sentinel antenna 0.6 m (1.9 ft)

Class 4 antennas by the numbers

ETSI Class 4 antennas represent a major advance in microwave technology:

- 40 percent better spectrum reuse, yielding 40 percent greater link density
- Extremely low side lobes make them virtually immune to interference
- 10 dB or more off-axis interference discrimination improvement compared to Class 3 allows higher modulation schemes—greatly increasing capacity and lowering cost
- Higher initial cost offset many times over by improved performance and reduced maintenance requirements over its operational life

TCO AND THE BUSINESS SIDE OF BACKHAUL

Because they comprise such a small part of the overall network cost, microwave antennas are sometimes treated as an afterthought. Nevertheless, a conscientious antenna choice can deliver significant cost benefits, starting the day it is installed and lasting for many years over its life.

Lacking broader context, there appears to be a wide range of cost factors when pricing microwave antennas. This is true only insofar as the capital investment is concerned, and this actually represents only a very small component of the TCO over the long term—as little as 30 percent.



Consider the most common points of cost and difficulty, and the solutions become obvious:

- **Shipping.** As a general rule, less-sophisticated, less-expensive antennas can be more costly to ship and more prone to damage while in transit.
> **Solution:** More sophisticated, smaller antennas and split-reflector antennas that are less expensive to ship and less likely to suffer damage in transit.
- **Installation.** Large, heavy antennas are simply more difficult to install, and sourcing materials from multiple vendors can lead to installation errors like incompatibility of components, improper torquing of hardware, poor steel interfacing and poor installation of side struts.
> **Solution:** Source products from a quality vendor that can supply a complete solution including all hardware and accessories necessary to ensure proper installation.

TCO AND THE BUSINESS SIDE OF BACKHAUL CONTINUED

- **Downtime.** Lost traffic due to underperforming backhaul can quickly erase any initial savings realized in the purchase price. Frequent site visits to remedy these problems also add to operational costs.
> **Solution:** A high-performance antenna with superior performance and durability over its lifetime—and simpler installation—prevent the emergence of link quality problems and require much less maintenance..



- **Future-proofing and spectrum investment.**

A purely price-driven antenna choice can severely limit expansion options in the future and force the purchase of additional spectrum and equipment due to inferior reuse in an outdated antenna.

> **Solution:** Bearing the small incremental cost of a dual-polarized antenna over a single-polarized option leaves headroom to double capacity when needed. Also, choosing a Class 4 option yields 40 percent greater spectrum reuse over a comparable Class 3 antenna, which can delay or even eliminate the need to purchase additional spectrum to power a growing network.

When evaluated in the broader context of TCO, the initial capital investment cost fades into relative insignificance compared with the other costs involved over the operational life of the antenna. It seems then that—in microwave backhaul, at least—a penny saved is not a penny earned after all.

ANTENNA SELECTION AND MAXIMIZING ROI

The technology of microwave backhaul must serve the larger demands of an operator's business. While there are many steps involved in determining the right antenna for a given application, the correct choice is not always the obvious (or least expensive) choice.

Backhaul is a critical part of the wireless industry, and, like every other dimension, ROI is the final, most dependable metric that measures the value of each dollar spent. When you know your antenna options—as well as the other issues that proceed from those options—you can increase that value and avoid unpleasant surprises down the road.

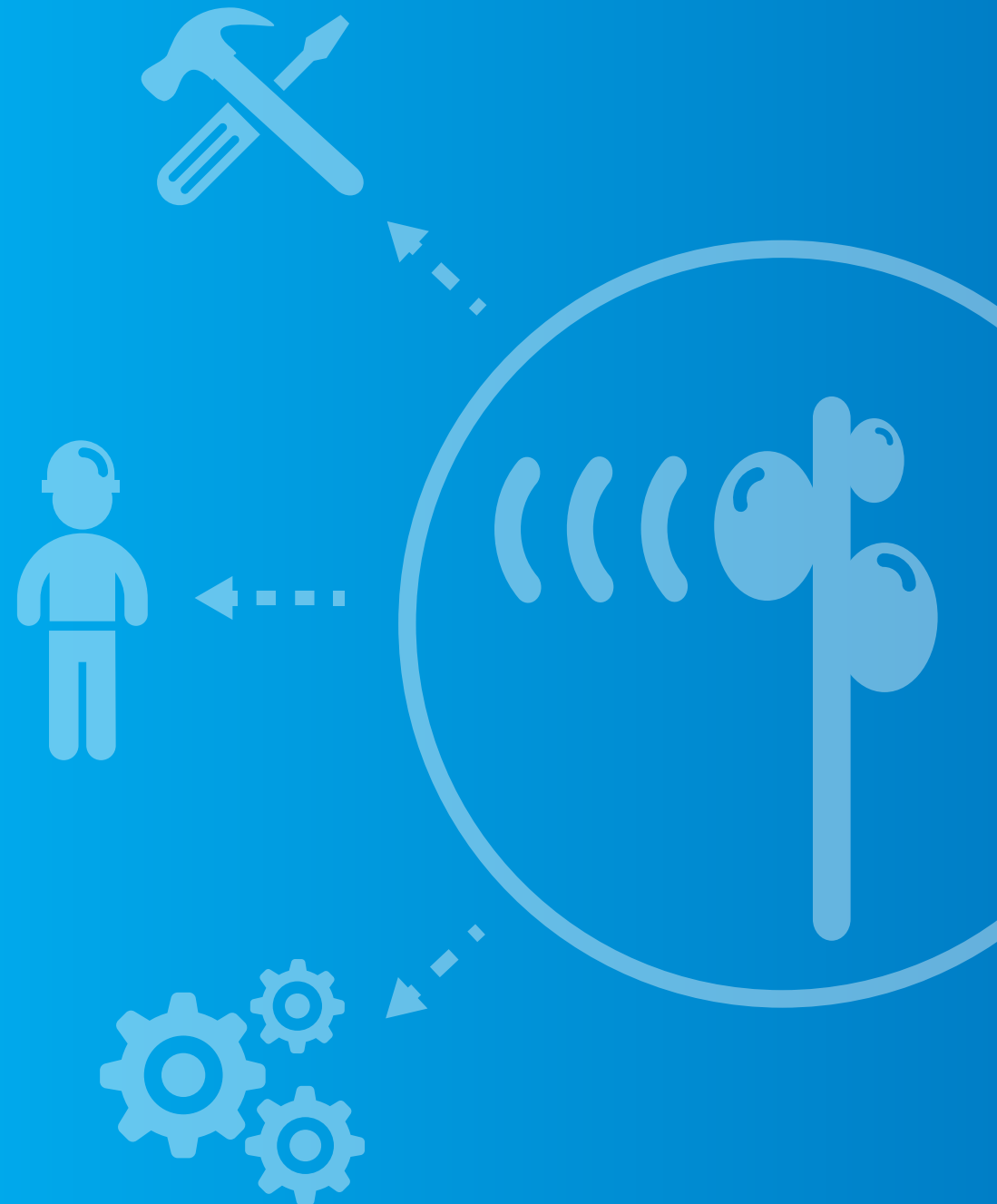
Chapter 7 summary

- ROI is realized in a balance between cost and performance
- Smart antenna decisions take a deep understanding of the link's needs
- A wide choice of antennas exists to suit specific applications, needs and conditions
- Up to 70 percent of antenna TCO comes after the initial investment
- Class 4 antennas represent a major advance in capacity and efficiency over Class 3 antennas—potentially, greatly reducing TCO

CHAPTER

8

Connectivity



WAVEGUIDE BY THE NUMBERS

As we've discussed elsewhere in this book, waveguide is a physical transmission medium used in microwave communications systems.

In this chapter, we will explore some specifics underpinning the use of waveguide in microwave systems.

ELLIPTICAL WAVEGUIDE

For microwave systems operating between 1.7 GHz and 23.6 GHz, elliptical waveguide is the recommended transmission line. Elliptical waveguide has an elliptical cross section, ideal for minimizing VSWR and eliminating signal distortion. It is optimized for the lowest loss in significant user bands. The elliptical waveguide attenuation is significantly lower than standard rectangular waveguide which provides efficient signal transfer and optimum system performance.

WAVEGUIDE CONSTRUCTION

Elliptical waveguide is formed from corrugated high-conductivity copper and has an elliptical cross section, which offers superior crush strength as well as good flexibility and light weight. The outer jacket is made from rugged black polyethylene material that adds weatherproofing and UV stabilization to protect the waveguide.

Typically, waveguide's operational temperature can be as low as -54°C (-65°F), and it can be installed in temperatures as low as -40°C (-40°F). Additionally, waveguide must be pressurized in order to prevent moisture from getting inside and attenuating the signal. We will cover pressurization and dehydration in Chapter 9.



CONNECTORS AND CONNECTOR ATTACHMENTS

Waveguide connectors are tapered through multistep transitions that adjust their shape in stages from elliptical to the rectangular shape of industry-standard waveguide flanges.

Each connector has a pressure inlet to allow the connection of pressurization equipment. Because they are made of brass, these connectors are designed to provide long service life and compatibility with the metals used in the waveguide itself. Incompatible metals can cause galvanic corrosion, which we covered in Chapter 6.

Parts of the connector are molded silicone rubber gaskets designed to conform to the shape of the waveguide's corrugations to keep the compression sleeve of the connector in place. A split flare ring on the corrugation allows the transition body of the connector to be attached to the compression ring.



Figure 8.1 Waveguide connector examples

HANDLING AND INSTALLATION

Because waveguide contains a hollow cavity, extreme care must be used in handling and installing it. For vertical runs—such as those up the side of a tower—a pulley is recommended. Hoisting grips should also be used every 60 meters (200 feet) to support the cable's weight. Manufacturers specify how far apart the prepositioned waveguide hangers should be.

During installation, the waveguide should be supported on an axle to permit free rotation as it is being hoisted—preferably paid out from the bottom of the reel. At ground level, the waveguide run between the equipment enclosure and the base of the tower is supported by horizontal support members called a waveguide bridge.

In most installations, the waveguide can be connected directly to the antenna's input flange, but, if necessary, a flexible waveguide jumper can be used to make connections that are too tight or hard to reach.

Waveguide has a maximum bend radius limit; it's important not to exceed that limit or the inner cavity can become compressed or crushed. Waveguide also requires pressurization as part of installation, which we will explore in detail in the next chapter.



Dehydrator with waveguide

Electrical grounding

Because of its construction and location, waveguide must be properly grounded for protection against lightning.

Grounding kits should be installed at both the top and bottom of the run, as well as at the entrance to the equipment enclosure.

INSTALLATION PROBLEMS AND SOLUTIONS

Flexible waveguides

Also called “flex twists,” these waveguides are designed to isolate vibration and eliminate installation difficulties caused by misalignment. They also provide assistance in the process of positioning and aligning the microwave antenna by adding enough “slack” to allow sufficient adjustment. Flex twists are made of helically-wound waveguide core supported by protective neoprene jacketing.



Example of flexible waveguide

INSTALLATION PROBLEMS AND SOLUTIONS CONTINUED

Rectangular (rigid) waveguide

Built with a rectangular cross section, rigid waveguide is most commonly used as a final assembly point in the equipment rooms, connecting to the radios.

Rigid waveguide components:

- Straight sections
These linear pieces are used to make connections just a few inches in length.
- E and H bends
These pieces allow the installer to make a connection that is in the opposite plane.
- Twists
These allow a straight section to “twist” to a different plane.



Figure 8.2 Examples of various waveguide components

FLANGES

The other half of the connectivity picture is the flange—where the waveguide meets the antenna. Depending on the specific application, there are a number of different flanges available to suit the antenna and waveguide.

CommScope, for example, offers an extensive line of flanges designed to work with various antenna and waveguide specifications. Some of these styles are shown below in Figure 8.3.

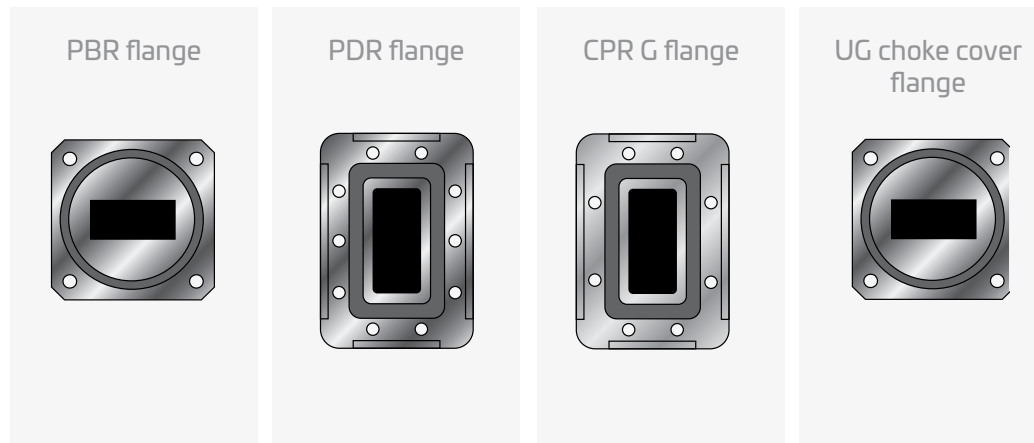


Figure 8.3: Examples of different flange types

FLANGES CONTINUED

Each flange configuration has different mating characteristics with other flanges, depending on various factors such as whether the connection can be pressurized. In questionable cases, it is always best to check with the manufacturer to confirm a particular mating scheme is possible or recommended.

As you can see in Figure 8.4 below, however, there are very many possible combinations—and impossible ones.

	PDR	PBR	UDR	UBR	CPR G	CPR F	UG Choke Cover	UG Cover	
PDR	✓	X	✓	X	?	?	X	X	✓ Mates and can be pressurized
PBR	X	✓	X	✓	X	X	✓	✓	X Does not mate or cannot be pressurized
UDR	✓	X	X	X	?	X	X	X	?
UBR	X	✓	X	X	X	X	✓	X	May possibly mate—Contact manufacturer for exact details
CPR G	?	X	?	X	✓	✓	X	X	
CPR F	?	X	X	X	✓	X	X	X	
UG Choke Cover	X	✓	X	✓	X	X	✓	✓	
UG Cover	X	✓	X	X	X	X	✓	X	

Figure 8.4: The different mating configurations between various flange types

OTHER COMPONENTS

Apart from the waveguide and flanges, there are other components that also play important roles in microwave systems. These include:

- **Waveguide-to-coaxial cable transitions**, which are used to connect a rectangular waveguide interface to a coaxial cable flange interface.
- **Termination loads**, which are used when one or the other polarization ports of a polarized antenna are not currently in use. They may be made of ferrite material if used in terrestrial, long-haul microwave antennas, or rubber absorber material for small loads on short-haul antennas.
- **Pressure windows**, which provide separation between components that require pressurization from those that do not require it. These are typically installed at the equipment room end of the feeder line, where they can be situated in a more controlled environment.

- **Gaskets**, which are present throughout the systems wherever pressurization is required. Full or half gaskets are used in flange mating combinations, where one flange is flat faced and the other has a gasket groove.



Figure 8.5: Waveguide-to-coaxial cable transition



Figure 8.6: Ferrite termination load

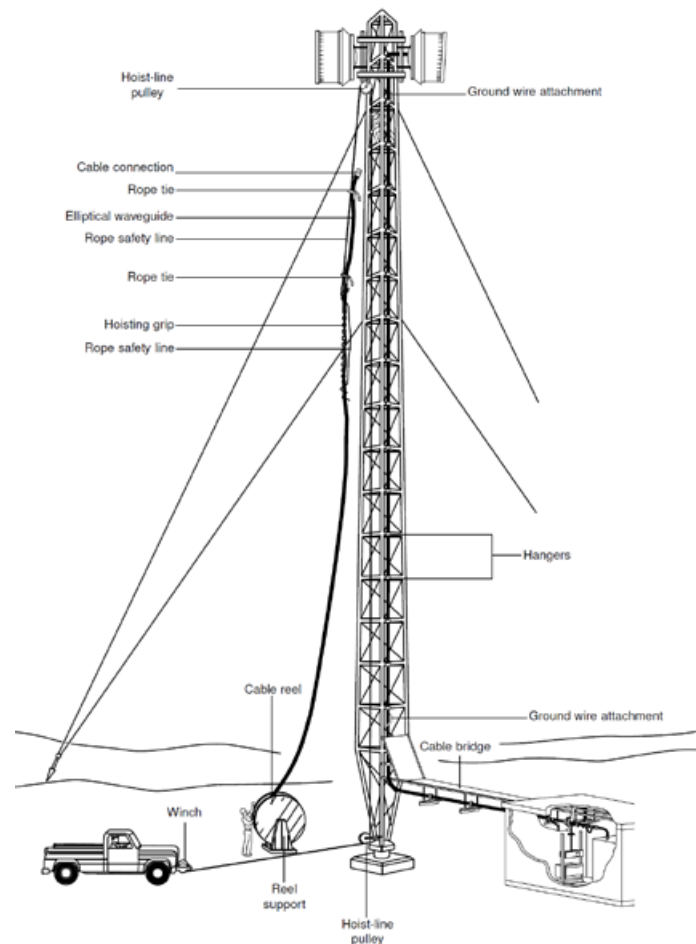


Figure 8.7: Pressure window

CONNECTIVITY

Waveguide is specifically engineered for microwave communications. Using it requires highly specialized parts, tools and skills for it to perform its best.

When properly installed, carefully hung and securely connected to the antenna and radio, elliptical waveguide is an amazingly effective means of channeling microwaves to and from the open air.



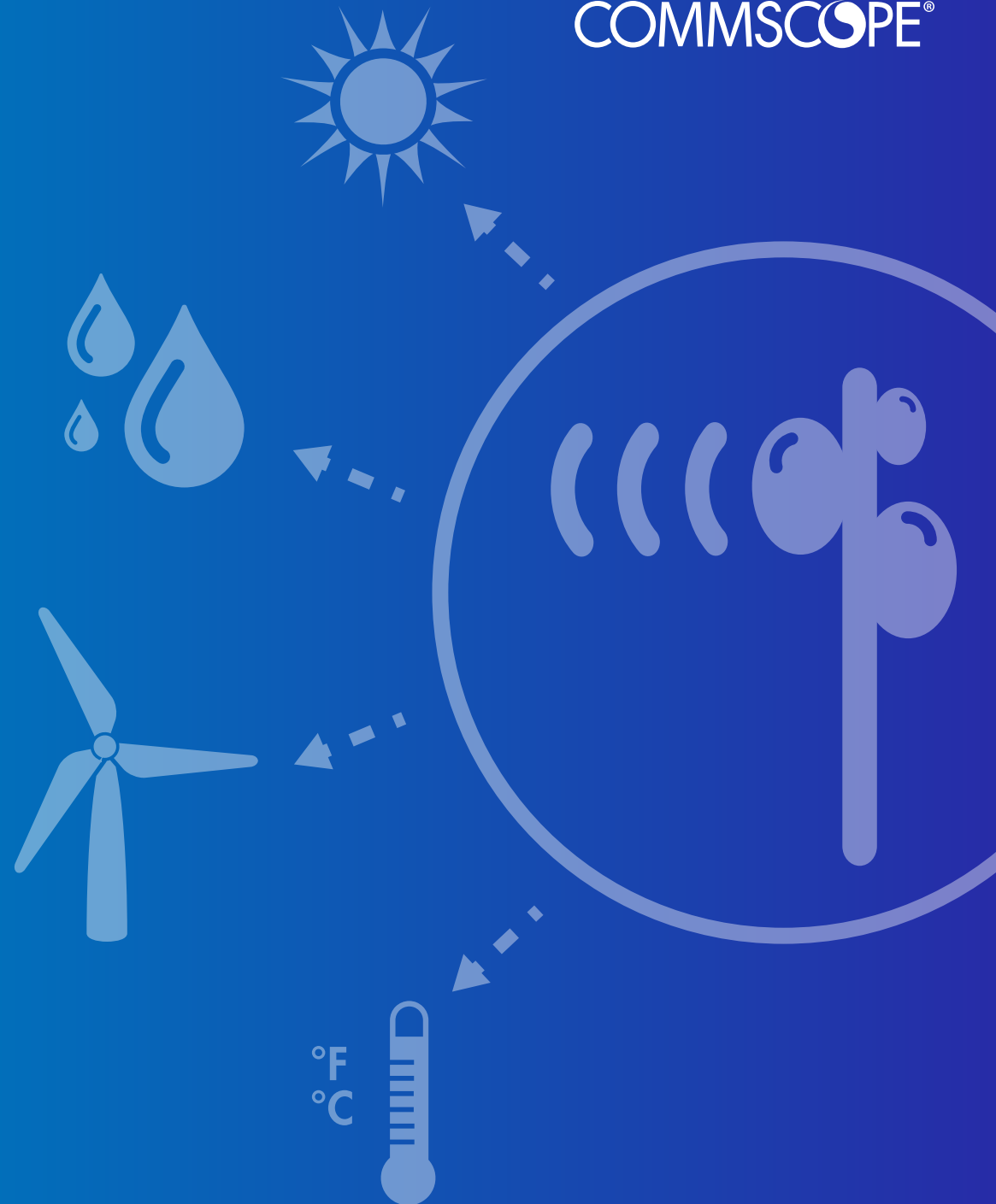
Chapter 8 summary

- Elliptical waveguide is suitable for systems between 1.7 GHz and 23.6 GHz
- Waveguide must be kept free from moisture ingress during transportation, installation and operation
- Flanges connect waveguide to antennas
- Installers must observe manufacturer recommendations of hanger interval and bend radius
- Not all flanges mate with all other flanges

CHAPTER

9

Waveguide pressurization



KEEPING MOISTURE AT BAY

As explored in previous chapters, elliptical waveguide is a hollow, corrugated metal tube with an elliptical cross section used to guide microwaves.

Unlike ordinary cables, waveguide has no interior conductor—merely air or nitrogen as a dielectric. To maintain the efficiency of waveguide as a transmission medium, it must be kept free of moisture, since water inside waveguide inflicts the same attenuating effects as rainfall does when microwaves are transmitted through atmosphere. Any moisture can attenuate a signal and increase VSWR.

A recommended method of keeping waveguide clear of moisture is pressurization, wherein the interior of the waveguide is hooked into a dehydrator that provides a pumped source of dry air or nitrogen. Because this creates positive pressure inside, nothing can infiltrate

from the outside—including unwanted moisture. Without pressurization, the system tends to “breathe” as temperatures change, allowing moisture in as humidity in the air, which then condenses into water when temperatures drop.

Pressurization

The practice of applying positive pressure—in the form of dry air or nitrogen—to elliptical waveguide in order to prevent the introduction of humidity or other outside moisture that would impede its transmission efficiency.

ASSESSING PRESSURIZATION NEEDS

The choice of waveguide pressurization equipment requires as much careful consideration of the specific site as the choice of microwave antennas. Apart from logistical factors such as the availability of reliable power and maintenance access to the equipment, the most important factor is the volume of dry air required by the waveguide.

This is a simple matter of calculating the total volume inside the waveguide using its length and cross section area; a large microwave system may have hundreds of feet of waveguide comprising many cubic feet of volume. The system must be able to accommodate this volume plus an additional 1 percent to account for leakage, and provide sufficient pressure during a 19°C (35°F) temperature drop over 60 minutes.

CommScope part number	Volume liters/1000m (ft³/1000 ft)
Elliptical waveguide	
EW240	56 (0.6)
EW220	74 (0.8)
EW180	111 (1.2)
EW132	167 (1.8)
EW127A	251 (2.7)
EW90	334 (3.6)
EW85	390 (4.2)
EW77	585 (6.3)
EW64	725 (7.8)
EW63	855 (9.2)
EW52	1045 (11.3)
EW43	1690 (18.2)
EW37	1960 (21.1)
EW34	2323 (25)
EW28	3345 (36)
EW20	5621 (60.5)
EW17	6596 (71)

Figure 9.1: Typical volumes for waveguide transmission lines

HOW MUCH IS ENOUGH?

The positive pressure inside an elliptical waveguide transmission line should be below the maximum pressure rating of all the components involved, including the waveguide itself, the antenna feed and pressure window.

Most components are rated up to 70 kPa (10 PSI), but pressure need not be this high to be effective. Pressurization of only 3.5 to 35 kPa (0.5 to 5 PSI) is generally recommended.

PRESSURE POWER

Another consideration is the power source available for the pressurization equipment. To prevent voltage drops between the site's main power and the dehydrator, it is vital that the correct electrical wire size be used on an appropriately-sized circuit breaker.



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THE PRESSURIZATION OPTIONS

Pressurization systems are available in two basic types: static and dynamic. Determining which is best for a given application depends on which best aligns with the specific requirements.

1. Static systems

In a nonpressurized system, the use of a breathing static desiccator is one option. As breathing leads to increased pressure, air is forced out through the desiccator. Later, as breathing decreases the pressure, new air enters through the desiccator, which absorbs moisture before it enters the waveguide. The desiccator has a limited lifespan and must be periodically replaced, but it is very effective and may last many months in a small, tight system of 57 liters (2 cubic feet) or less.

In a pressurized system, the waveguide is connected to an external pump, pressurized and then disconnected from the pump—much like inflating a tyre. Since the microwave system is not hermetically sealed, frequent recharging is required.



Figure 9.2: *Static desiccator example*

THE PRESSURIZATION OPTIONS

2. Dynamic systems

A dynamic system remains connected to a pressurization pump that automatically provides additional dry gas as needed to maintain a specified pressure level. This gas may be nitrogen—stored in a tank with a regulator—or it may be one of several kinds of dehydrators.

Nitrogen tanks are ideal for small, tight systems where ac power is unavailable. They have no moving parts and provide a low dew point to stave off moisture. The drawbacks of using nitrogen are their relatively high cost and the frequency at which they must be replaced in locations where leaks bleed them quickly.

Membrane dehydrators are designed for low to high system volumes and remote site locations. These systems use a membrane filtration system to remove moisture from the air. They operate continuously, using an integrated controller to monitor system pressure and adjust the air pumps appropriately.

Heat regeneration dehydrators are used for small-to medium-sized systems where low pressure and low power use are preferred. They operate continuously, using an integrated controller to monitor system pressure and adjust the air pumps appropriately. These perform their own regeneration of the desiccant, so they require no periodic maintenance.

SYSTEM EXPANSION

All these choices are predicated on knowing the volume of air to be pressurized, but—as microwave backhaul increases its prominence in the fast-growing world of wireless communications—it's a certainty that the amount of waveguide will expand. Manifolds are one way to keep up with this expansion.

As additional waveguide lines are added, a manifold system allows multiple lines to be serviced by a single dehydrator, and makes it a simple matter to add pressure or flow gauges to the system.



Figure 9.3: System manifold example

ALARMS

Because pressurization systems often operate in remote locations, it’s important to know when something goes wrong or maintenance is required. Heat regeneration, automatic regeneration and some manual regeneration dehydrator systems include basic alarm functions—alerting operators to such problems as low pressure, excess run time and power failure. Some include humidity alarms and the ability to monitor other alarm conditions.

Each product features its own published specification regarding which alarm function it supports (Figure 9.4).

Technology/ Type of Regeneration	Output Capacity l/min (ft³/min)	Output pressure range kPa (lb/in²)
Static Desiccator		
SD-003UV	28 liters (1ft³ max system volume)	n/a
Membrane Dehydrator		
MT050C	1700 liters (60ft³)	20 kPa (3psi), (14-40 kPa (2-6psi) adjustable)
MT500D	3400 liters (120ft³)	14 - 35 kPa (2-5psi)
SAHARA2	2800-31150 liters (100ft³-1100ft³)	14 - 35 kPa (2-5psi)
Heat Regeneration		
HR150	600 liters (21ft³)	3kPa (0.44psi)
HR300	1000 liters (35ft³)	3kPa (0.44psi)

Figure 9.4: A sample of different pressurization system specifications

WAVEGUIDE PRESSURIZATION

There's an entire science underpinning the use of elliptical waveguide in microwave transmission systems. Ideal performance comes only with ideal conditions—and that means a dry air dielectric inside the waveguide at all times.

Depending on the needs and budget, there are several ways to accomplish this level of dehydration, but only by examining the specifics of the individual deployment will the best answer present itself.

Chapter 9 summary

- Elliptical waveguide must be kept dry internally
- Any moisture infiltration can attenuate signal and increase VSWR
- Pressurized, dehydrated gas—air or nitrogen—keeps moisture out
- Dehydration can be achieved via nitrogen gas or the use of desiccants

CHAPTER

10

Installation and
path alignment

BRINGING THE PLAN TO LIFE—THE RIGHT WAY

The installation and commissioning of the microwave link is a critical stage in the overall system process.

No matter how well the link has been planned—or how much care has been taken in the selection of equipment—poor installation practices will jeopardize the link's reliability and deliver performance far below planned expectations.

Further complicating things, every installation is different. The location of the site, the direction of the antenna, the presence of nearby equipment, and other prevailing local conditions mean each installation presents unique challenges requiring careful attention. There are no one-size-fits-all solutions or processes for this challenge. While manufacturers provide detailed instructions on how to best assemble and install equipment, it's the expertise, skill and care of the installation crew that will ultimately determine if the link fulfills its performance and reliability goals.

OCCUPATIONAL HAZARDS

Installation of microwave antennas involves working at height—often in remote areas. The towers where installations take place are often already-congested areas full of equipment—much or all of which must remain powered at dangerous voltages while the installation occurs. This presents an extremely hazardous working environment in which good safety practices are essential.

To ensure the safety of the technicians on the tower and people on the ground below—as well as protect the equipment itself—installations must be performed by crews properly trained and equipped to handle the job. They must also be fully aware of all governing legislation, regulation and zoning requirements, and follow those rules closely.



PUTTING THE PIECES INTO PLACE

Prior to installing the antenna and waveguide, the technician must usually first determine the antenna mount offset needed during the assembly process.

Although antenna centerlines and azimuths are provided by their manufacturers, in many cases further details such as actual tower pipe mount and antenna strut “tie back” locations are not provided.

Even for an experienced installer, this assessment can be challenging—requiring consideration of several factors to ensure that:

1. Available space exists on the structure at the specified height.

Typically, a tower structural analysis should be performed when adding any new antenna systems. This analysis should include tower drawings that include all existing installations.

2. The antenna will be able to be oriented to a rough compass heading.

The type and orientation of the tower structure itself play a large role in the way the technician will eventually align the antenna. Not all towers allow for all orientations.

3. The antenna will be able to move freely from side to side during alignment.

There must be lateral clearance for fine-tuning the antenna’s direction during the installation.

4. The correct offset is used in the installation of the antenna mount.

Depending on the terrain on the tower, a right- or left-offset mount may be preferable.

PUTTING THE PIECES INTO PLACE CONTINUED**5. There is a clear transmission line path to the antenna feed.**

Towers can have many different kinds of obstructions and protuberances that can get in the way of both transmission lines and installing technicians.

6. There is a suitable location for strut collars.

Struts have specifications relating to their installation angle tolerances. If the mount offset changes, so must the locations of the collars connecting the mount to the strut. As a rule, less angle allows for easier antenna movement during installation.

7. Strut collars are mounted within manufacturer-specified tolerances.**8. Strut ends can move freely past the collar during the alignment process—without coming into contact with other objects.**

Strut ends should be able to move 60 cm (2 ft) past the collar during alignment and not make contact with any other components already mounted on the tower.

Mapping the tower's terrain

An antenna installation can be a lot like navigating a 3D puzzle, looking for a solution that ensures:

- A clear transmission line path from the vertical cable ladder to the antenna feed
- No tower legs, structural steel, or climbing or cable ladders are in the way
- No turns or bends that exceed the rated flexibility of the coaxial cable or waveguide
- Allowance for potential movement during the alignment process itself
- In the case of waveguide, adequate clearance and bending space to allow the correct orientation for its polarization—either vertical or horizontal

BUILDING ON STRENGTH

To satisfy these demanding criteria, all supporting steelwork should be mounted on the tower. Pipe mounts should be vertically leveled (unless specifically required to meet a different orientation) because unlevelled mounts have a significant effect on the alignment process. And, as discussed in Chapter 5, all steelwork must be rated to support the wind load planned for each antenna. CommScope offers a complete line of antenna mounts and accessories suitable for virtually any installation, in virtually any environment.



INSTALLATION, PART ONE: ASSEMBLY AND LIFTING

The first challenge arises before we even get to the tower. Unpacking and assembling a microwave antenna is not always a straightforward process. Each antenna will come with manufacturer instructions explaining how to assemble and lift it. This second part is critical, as using a non-specified lifting point can result in extra handling and stresses that can damage the antenna while still on the ground.

Once assembled, the antenna should be hoisted by skilled riggers on the tower and secured prior to alignment. At this point, side struts should be installed if they are provided. See Chapter 6 for more on the purpose, use and importance of side struts.

INSTALLATION, PART TWO: MAKING CONNECTIONS

At this point, any transmission lines should be installed—being careful to avoid any kinking or damage by following the guidelines shown above. Depending on its type, waveguide can sometimes be twisted on the tower or structure to allow easier attachment to the antenna feed or radio port. If allowed, the waveguide will include specifications regarding allowable twist degrees per foot or meter of length.

Once these connections are made, VSWR/return loss testing should be performed, transmission line supports should be installed, and all electrical grounding connections should be completed.

Return loss testing

Measuring the amount of signal reflection along an RF path such as cable or waveguide. High return loss means reduced signal strength and indicates possible damage to the RF media.

INSTALLATION, PART THREE: ALIGNMENT

Alignment with a distant microwave antenna is the next step. Depending on the size and frequency of the antenna being installed, the target antenna on the other end of the link may be anywhere from a few hundred meters to more than 60 km (37 miles) away. Although all links require a clear LOS path between end points, it's not always feasible to visually orient an antenna to a distant point.

In these cases, the technician uses a map, compass and/or GPS data to align the antenna. It's important that the technician remembers to translate map bearings (normally referenced to true north) to correct for the compass bearing (referenced to magnetic north) to account for the magnetic declination appropriate for the site's location.

Governmental bodies publish and update declination constants for different countries and regions (Figure 10.1). The extremely high degree of accuracy required by a LOS microwave link means there is no room for

error or approximations by the installing technician; even a tiny miscalculation can mean hours of wasted time spent searching for precisely the correct bearing.

Microwave antennas can be aligned using either a customer-supplied radio or independent path alignment transceiver set. Microwave antennas must be accurately positioned on true azimuth—that is, absolutely horizontal and level—before path alignment. Most alignment difficulties are the result of incorrect azimuth position or inadequate leveling.

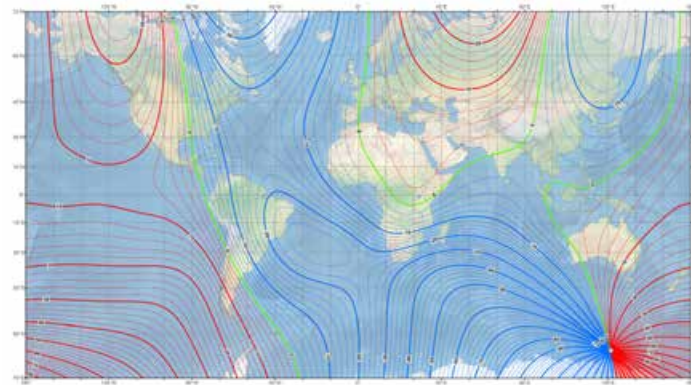


Figure 10.1: Global declination constant map

Magnetic declination

The angular distance between true and magnetic north, calculated from a specific location and time.

HEIGHT AND LOS

Although there are some exceptions, most microwave paths are between antennas sited at similar heights. To understand why, consider the examples shown in Figure 10.2 and Figure 10.3 below.

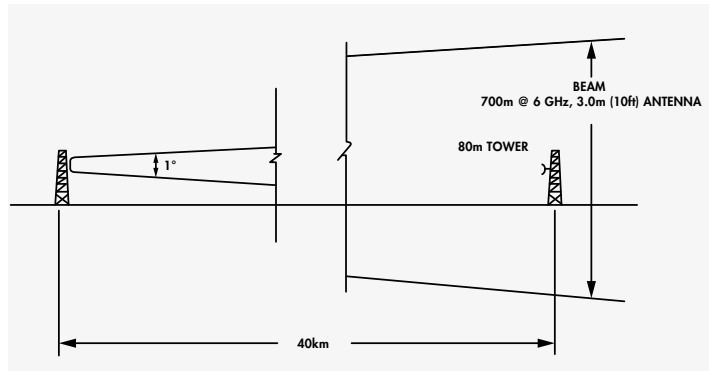


Figure 10.2: A level antenna, beam width at 40km is typically many times the height of a 80m tower.

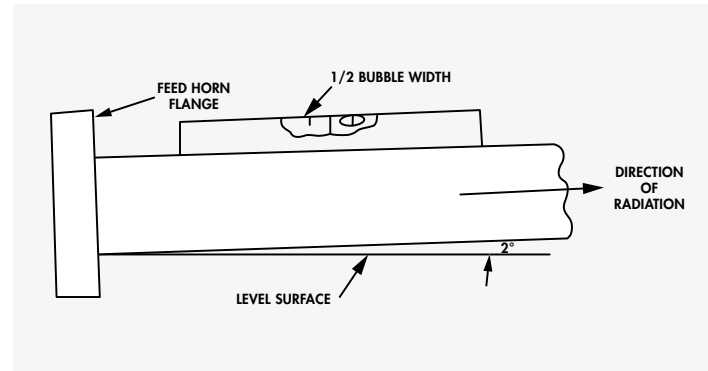


Figure 10.3: If the basic level position is only half a bubble width off level, as shown above, the antenna's main beam will be shifted 2 degrees, missing the adjacent tower by a 800m.

EXAMPLE:

A 0.6 m (2ft) 23 GHz antenna has a 3 dB beamwidth of 1.6 degrees.

Allowing for a path length of about 4 km (2.5 miles), the actual beamwidth at the receiving antenna is around 112 m (370 ft) and is, therefore, likely to be greater than the height of the tower.

If the antenna's out of horizontal by even a couple of degrees to start, the antennas will miss by around 140 m (460 ft) and not be able to "see" each other.

CALCULATING SIGNAL STRENGTH TO CONFIRM ALIGNMENT

Signal strength readings are usually measurable when at least the main beam of one antenna and its first side lobe of the other antenna are aligned. The strongest signal occurs at the center of both main beams.

Consider a typical 6 GHz system with the highest first lobe signal of 20-25 dB less than the main beam signal. When both antennas are aligned for maximum main beam signal strength, net path loss will typically be -50 to -65 dB (Figure 10.3).

To calculate the net path loss, we must apply a few simple calculations. The loss at 6 GHz over a 30 km (18.6 mile) link is 138 dB. Typical antenna gain for a 3 m (10 ft) antenna at 6 GHz is 43 dB per antenna—or 86 dB for both antennas. So, to calculate the net path loss, we simply find the difference between gain and loss, thus:

-138 dB path loss + 86 dB antenna gain (both antennas) =
-52 dB net path loss

So, if the measured signal was near -52 dB, we can be confident that the antennas are indeed aligned on main beam and only exhibiting the loss we would expect. If, however, the measured signal was only -80 dB, one antenna would be aligned on the first side lobe rather than the main beam. If both antennas were aligned on their first side lobes, then the receive signal would probably be too low to be measured.

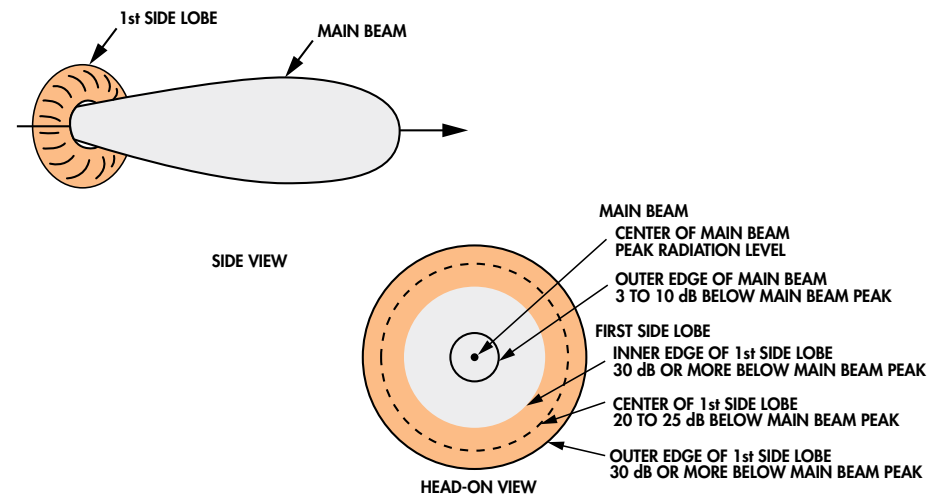


Figure 10.4: The main beam and first side lobe of a microwave signal representing path loss.

TROUBLESHOOTING AND FINE TUNING

Where no signal can be found, the usual culprit is improperly installed pipe mounts or an antenna that has not been properly leveled, is not on its azimuth, or has not been adjusted to account for local magnetic declination. Both ends of the link must be checked for these inconsistencies.

Once any errors have been corrected, the technician should sweep one of the antennas through its full azimuth range—that is, he should pivot it horizontally—until the signal is found. If no signal is found, the technician should return it to its original compass position and azimuth bearing and repeat the process with the other antenna on the far end of the link.

By doing this, the link can be re-established regardless of which antenna is out of alignment. Once the signal is found, smaller adjustments should be applied to

locate the main beam. This fine tuning means even partial turns in adjustment hardware can have a dramatic effect on signal strength.

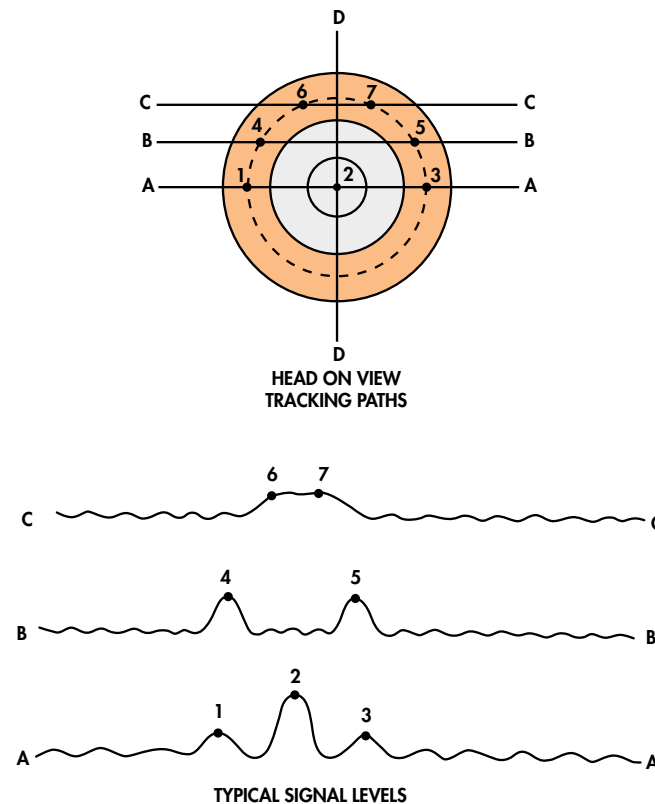


Figure 10.5: A head-on view of a radiation pattern, showing different strengths at different heights.

First lobe false positives

While aligning a microwave link, it's easy to mistake the first lobe signal strength for the main beam strength.

Because of the shape of the signal, the strongest part of the first lobe is actually stronger than the edges of the main beam.

Figures 10.5 and 10.6 show the relative strengths of the three typical tracking paths.

TROUBLESHOOTING AND FINE TUNING CONTINUED

In Figure 10.5, line AA represents the tracking path of a properly aligned antenna. This shows the signal level as the antenna is moved from left to right. The main beam is at point 2, and the first side lobes at points 1 and 3.

Line BB represents a tracking path with the antenna tilted down slightly. Here, the signal strength shows up only in the first side lobe peaks—points 4 and 5—as the antenna moves left to right.

Typically, this signal looks more like signal WW—points 1 and 2 (Figure 10.6)—where the first side lobe peaks are unequal due to antenna pattern performance issues. This larger first lobe peak is often mistaken for the main beam. The correct method of locating the main beam in this case is to set the azimuth position midway between the first side lobe peaks, and then adjust elevation to locate the main beam's maximum signal.

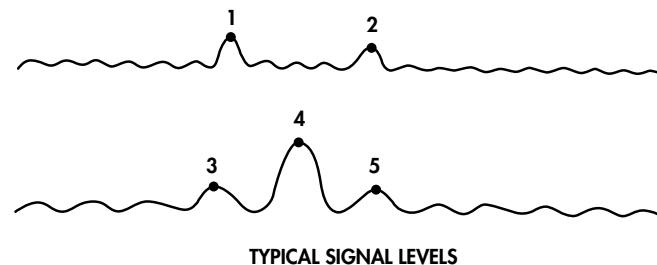
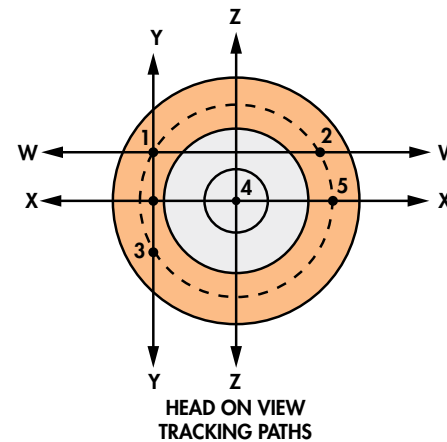


Figure 10.6: Head-on view of a radiation pattern, showing different strengths at different azimuths.

POLARIZATION

As discussed in Chapter 2, polarization is the orientation of a signal's energy in one of two directions, either horizontally or vertically. In a dual-polarized system, there are two outputs—one designated horizontal (H) and one vertical (V). These will be labeled on the antenna or antenna feed. Once both antennas are correctly aligned, the technician should then optimize the cross-polarization performance.

The equipment used is identical to that used in initial antenna alignment, except that the transmitter and receiver are now connected to different polarizations. The polarization is adjusted to ensure that signals measured H-V (horizontal transmit-vertical receive) are within 3 dB of the signal transmitted in the vertical polarization but received horizontally.



Traditional dual polarized feed assembly

Cross-polar discrimination (XPD)

The ability of an antenna to distinguish between signals of differing polarization.

THE FINAL TOUCHES

Once the antennas are aligned, the technician must check that struts are still within the allowed angular tolerances and then use a properly calibrated torque wrench to fully tighten all adjusting hardware to the torque values specified on the manufacturer's instructions.

Due to changes in antenna alignment and cross-polarization adjustments that require their rotation, waveguides may need to be reformed prior to permanently attaching them to the feeds. Transmission line connector attachment hardware should slide relatively easily through the flanges, and not bind due to interface misalignment.

Pressurize elliptical waveguide and antenna feed systems as soon as possible, and purge per manufacturer recommendations. To learn more about waveguide dehydration and pressurization, refer to Chapter 9.

Finally, the technician must ensure that all necessary commissioning documentation is completed and the site is left secure and tidy—with all rubbish and packaging materials properly removed.



Typical completed microwave installation

INSTALLATION AND PATH ALIGNMENT

Building a future-ready microwave backhaul strategy and choosing the optimal antennas are just the beginning. To realize optimal performance and positive ROI, each link must be installed with skill, care and attention to detail.

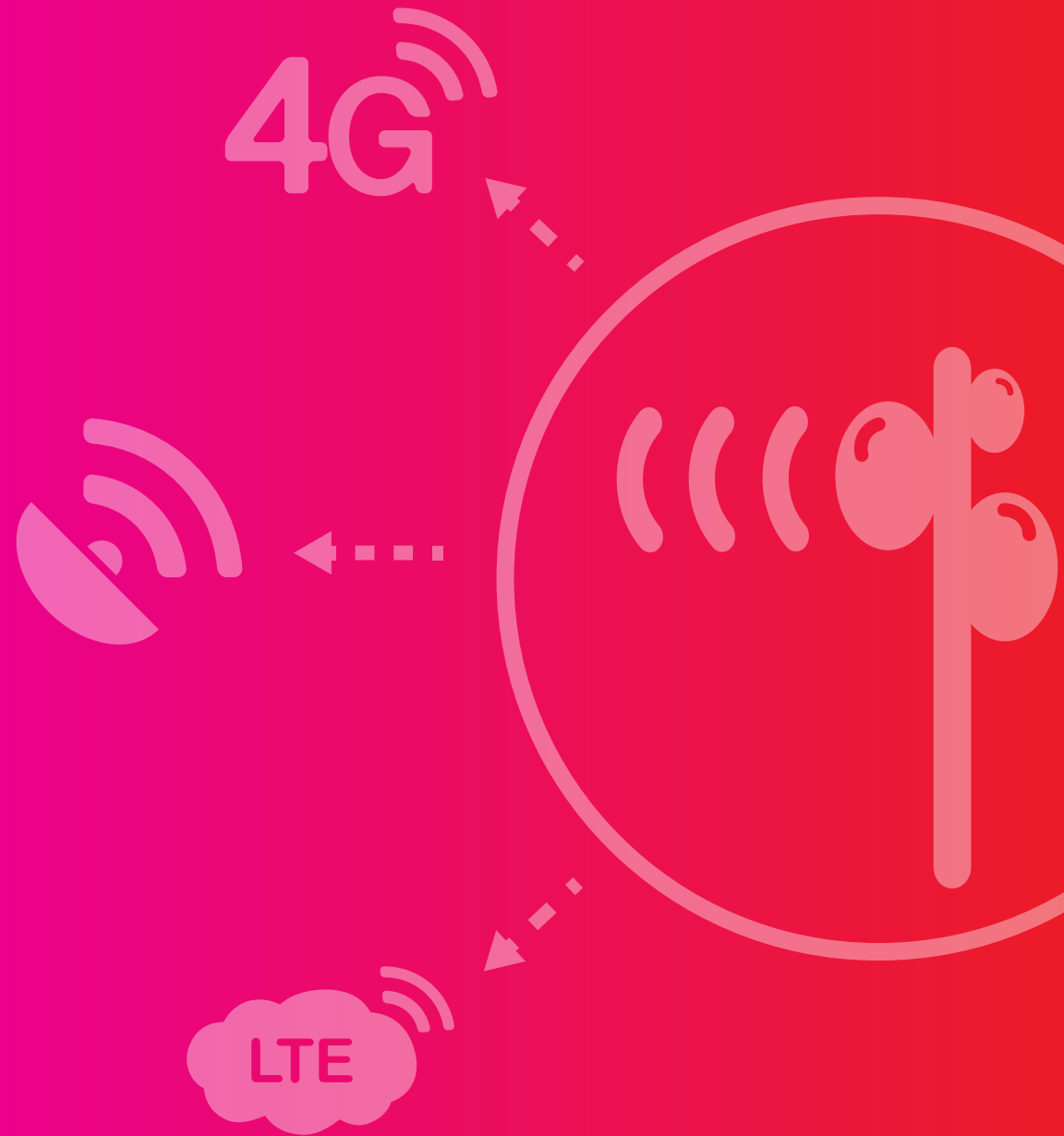
No matter if the link is a few hundred meters or more than 20 miles, a quality installation using the right tools and processes will ensure that the link will perform to expectations and continue to operate reliably for a long time to come.

Chapter 10 summary

- Performance depends on installation as much as planning or choice of solution
- Tower-top installations can be difficult and dangerous—safety first
- Map and avoid tower obstacles before installation
- Follow manufacturer specifications for all installed solutions
- Alignment requires careful calculation accounting for magnetic declination, distance and height
- Dual-polarization systems require separate optimization

CHAPTER

11

Millimeter
microwaves

THE HIGHER END OF MICROWAVE

As shown in Chapter 2, microwave bands cover a fairly large part of the accessible EM spectrum—from 1 GHz to 300 GHz.

Conventional microwave backhaul links employ mostly the lower end of this range—from 1 GHz up to 42 GHz. But there's a lot of spectrum above that, and it's becoming increasingly attractive as a means of providing backhaul: millimeter microwaves, or mmWave.

Millimeter microwave (mmWave)

Microwaves with exceptionally short wavelengths of 1 to 10 millimeters. They have correspondingly high frequencies up to 300 GHz and offer an efficient, high-capacity option for microwave links.

TWO BANDS, BIG CAPACITY

There are two bands used in LOS link applications: E-band and V-band. E-band covers 10 GHz of spectrum in two separate ranges—from 71 GHz to 76 GHz and 81 GHz to 86 GHz; V-band covers 7 GHz in one band from 57 GHz to 64 GHz. However, V-band can be expanded to reach an upper range of 66 GHz, increasing its spectrum to a total of 9 GHz overall. E-band is more commonly used in microwave backhaul for reasons that will be discussed later.

The main advantage of mmWave bands over commonly used lower-frequency microwave bands is capacity. It is now considered the best choice for point-to-point microwave links because it offers more spectrum and more bandwidth than lower frequencies, an important feature for operators struggling to keep up with skyrocketing user demand for data on 4G LTE networks.



mmWave bands used in LOS systems by the numbers:

E-band

- An established technology first used in 2000
- Comprises two 5 GHz bands: 71 GHz to 76 GHz and 81 GHz to 86 GHz

V-band

- Comprises one 7 GHz band: 57 GHz to 64 GHz
- Can be expanded to 66 GHz for a total of 9 GHz of spectrum

REUSE IN CONGESTED AREAS

So critical in the design of any efficient LOS system is narrow beam paths and the resulting high frequency reuse, and it is here that mmWave distinguishes itself. Particularly in crowded urban environments where antennas are colocated with other carriers' equipment or servicing multiple links, narrow beams minimize the risk of interference—a major advantage in locations where fiber access is impossible or impractical.

Like lower-frequency microwave antennas, mmWave antennas support capacity enhancement options like dual polarization with the efficient integrated radio configurations. This lets operators move more data without minimal additional infrastructure. This high-capacity, high-reuse scheme gives mmWave systems extremely attractive TCO helped by the characteristics of the antenna.

Even with all these advantages, mmWave antennas must be built to high quality standards to optimize their performance and capacity. A quality antenna will feature an RPE compliant to ETSI Class 3 specifications

or better—guaranteeing that its RF energy will stay contained to a single beam along the link path, as show in Figure 11.1.

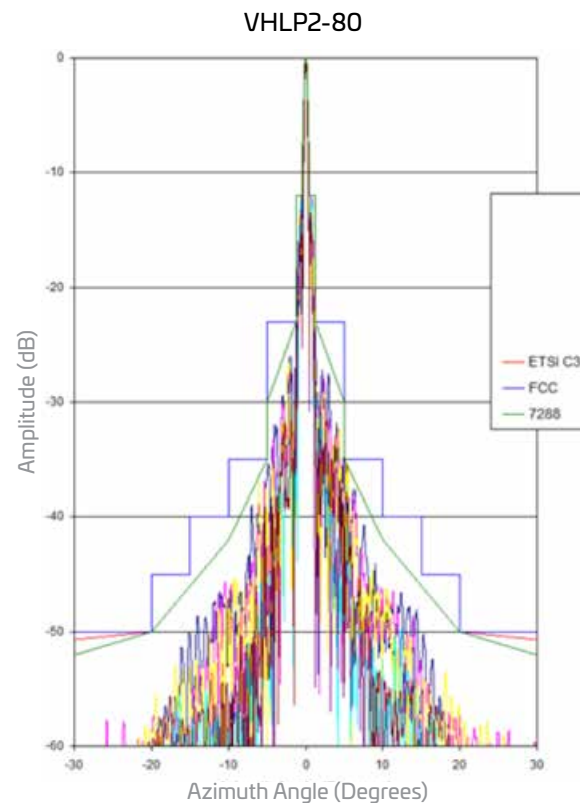


Figure 11.1: A diagram representing the RPE of a quality (i.e., > Class 3) mmWave antenna

4G LTE

Interchangeable terms denoting the “fourth generation,” “long-term evolution” wireless networks. 4G LTE supports up to 300 Mbit downlink speeds and radio latency of less than 5 milliseconds.

THE REGULATORY ADVANTAGE

Another feature contributing to its attractive TCO profile is the fact that mmWave is relatively easy and inexpensive to license. Most regulatory bodies impose only a low, one-time fee or no licensing at all. Considering the large costs of spectrum licensing in sub 40 GHz frequency bands, this is a significant advantage.

The downside to this is the question of availability. Being only lightly licensed or not at all, the proliferation of mmWave links raises the very real possibility of interference. Again, the build quality of the antenna is critical: a Class 3 or better RPE will minimize any role interference has in a mmWave link because a tightly-controlled radiation pattern not only directs RF energy with more precision, it is also more discriminating in which RF energy it will accept.



Example of a Class 3 antenna

V-BAND, E-BAND AND ATMOSPHERE

One limitation associated with V-band mmWave is the fact that V-band frequencies are readily absorbed by oxygen in the atmosphere, so link lengths are restricted to about one kilometer or less (Figure 11.2).

However, the inherently high capability for frequency reuse—combined with its small footprint—means that V-band antennas still have an important role to play in a backhaul network.

E-band, in contrast, does not have the same issue of oxygen absorption as V-band does, making it a smart choice for links several kilometers long, and a likely candidate for upgrading existing conventional microwave links, since mmWave bands can deliver Gbps capacity.

Gbps capacity

A link capable of delivering the accurate transmission of a billion bits of data per second

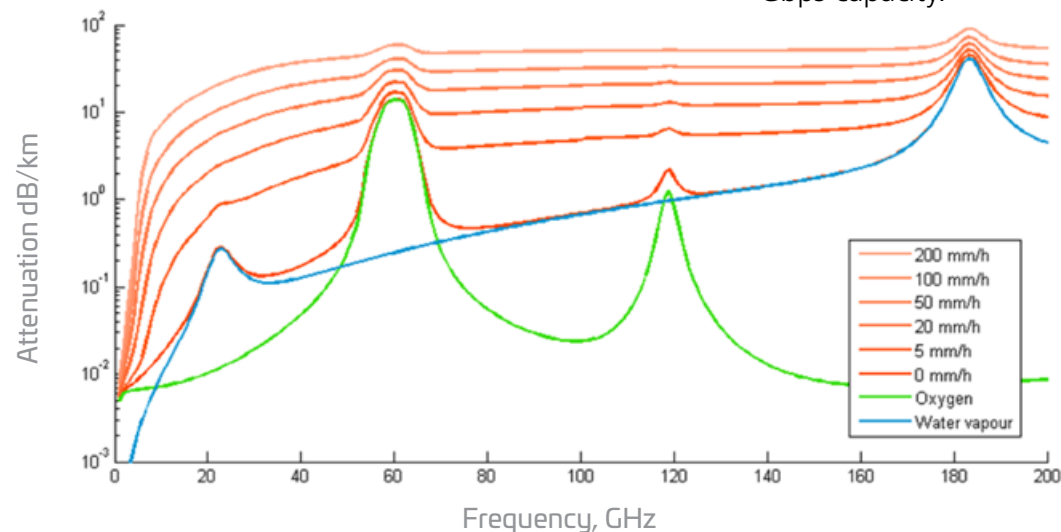


Figure 11.2: Attenuation due to atmospheric oxygen absorption of mmWaves

SMALLER ANTENNAS MEAN BIG OPPORTUNITIES

Although the higher frequencies deliver higher gains for a given antenna size, the atmospheric attenuation limits the range of these antennas. This is not an issue in dense urban networks, where links are typically very short, allowing the deployment of very small, inconspicuous antennas, that may even be embedded in the radio itself.



Figure 11.3: A 0.3 m CommScope ValuLine® antenna and a smaller mmWave antenna



Figure 11.4: Smaller mmWave antennas can be integrated into radio enclosures

Small size. Big difference.

The smallest conventional microwave antennas can be pretty small—about 0.3 m (1 ft).

mmWave antennas, on the other hand, offer ultra-low profiles in sizes as little as 12 cm (5 in) across.

MILLIMETER MICROWAVE (mmWave)

mmWave represents an incredible advance in point-to-point microwave communications. Leveraging the versatility of LOS links, mmWave systems provide capacity and reliability comparable to fiber-optic connections that are often difficult, expensive or even impossible to link to a needed location.

To realize the capacity, efficiency and TCO advantages of mmWave, however, it's vitally important to choose a quality antenna compliant with ETSI Class 3 or better, or interference can put the brakes on a much faster, more powerful and reliable backhaul network.

Chapter 11 summary

- mmWave frequencies are higher than conventional microwave systems
- E-band: 71–76 GHz and 81–86 GHz
- V-band: 57–64 GHz, expandable up to 66 GHz
- Characterized by antennas with narrow beams and high spectrum reuse
- Easier to license than conventional microwave
- Build quality extremely important: ETSI Class 3 or better
- V-band for short links of 1 km or less; E-band for longer links or upgrades

CHAPTER

12

Reference information and
commonly used tables



GLOSSARY

Main parts of an antenna

The key components of a microwave antenna—such as that manufactured by CommScope—are as follows:

Parabolic reflector (paraboloid)—a circularly symmetric specially shaped metal (usually aluminum) disc.

Feed system—also known as “launch unit”—the feed allows the transfer of the signal from the guided waveguide structure to the open air by efficiently illuminating the reflector.

Mount—the structural interface between the antenna and the mounting pole on the tower. It usually includes the azimuth and elevation adjustment mechanisms.

Shields—the cylindrical extension between the reflector and radome on high-performance antennas. They improve the radiation pattern of the antenna by reducing the sensitivity of the antenna at angles away from the antenna boresight. They

are lined with RF-absorbing material, which soaks up the unwanted radiation. As a consequence, they also improve the front-to-back performance of the antenna by reducing the sensitivity of the antenna in the region immediately behind it.

Radome—protective cover positioned over the aperture of the antenna to reduce windloading and protect the feed assembly from damage. The material selection, shape and thickness are critical to avoid degrading the performance of the antenna.

Interface plate—for direct-mounted antennas.

Side strut—also known as a sway-bar—a length of structural steel tubing used to provide additional rigidity to the antenna. Must be installed within the specified envelope to work effectively.

GLOSSARY

Common terms

Radio waves

Radio waves are a combination of electric and magnetic fields that travel through the atmosphere.

These electromagnetic waves travel at the speed of light (299,793,077 meters per second) and carry radiocommunications—they are often referred to as 'carriers.'

Frequency

Frequency describes the number of cycles a radio wave makes in one second of time.

One cycle per second is known as a Hertz.

Kilo-Hertz denotes 1,000 cycles per second.

Mega-Hertz denotes 1,000,000 cycles per second.

Giga-Hertz denotes 1,000,000,000 cycles per second.

Wavelength

Wavelength is the physical distance between similar points in a radio wave, separated by one cycle.

Frequency and wavelength are related by the following relationship:

$$\text{wavelength (m)} = 3 \times 10^8 / \text{frequency (Hz)}$$

GLOSSARY

Key MW antenna electrical parameters

Directivity

All antennas exhibit directive effects in that they are more sensitive to some directions than others. You'll be familiar with having to orientate your portable radio telescopic antenna in a particular direction for best reception—similarly, your television antenna on your house needs to point in a specific direction. This property of varying sensitivity with direction is called directivity.

Directivity is referenced against a practically impossible antenna to manufacture—namely an isotropic radiator.

Gain

Gain is another term used to describe the directional characteristics of an antenna and is very similar to directivity. Gain includes the inherent losses of the antenna system, and is therefore a much more meaningful figure of merit.

Gain = Directivity – Losses

The formula for Gain is:

$Ga\text{ (dBi)} = 10 \log_{10} \eta [4\pi A_a / \lambda^2]$

where Ga is the antenna gain,

η is the antenna efficiency, typically 0.55 corresponding to 55 percent

A_a is the antenna aperture area = $.25 \times \pi \times \text{dia}^2$,

λ is the operating wavelength, and

π is 3.1415926

GLOSSARY

Key MW antenna electrical parameters

Polarization

The term 'polarization' commonly refers to the electric field component of the radio wave. In terrestrial microwave antennas, the polarization of the radio waves will be either horizontal or vertical. That is, the electric field will be either horizontally or vertically orientated.

Co-polarization

The term "co-polarization" is used to describe the condition over a microwave hop where the transmit and receive polarizations are the same, e.g., either vertical or horizontal. We refer to the transmit and receive antennas as being co-polarized and is the wanted signal over a microwave hop.

Cross-polarization

This term is used to describe the condition over a microwave hop where the transmit and receive polarizations are orthogonal, or at right angles to each other.

Radiation pattern

Radiation patterns demonstrate the antenna's gain as a function of angle and provide an instant view of the antenna's directive properties. Think of a radiation pattern as a picture of the antenna's sensitivity as a function of angle. Patterns are measured both in the antenna's co-polarized mode of operation and in the cross-polarized condition.

Beamwidth

Microwave antennas are highly directive. However, beyond the main beam area, the directivity reduces into a number of side beams that are much smaller than the main beam and which repeat with generally lesser magnitude as they get farther away from the main beam.

The half-power beamwidth in degrees is the angular extent by which the power response has fallen to one half the level of the maximum level within the main beam. Typically referred to as the 3dB beamwidth.

GLOSSARY

Key MW antenna electrical parameters

XPD (cross-polar discrimination)

Cross-polarization discrimination, in dB, is the difference between the peak of the co-polarized main beam and the maximum cross-polarized signal over an angle twice the 3dB beamwidth of the co-polarized main beam.

Cross-polar discrimination, or XPD, is the term used to describe the antenna's ability to maintain radiated or received polarization purity between horizontally and vertically polarized signals.

In transmit mode, it is the proportion of signal that is transmitted in the orthogonal polarization to that required—while, in receive mode, it is the antenna's ability to maintain the incident signal's polarization characteristics.

$\text{XPD, dB} = -10 \log_{10} (\text{cross-polarized received power/co-polarized receive power})$

IPI (interport isolation)

IPI stands for interport isolation, and refers to dual-polarized antennas, where there are two ports on the feed—one for horizontally polarized radio waves and one for vertically polarized radio waves.

IPI is stated in 'dB' and is the level of polarization coupling or leakage between the two ports. Thus, if a radio wave signal were to be injected into the backport, for example, a very small proportion would be detected at the front port, and vice versa. The received signal is unwanted, and—if of too high a value—will cause errors in the radio system.

Front to back

The front to back ratio denotes the sensitivity of an antenna to radio waves in the region $180^\circ \pm 40^\circ$ from the main beam direction. That is, the area of space behind the antenna. It is defined in dB relative to the peak of the main beam.

GLOSSARY

Key MW antenna electrical parameters

Return loss

The antenna return loss is a figure that indicates the proportion of radio waves incident upon the antenna that are rejected as a ratio against those that are accepted. It is specified in 'dB' relative to a short circuit (100 percent rejection).

VSWR

VSWR is an alternative representation of return loss. It stands for voltage standing wave ratio, and is a reference to the actual voltages created within a transmission line system when there are forward and reflected radio waves propagating simultaneously.

VSWR and return loss are related by the following equations:

P_r = reflected power

P_i = incident power

r = magnitude of reflection coefficient

$$R = \sqrt{(P_r/P_i)}$$

$$VSWR = (1+r)/(1-r)$$

$$\text{Return loss (dB)} = -20 \times \log_{10}(r)$$

TABLES

The dB (POWER)

Ratio	dB equivalent	Mathematics	
1/10,000,000	-70dB	log 1/10,000,000 x10	Loss
1/1,000,000	-60dB	log 1/1,000,000 x10	
1/100,000	-50dB	log 1/1000,000 x10	
1/10,000	-40dB	log 1/10,000 x10	
1/1,000	-30dB	log 1/1,000 x10	
1/500	-27dB	log 1/500 x10	
1/100	-20dB	log 1/100 x10	
1/50	-17dB	log 1/50 x10	
1/10	-10dB	log 1/10 x10	
1/5	-7dB	log 1/5 x10	
1/4	-6dB	log 1/4 x10	
1/3	-4.75dB	log 1/3 x10	
1/2	-3dB	log 1/2 x10	
1/1.25	-1dB	log 1/1.25 x10	
1	0dB	log 1/1 x10	
2	3dB	log 2 x10	Gain
3	4.75dB	log 3 x10	
4	6dB	log 4 x10	
5	7dB	log 5 x10	
10	10dB	log 10 x10	
50	17dB	log 50 x10	
100	20dB	log 100 x10	
500	27dB	log 500 x10	
1000	30dB	log 1,000 x10	
10000	40dB	log 10,000 x10	
100000	50dB	log 100,000 x10	
1000000	60dB	log 1,000,000 x10	
10000000	70dB	log 10,000,000 x10	

TABLES

VSWR to return loss conversion table

VSWR	RL(dB)	VSWR	RL(dB)	VSWR	RL(dB)	VSWR	RL(dB)
1.001	66.025	1.029	36.895	1.057	31.147	1.085	27.794
1.002	60.009	1.03	36.607	1.058	31	1.086	27.696
1.003	56.491	1.031	36.327	1.059	30.856	1.087	27.6
1.004	53.997	1.032	36.055	1.06	30.714	1.088	27.505
1.005	50.484	1.033	35.792	1.061	30.575	1.089	27.411
1.006	50.484	1.034	35.537	1.062	30.438	1.09	27.318
1.007	49.149	1.035	35.29	1.063	30.303	1.091	27.266
1.008	47.993	1.036	35.049	1.064	30.171	1.092	27.135
1.009	46.975	1.037	34.816	1.065	30.04	1.093	27.046
1.01	46.064	1.038	34.588	1.066	29.912	1.094	26.957
1.011	45.24	1.039	34.367	1.067	29.785	1.095	26.869
1.012	44.489	1.04	34.151	1.068	29.661	1.096	26.782
1.013	43.798	1.041	33.941	1.069	29.538	1.097	26.697
1.014	43.159	1.042	33.763	1.07	29.417	1.098	26.612
1.015	42.564	1.043	33.536	1.071	29.298	1.099	26.528
1.016	42.007	1.044	33.341	1.072	29.181	1.1	26.444
1.017	41.485	1.045	33.15	1.073	29.066	1.102	26.281
1.018	40.993	1.046	32.963	1.074	28.952	1.104	26.12
1.019	40.528	1.047	32.78	1.075	28.839	1.106	25.963
1.02	40.086	1.048	32.602	1.076	28.728	1.108	25.809
1.021	39.667	1.049	32.427	1.077	28.619	1.11	25.658
1.022	39.867	1.05	32.256	1.078	28.511	1.112	25.51
1.023	38.885	1.051	32.088	1.079	28.405	1.114	25.364
1.024	38.52	1.052	31.923	1.08	28.299	1.116	25.221
1.025	38.7	1.053	31.762	1.081	28.196	1.118	25.081
1.026	37.833	1.054	31.604	1.082	28.093	1.12	24.943
1.027	37.51	1.055	31.449	1.083	27.992	1.122	24.808
1.028	37.198	1.056	31.297	1.084	27.892	1.124	24.675

TABLES

VSWR to return loss
conversion table
continued

VSWR	RL(dB)	VSWR	RL(dB)	VSWR	RL(dB)	VSWR	RL(dB)
1.126	24.544	1.182	21.576	1.39	15.747	1.84	10.581
1.128	24.415	1.184	21.489	1.4	15.563	1.86	10.437
1.13	24.289	1.186	21.403	1.41	15.385	1.88	10.298
1.132	24.164	1.188	21.318	1.42	15.211	1.9	10.163
1.134	24.042	1.19	21.234	1.43	15.043	1.92	10.032
1.136	23.921	1.192	21.151	1.44	14.879	1.94	9.904
1.138	23.803	1.194	21.069	1.45	14.719	1.96	9.78
1.14	23.686	1.196	20.988	1.46	14.564	1.98	9.66
1.142	23.571	1.198	20.907	1.47	14.412	2	9.542
1.144	23.457	1.2	20.828	1.48	14.264		
1.146	23.346	1.21	20.443	1.49	14.12		
1.148	23.235	1.22	20.079	1.5	13.979		
1.15	23.127	1.23	19.732	1.52	13.708		
1.152	23.02	1.24	19.401	1.54	13.449		
1.154	22.914	1.25	19.085	1.56	13.201		
1.156	22.81	1.26	18.783	1.58	12.964		
1.158	22.708	1.27	18.493	1.6	12.736		
1.16	22.607	1.28	18.216	1.62	12.518		
1.162	22.507	1.29	17.949	1.64	12.308		
1.164	22.408	1.3	17.692	1.66	12.107		
1.166	22.311	1.31	17.445	1.68	11.913		
1.168	22.215	1.32	17.207	1.7	11.725		
1.17	22.12	1.33	16.977	1.72	11.545		
1.172	22.027	1.34	16.755	1.74	11.37		
1.174	21.934	1.35	16.54	1.76	11.202		
1.176	21.843	1.36	16.322	1.78	11.039		
1.178	21.753	1.37	16.131	1.8	10.881		
1.18	21.664	1.38	15.936	1.82	10.279		

TABLES

Some typical
beamwidths as a
function of frequency
and antenna diameter

Dia/freq	2 GHz	6 GHz	11 GHz	15 GHz	23 GHz	40 GHz
1' dia	33.5°	11.1°	5.6°	4.5°	2.8°	1.7°
2' dia	17.2°	5.7°	3.4°	2.4°	1.6°	1.0°
4' dia	8.2°	2.8°	1.8°	1.2°	0.8°	0.4°
6' dia	5.5°	1.8°	1.0°	0.8°	0.5°	0.3°
8' dia	4.1°	1.4°	0.8°	0.6°	0.4°	0.2°
10' dia	3.3°	1.1°	0.7°	0.5°	0.3°	0.18°
12' dia	2.8°	0.9°	0.5°	0.4°	0.25°	0.15°
15' dia	2.2°	0.8°	0.4°	0.3°	0.2°	0.1°

Antennas with beamwidths below 0.5 are not practical for point-to-point links due to difficulties in alignment and the extremely stiff mounting structures required.

TABLES

Distance between antenna links (hops)

Frequency band	Frequencies, GHz	Typical maximum link length, km	Typical minimum link length, km
0.9 (unlicensed)	0.902–0.928	100	-
2.4 (unlicensed)	2.4–2.5	100	-
4	3.6–4.2	70	24
5	4.4–5.0	60	16
5 (unlicensed)	5.3, 5.4 and 5.8	50	-
L6	5.925–6.425	50	16
U6	6.425–7.125	50	16
L7	7.1–7.75	50	10
U8	7.75–8.5	50	10
10	10–10.7	20	10
11	10.7–11.7	20	10
13	12.7–13.25	20	6
15	14.4–15.35	20	6
18	17.7–19.7	20	2
23	21.2–23.6	20	2
26	24.25–26.5	20	2
28	27.5–29.5	15	2
32	31.0–33.4	10	1.5
38	37.0–40.0	10	1
42	40.5–43.5	10	1
60 (unlicensed)	57.0–66.0	1	-
80	71–76/81–86	5	-

The following table summarizes the typical single hop ranges that can be achieved at microwave frequencies.

TABLES

Waveguide flange hardware requirements by frequency band

Frequency range (GHz)	EIA WR standard output	IEC R	British WG	PDR/UDR (metric)	PBR/ UBR (metric)	UG/ choke (imperial)	CPR (G)/ CPR(F) (imperial)
3.30–4.90	WR229	R40	WG11A	M6	NA	1/4 -20	1/4 -20
3.94–5.99	WR187	R48	WG12	M6	NA	1/4 -20	1/4 -20
4.64–7.05	WR159	R58	WG15	M6	NA	1/4 -20	1/4 - 20
5.38–8.18	WR137	R70	WG14	M5	NA	#10-32	#10-32
6.58–10.0	WR 112	R84	WG15	M5	M5	#8-32	#8-32
8.20–12.5	WR90	R100	WG16	M4	M4	#8-32	#8-32
9.84–15.0	WR75	R120	WG17	M4	M4	#6-32	NA
11.9–18.0	WR62	R140	WG18	M4	M4	#6-32	NA
14.5–22.0	WR51	R180	WG21	M4	M4	#6-32	NA
17.6–26.7	WR42	R220	WG20	M3	M3	#4-40	NA
21.7–33.0	WR34	R260	WG21	M3	M3	#4-40	NA
26.4–40.1	WR28	R320	WG22	M3	M3	#4-40	NA

FLANGES

Flange selection

Flange	Generic type	Description	Mating (to seal)	Use
PBR 	IEC—metric	Square flange with gasket	Ideally will mate to the corresponding UBR flange. Can mate with another PBR flange using the gasket supplied on both flanges	Normally used at 7 GHz and above (WR112)
UBR	IEC—metric	Square flange without gasket	Must mate to the corresponding PBR flange	Normally used at 7 GHz and above (WR112)
PDR 	IEC—metric	Rectangular flange with gasket	Ideally will mate to the corresponding UDR flange. Can mate with another PDR flange using the gasket supplied on both flanges.	Normally used at 7 GHz and below (WR112); occasionally at higher frequencies
UDR	IEC—metric	Rectangular flange without gasket	Must mate to the corresponding PDR flange	Normally used at 7 GHz and below (WR112); occasionally at higher frequencies
CPR G 	EIA—imperial	Rectangular flange with gasket	Mates with another CPR G flange using the gasket supplied. Can also mate with the corresponding CPR F flange using a half-thickness gasket (ordered separately).	Available at 11 GHz (WR90) and lower frequencies
CPR F	EIA—imperial	Rectangular flange without gasket	Must mate with CPR G flange using a half-thickness gasket supplied	
UG choke cover 	EIA—imperial	Square flange with gasket	Ideally will mate with the corresponding UG cover flange. Can mate with another UG choke cover flange using the gasket supplied on both flanges.	Normally used at 13 GHz (WR75) and above
UG cover	EIA—imperial	Square flange without gasket	Must mate with corresponding UG choke cover flange.	Normally used at 13 GHz (WR75) and above

FLANGES

Flange mating table

	PDR	PBR	UDR	UBR	CPR G	CPR F	UG Choke Cover	UG Cover
PDR	✓	X	✓	X	?	?	X	X
PBR	X	✓	X	✓	X	X	✓	✓
UDR	✓	X	X	X	?	X	X	X
UBR	X	✓	X	X	X	X	✓	X
CPR G	?	X	?	X	✓	✓	X	X
CPR F	?	X	X	X	✓	X	X	X
UG Choke Cover	X	✓	X	✓	X	X	✓	✓
UG Cover	X	✓	X	X	X	X	✓	X

✓ Mates and can be pressurized

X Does not mate or cannot be pressurized

? May possibly mate—Contact manufacturer for exact details

PRESSURIZATION AND WAVEGUIDE

Total system volume

System volume is determined by adding up the volume of each air dielectric transmission line component for a given installation. For an Earth station antenna, the system volume may consist of less than one cubic foot inside the feed and combiner. For a large microwave or broadcast system, it may consist of many cubic feet of air contained in several hundred feet of air dielectric cable or waveguide.

The selected dehydrator must be capable of supplying this volume plus an anticipated leak rate of 1 percent, and provide sufficient capacity to maintain pressure during a 19°C (35°F) temperature drop in 60 minutes.

Some typical volume requirements for transmission lines are in the tables below.

Commonly used conversion factors

U.S. customary units (imperial)

$$1 \text{ lb/in}^2 = 69 \text{ mbar} = 6.9 \text{ kPa}$$

$$1 \text{ in H}_2\text{O} = 0.04 \text{ lb/in}^2 = 25.4 \text{ mm H}_2\text{O} = 0.25 \text{ kPa}$$

$$1 \text{ SCFM} = 60 \text{ SCFH} = 1670 \text{ l/hr}$$

$$1 \text{ gal} = 0.134 \text{ ft}^3 = 3.78 \text{ liters}$$

$$1 \text{ ft}^3 = 7.48 \text{ gal} = 28.32 \text{ liters} = 0.028 \text{ m}^3$$

$$1 \text{ in} = 25.4 \text{ mm} = 2.54 \text{ cm}$$

SI units (metric)

$$10 \text{ kPa} = 100 \text{ mbar} = 1.45 \text{ lb/in}^2$$

$$100 \text{ mm H}_2\text{O} = 1 \text{ kPa} = 0.14 \text{ lb/in}^2 = 4.01 \text{ in H}_2\text{O}$$

$$100 \text{ l/hr} = 3.53 \text{ SCFH} = 0.059 \text{ SCFM}$$

$$1 \text{ liter} = 0.26 \text{ gal} = 0.04 \text{ ft}^3$$

$$1 \text{ m}^3 = 1,000 \text{ liters} = 35.3 \text{ ft}^3 = 259.7 \text{ gal}$$

$$1 \text{ cm} = 10 \text{ mm} = 0.39 \text{ in}$$

PRESSURIZATION AND WAVEGUIDE

Typical volumes for
waveguide transmission
lines

CommScope part number	Frequency range	Volume ft ³ /1000 ft	Volume litres/1000m
Elliptical waveguide			
EW240	24.0–26.5 GHz	0.6	56
EW220	21.2–23.6 GHz	0.8	74
EW180	17.7–19.7 GHz	1.2	111
EW132	14.0–15.35 GHz	1.8	167
EW127A	11.7–13.25 GHz	2.7	251
EW90	10.5–11.7 GHz	3.6	334
EW85	8.5–9.8 GHz	4.2	390
EW77	7.125–8.5 GHz	6.3	585
EW64	7.125–7.750 GHz	7.8	725
EW63	6.425–7.125 GHz	9.2	855
EW52	5.6–4.25 GHz	11.3	1045
EW43	4.4–5.0 GHz	18.2	1690
EW37	3.58–4.26 GHz	21.1	1960
EW34	3.58–4.26 GHz	25	2323
EW28	2.9–3.4 GHz	36	3345
EW20	2.5–2.7 GHz	60.5	5621
EW17	1.7–2.3 GHz	71	6596
Rectangular waveguide			
WR42	17.7–26.5 GHz	0.5	46
WR62	12.4–18.0 GHz	1.3	124
WR75	10.0–15.0 GHz	2	181
WR90	8.2–12.4 GHz	2.5	232
WR112	7.05–10.0 GHz	3.9	362
WR137	5.85–8.2 GHz	6	551
WR159	4.9–7.05 GHz	8.8	817
WR187	3.95–5.85 GHz	11.3	1053
WR229	3.3–4.9 GHz	18.2	1691

ELLIPTICAL WAVEGUIDE SPACING

Recommended Maximum Hanger Spacing for Elliptical Waveguide

Recommended Maximum Hanger Spacing for Elliptical Waveguide, m (ft)									
Waveguide Type Maximum Wind- speed	160km/h (100mph)			200km/h (125mph)			240km/h (150mph)		
Radial Ice	No ice	13mm (0.5in)	25mm (1in)	No Ice	13mm (0.5in)*	25mm (1in)	No ice	13mm (0.5in)	25mm (1in)
EW17	1.8 (6)	1.8 (6)	1.8 (6)	1.8 (6)	1.8 (6)	1.7 (5.5)	1.5 (5)	1.5 (5)	1.35 (4.5)
EW20	1.8 (6)	1.8 (6)	1.8 (6)	1.7 (5.5)	1.7 (5.5)	1.5 (5)	1.35 (4.5)	1.35 (4.5)	1.2 (4)
EW28	1.8 (6)	1.8 (6)	1.8 (6)	1.5 (5)	1.5 (5)	1.35 (4.5)	1.2 (4)	1.2 (4)	1.0 (3.5)
EW34	1.8 (6)	1.8 (6)	1.7 (5.5)	1.35 (4.5)	1.35 (4.5)	1.2 (4)	1.2 (4)	1.0 (3.5)	1.2 (4)
EW37	1.7 (5.5)	1.7 (5.5)	1.5 (5)	1.35 (4.5)	1.35 (4.5)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)
EW43	1.5 (5)	1.5 (5)	1.35 (4.5)	1.2 (4)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	1.0 (3.5)	0.9 (3)
EW52	1.35 (4.5)	1.35 (4.5)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)	0.9 (3)	0.9 (3)	0.75 (2.5)
EW63	1.2 (4)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.75 (2.5)	0.75 (2.5)	0.6 (2)
EW64	1.35 (4.5)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW77	1.35 (4.5)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW85	1.35 (4.5)	1.2 (4)	1.0 (3.5)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW90	1.35 (4.5)	1.2 (4)	0.9 (3)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW127A	1.35 (4.5)	1.2 (4)	0.9 (3)	1.0 (3.5)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW132	1.5 (5)	1.2 (4)	0.9 (3)	1.2 (4)	0.9 (3)	0.75 (2.5)	0.9 (3)	0.75 (2.5)	0.6 (2)
EW180	1.5 (5)	1.2 (4)	0.9 (3)	1.2 (4)	0.9 (3)	0.75 (2.5)	1.0 (3.5)	0.75 (2.5)	0.6 (2)
EW220	1.5 (5)	1.2 (4)	0.9 (3)	1.2 (4)	0.9 (3)	0.75 (2.5)	1.0 (3.5)	0.75 (2.5)	0.6 (2)
EW240	1.5 (5)	1.2 (4)	0.9 (3)	1.2 (4)	0.9 (3)	0.75 (2.5)	1.0 (3.5)	0.75 (2.5)	0.6 (2)

*Standard survival limit for microwave systems

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