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Welcome to

Microwave 101

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Microwave 101 Webinar Series

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TODAY'S PRESENTER:

Joe Marzin
Director, Technology Group

DAY 1: **Microwave Fundamentals—Part I**
- Microwave Components
- RF Propagation
- Field Survey

DAY 2: **Microwave Fundamentals—Part II**
- Path Reliability
- Path Design Considerations
- iQ·link®—Microwave Design Software (Live Demo)

DAY 3: **Understanding the Frequency Coordination Process**
- Interference Analysis
  - Microwave
  - Earth Station
- Frequency Planning & Protection
- FCC Licensing & Management
- FCC Regulatory Updates (6 GHz, 80 GHz, 13 GHz)

Microwave Fundamentals—Part I

1. Microwave Components

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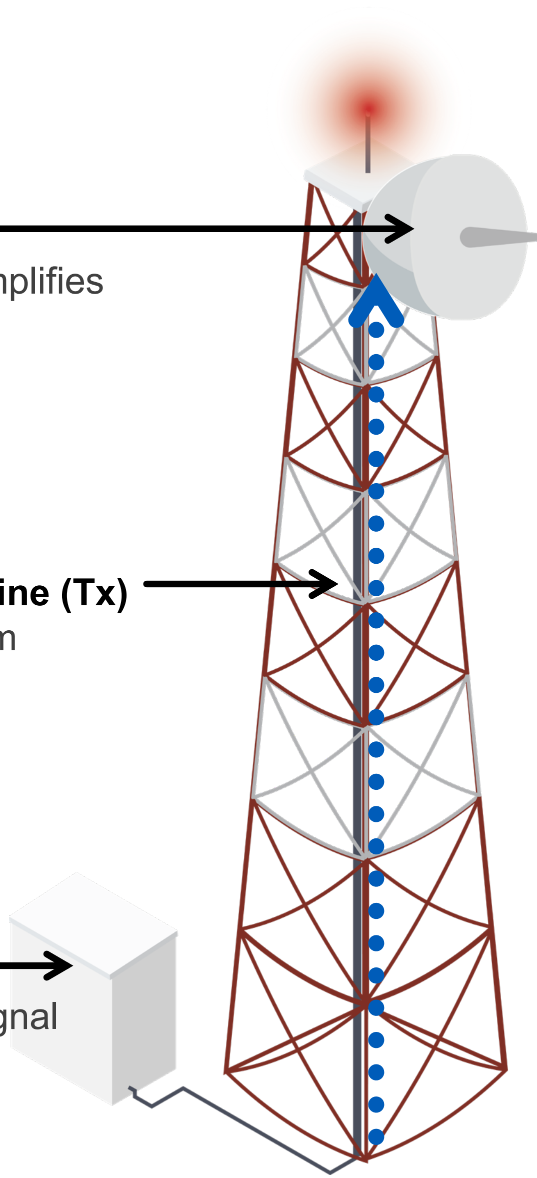


Antenna (Tx)
transmits and amplifies the signal

Transmission Line (Tx)
brings signal from radio to antenna

Radio (Tx)
generates the signal

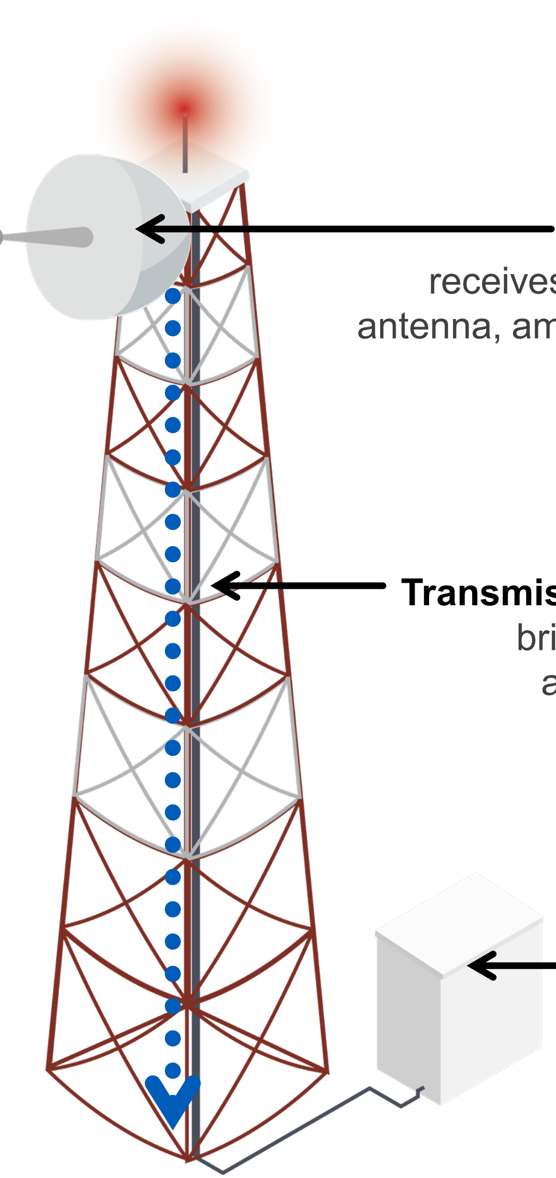
SIGNAL

What is a microwave path?

A connection from one point to another that transmits data via microwaves

(also called a “link” or a “hop”)

RECEIVING END

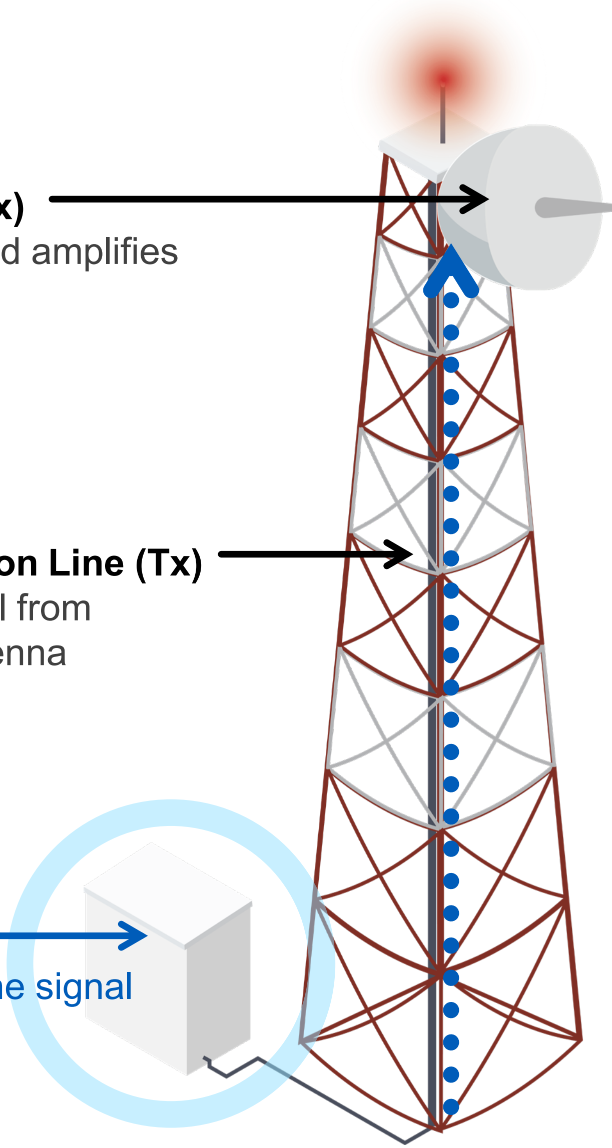


Antenna (Rx)
receives signal from Tx antenna, amplifying it again

Transmission Line (Rx)
brings signal from antenna to radio

Radio (Rx)
receives signal

TRANSMITTING END



Antenna (Tx)
transmits and amplifies the signal

Transmission Line (Tx)
brings signal from radio to antenna

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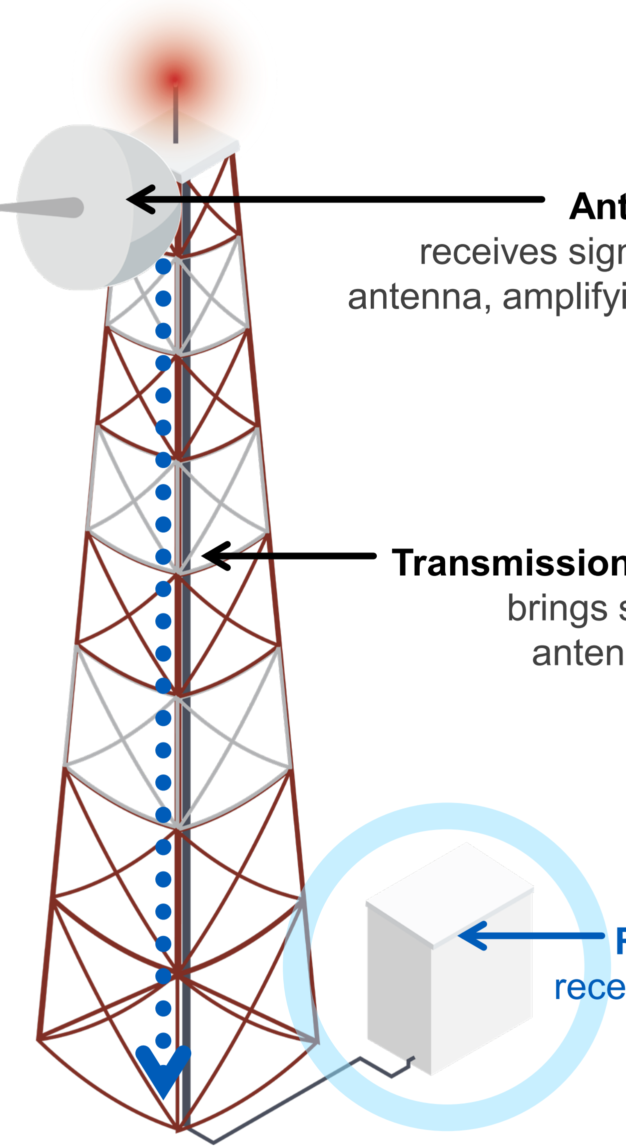
generates the signal

SIGNAL

RECEIVING END



Antenna (Rx)
receives signal from Tx antenna, amplifying it again

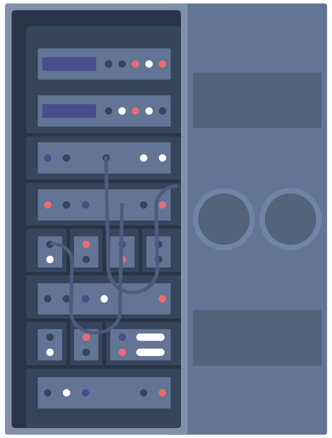
Transmission Line (Rx)
brings signal from antenna to radio

Radio (Rx)
receives signal

What is the function of the radio?

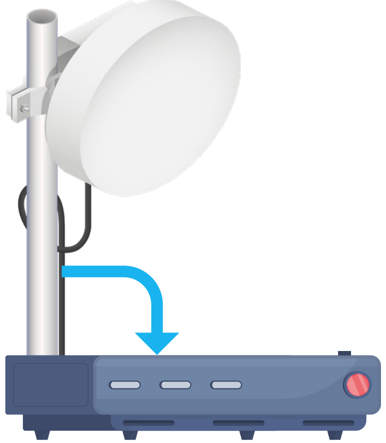
Transforms information to be transmitted over the air and converts back to original form when received

MICROWAVE COMPONENTS | RADIO CONFIGURATION



ALL INDOOR

Rack-mounted inside shelter with transmission line running to outdoor antenna



SPLIT-MOUNT

Outdoor RF unit mounted close to the antenna and indoor unit with interfaces and modem in the rack within shelter

ALL OUTDOOR

Entire unit is outdoor mounted behind the antenna

- ✓ Easy maintenance and upgrades (no tower climbs)
- ✓ Higher transmission line losses
- ✓ Typically requires waveguide

- ✓ Eliminates waveguide and/or high transmission line losses
- ✓ Easy maintenance of indoor unit
- ✓ Requires inside rack space and tower climbs for access to the radio unit

- ✓ Eliminates the need and cost for indoor space
- ✓ If not installed on an easy to access rooftop, requires tower climbs for maintenance and upgrades

COMMON TERMS

Power
Radio transmitter output power at the antenna port (dBm)

Bandwidth
The overall occupied spectrum that falls within a specified industry mask (FCC)

Received Signal Level (RSL)
Signal level at the receiver input terminal (dBm)

Throughput (data rate)
The number of bits, characters, or blocks passing through a communications system over a period of time (Mbps)

Bit Error Rate (BER)
Number of errored bits out of the total received over a period of time

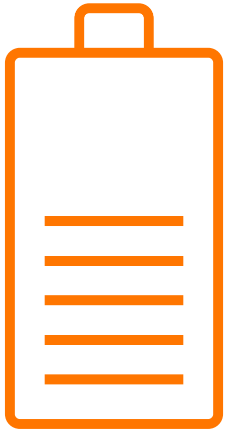
Receiver Threshold
Minimum receiver input level below which BER becomes excessive

Saturation
Maximum receiver input level above which BER becomes excessive

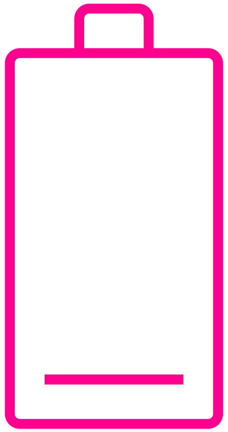
ATPC radios adjust power based on path fading

Automatic Transmitter Power Control (ATPC)
Transmitter output power automatically adjusts based on path fading detected at the far-end receiver

Maximum Transmitter Power
The power that will not be exceeded at any time



Coordinated Transmitter Power
The power used in calculating interference levels for frequency coordination



Nominal Transmitter Power
The power in normal, unfaded conditions, at or below the coordinated power

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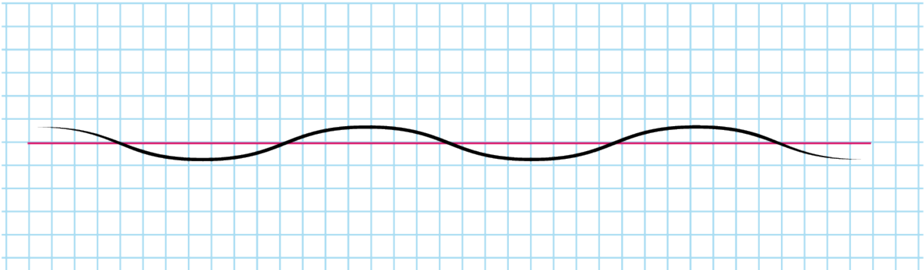
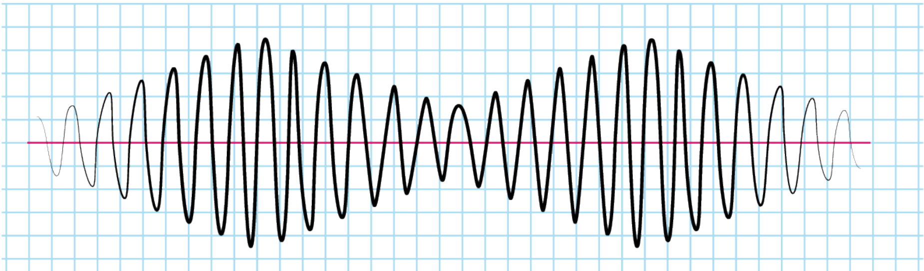
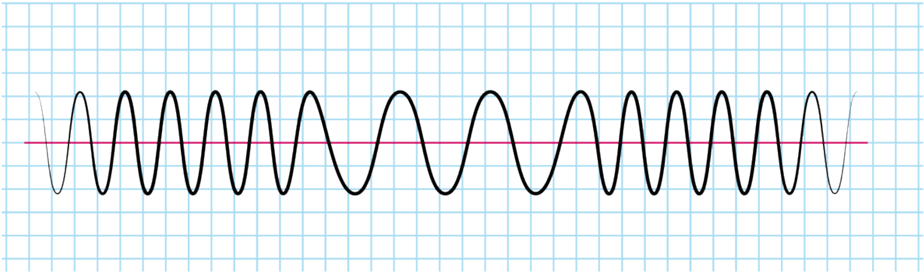
DATA SIGNAL



AMPLITUDE MODULATION (AM)



FREQUENCY MODULATION (FM)

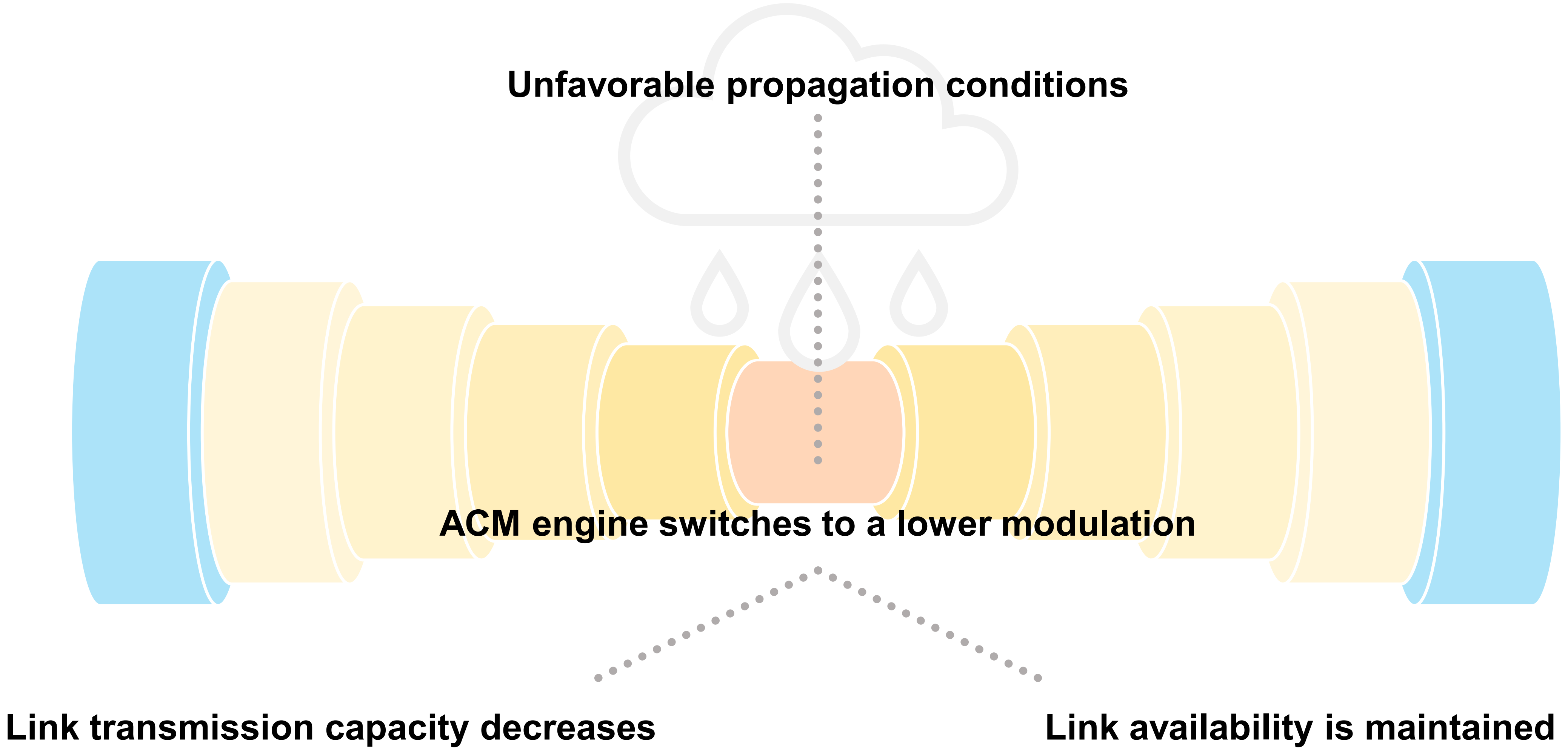


What is **Modulation**?

The process of varying one or more properties of a periodic waveform, called the carrier signal, with a modulating signal that contains information to be transmitted.

$$v_{bp}(t) = A(t)\cos\left[\omega_c t + \phi(t)\right]$$

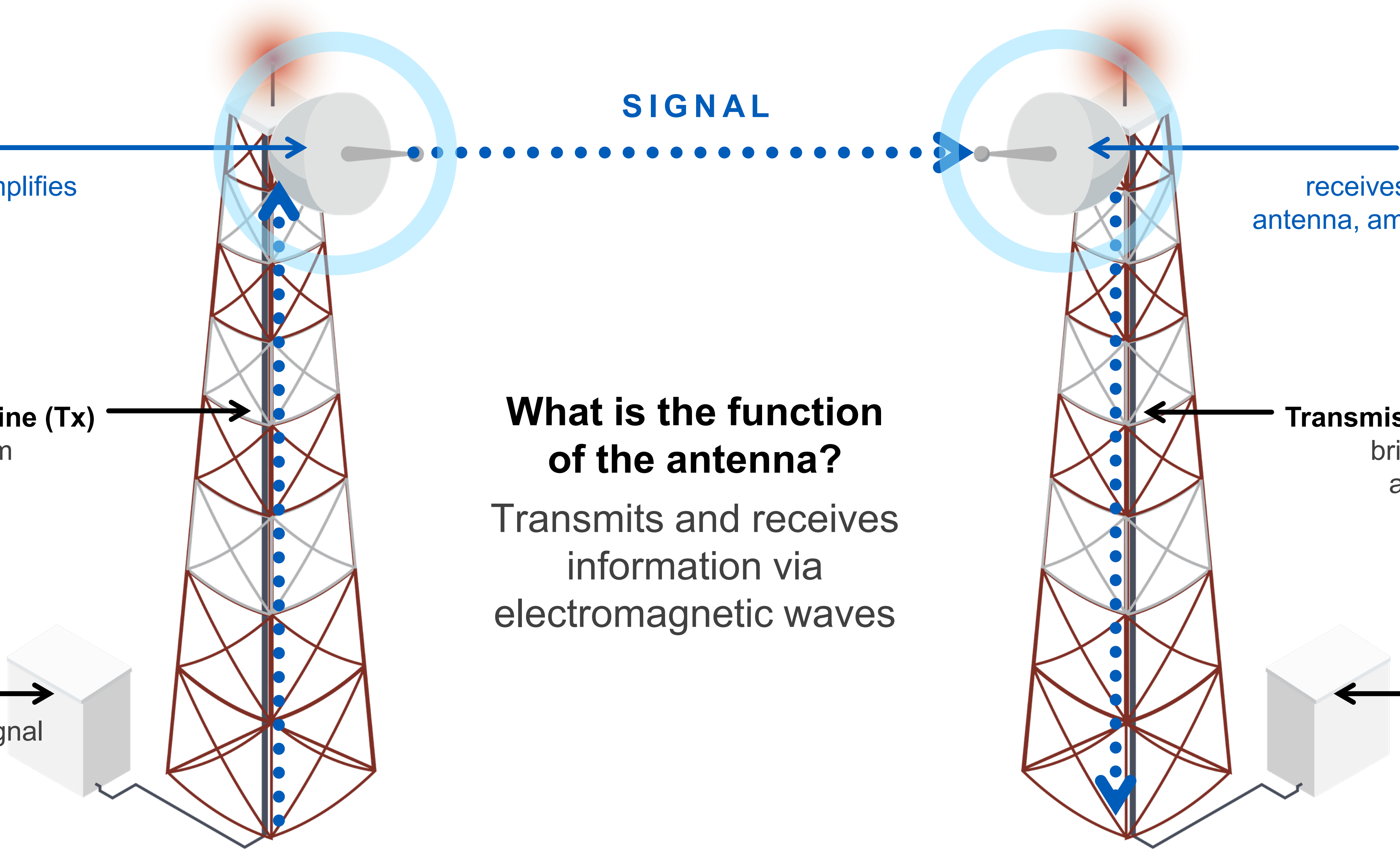
Adaptive Coding & Modulation (ACM)



Adaptive Coding & Modulation

Modulation	Traffic Data Rate (Mbps)	Composite Fade Margin (dB)	Reliability (%)
4096 QAM	544	11.2	99.226073
2048 QAM	508	16.2	99.755188
1024 QAM	460	20.2	99.902492
512 QAM	408	24.7	99.965367
256 QAM	356	28.2	99.984515
128 QAM	308	32.2	99.993824
64 QAM	270	34.7	99.996525
32 QAM	202	39.1	99.998764
16 QAM	180	41.7	99.999307
QPSK	76	53.6	99.999955

6.1 GHz link with path length of **7.16 mi**



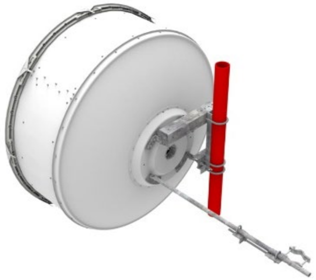
What is the function of the antenna?

Transmits and receives information via electromagnetic waves

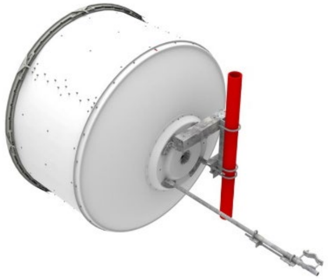
MICROWAVE ANTENNA

- ✓ **Performance**
- ✓ **Interference Mitigation**
- ✓ **Cost**

ValuLine®
Low Side-lobe
High Performance
VHLPX



ValuLine®
Low Side-lobe
High Performance
HX



Sentinel®
Ultra-low Side-lobe
Ultra High Performance
USX

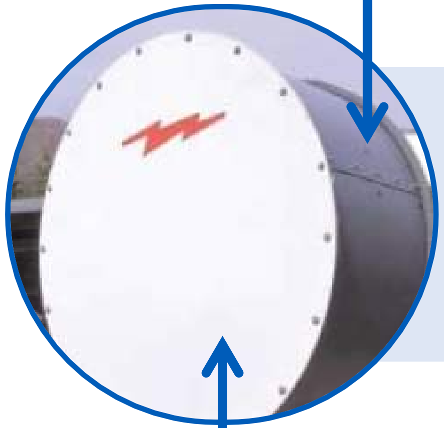
Sentinel®
Ultra-low Side-lobe
Ultra High Performance
SHPX

One Antenna: Multiple ODUs, two distinct bands

- ✓ 80/18 GHz
- ✓ 80/23 GHz
- ✓ 6/11 GHz

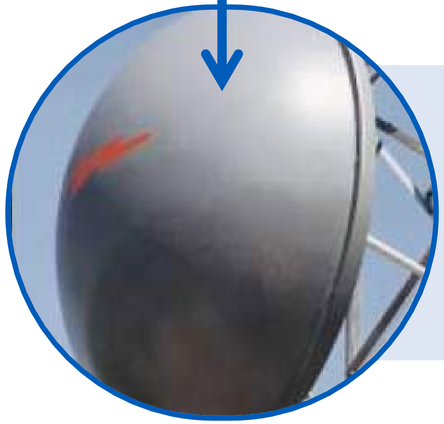


SHROUD

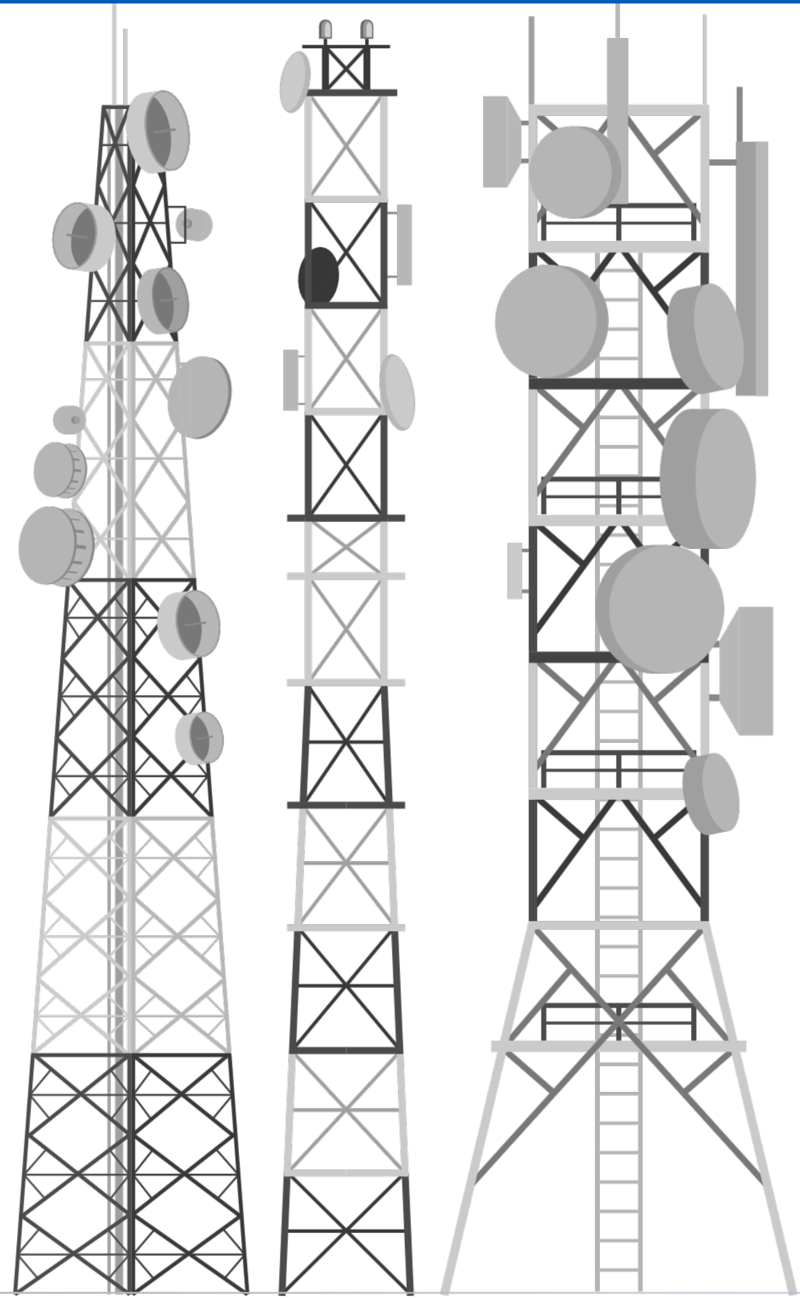


Shrouds provide off-angle suppression to reduce interference potential

RADOME



Radomes protect antenna feeds from ice, snow and dirt for better reliability and longer life



Antenna Gain = relative measure of antenna's ability to direct signal in a particular direction

VARIABLE	RELATIONSHIP
Antenna Size	**Larger** Antenna → **Higher** Gain
Frequency Band	**Higher** Frequency Band → **Higher** Gain
Antenna Beamwidth	**Larger** Antenna → **Narrower** Beamwidth

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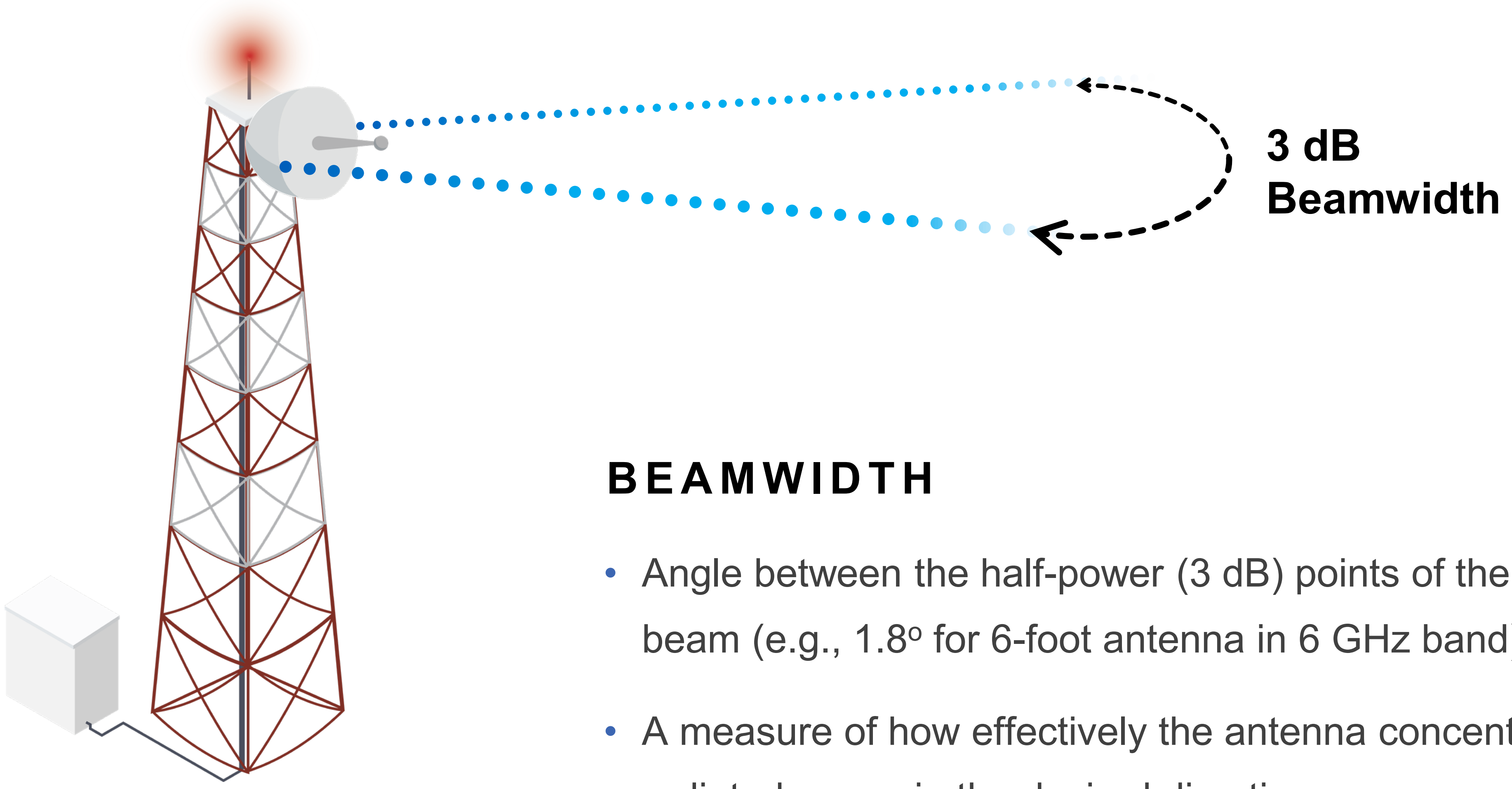
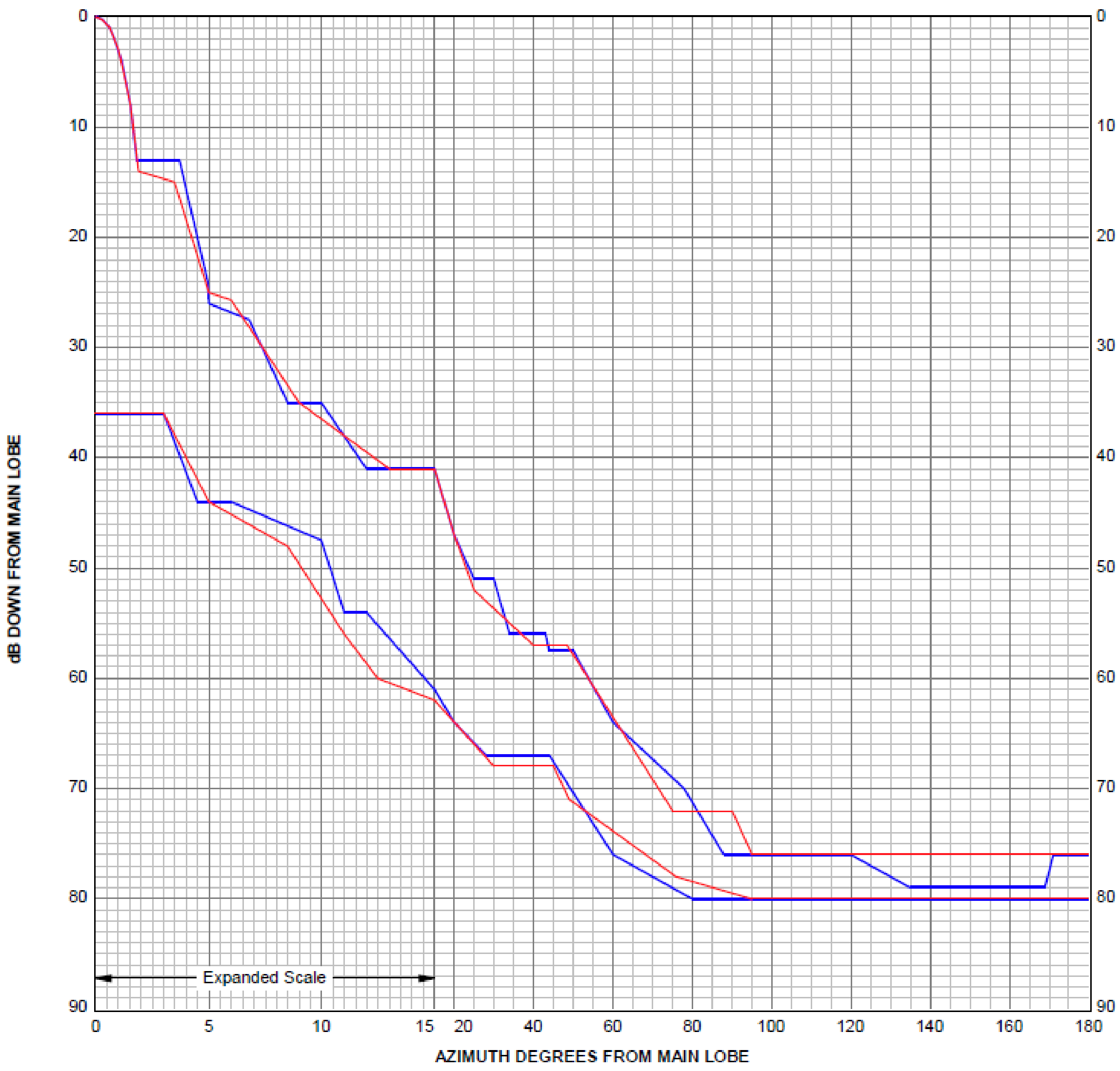


BEAMWIDTH

- Angle between the half-power (3 dB) points of the main beam (e.g., 1.8º for 6-foot antenna in 6 GHz band)
- A measure of how effectively the antenna concentrates the radiated power in the desired direction



RADIATION PATTERN ENVELOPE

Antenna Type Number: USX6-6W
6.00 Foot Antenna 5.925-7.125 GHz Dual Polarized
Gain: 38.80 dBi at 6.525 GHz
Envelope for a Horizontally Polarized Antenna (HH, HV)
Envelope for a Vertically Polarized Antenna (VV, VH)

For further information, ask for Andrew Bulletin 1032, "Radiation Pattern Envelopes".

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RPE 7373

Engineering Approved:
31 October 2017

RPE for the USX6-6W

This antenna is symmetrical so only 0-180 degrees is shown

FCC PART 101.115 ANTENNA CATEGORIES

CATEGORY A

- Highest performance category
- Highest level of frequency reuse
- Needed in congested areas

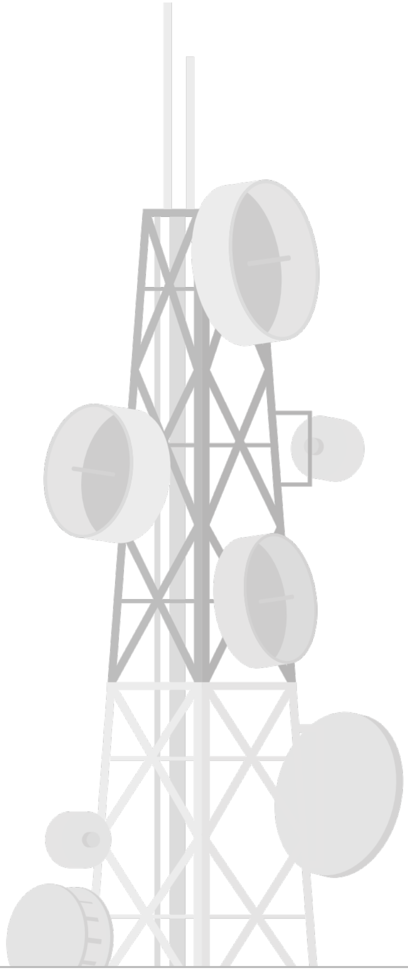
CATEGORY B1

- Lower performance category
- Subject to FCC upgrade clause

CATEGORY B2

- Newest category
- High performance, small diameter
- Subject to FCC upgrade clause

CATEGORY B2 ANTENNAS

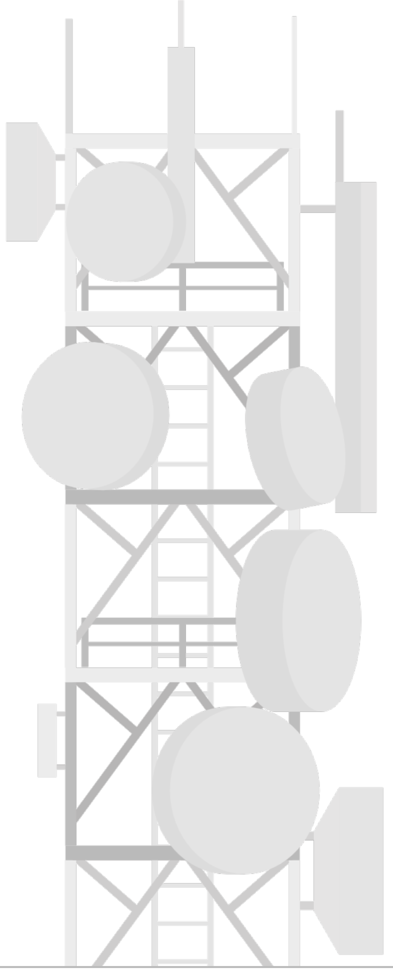


Smaller category B2 antennas have excellent side lobe suppression

+

Previous category B became category B1

Frequency Band (GHz)	**Diameter** (Feet)
6.1 / 6.7	3
18	1
23	0.75 (8 inch)



WHY **AUTO-ALIGN** ANTENNA SYSTEMS?

Microwave **antennas are regularly mounted in exposed environments** or on support structures that may not be ideal

Any movement of the support structure can result in antenna movement that results in **lower data rates, or the line of sight being lost and the link dropping out**

Issue at higher frequencies such as 80 GHz (E-band) where antenna 3 dB beamwidths are extremely narrow

E-band

The desire to push E-band transmission over longer distances means that **initial and continuous link alignment becomes difficult**

This has driven the **need for E-band antennas that can adjust signal direction** to maintain link throughput

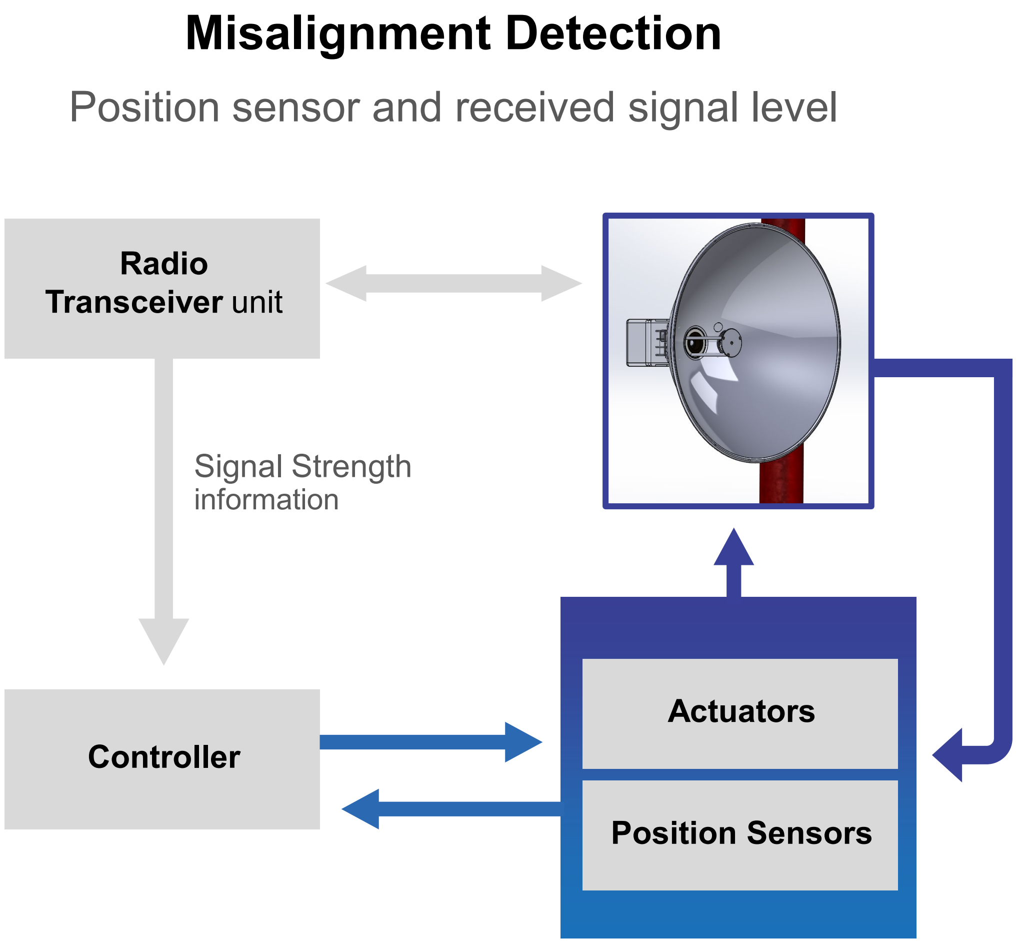
Mitigates the risk of **twist/sway** and **thermal expansion** of the antenna support structure

Develop a beam steering system for **electrically large** (≥2 ft/ 0.6 m) parabolic reflector antennas at E-band

20 sec video

0.6 m (2 ft) and 0.9 m (3 ft) antennas are under development

HOW DOES AUTO-ALIGNMENT **WORK**?

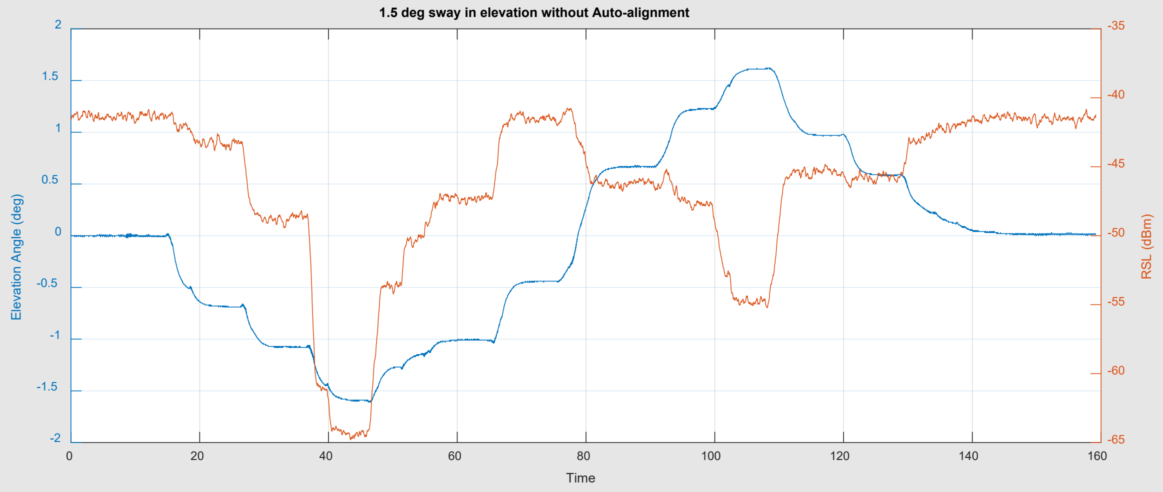


- The antenna beam is adjusted based on inputs from both **position sensors and radio RSL levels**
- Radio connection through an **OEM-specific cable**
- Initial set-up of the system **calibrates the position sensors →** to discriminate between RSL drops due to atmospheric conditions and actual antenna movement
- When a combination of antenna movement and RSL drop is observed, the auto-align antenna system **adjusts the antenna beam** to ensure the link is optimized

Antenna moving in elevation between **+1.5°** and **-1.5°**

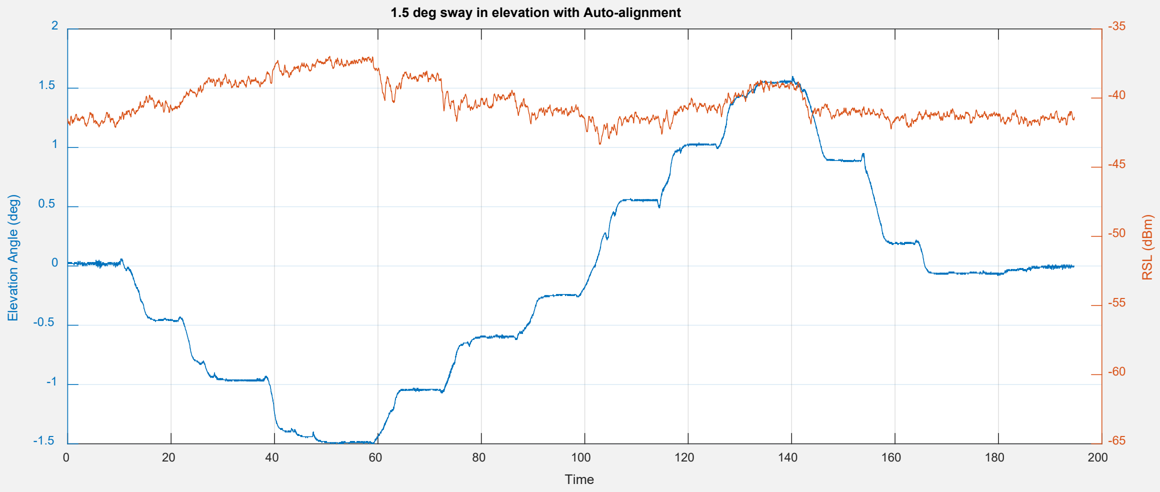
No auto-alignment

(↓) the signal level drop reaches 25 dB

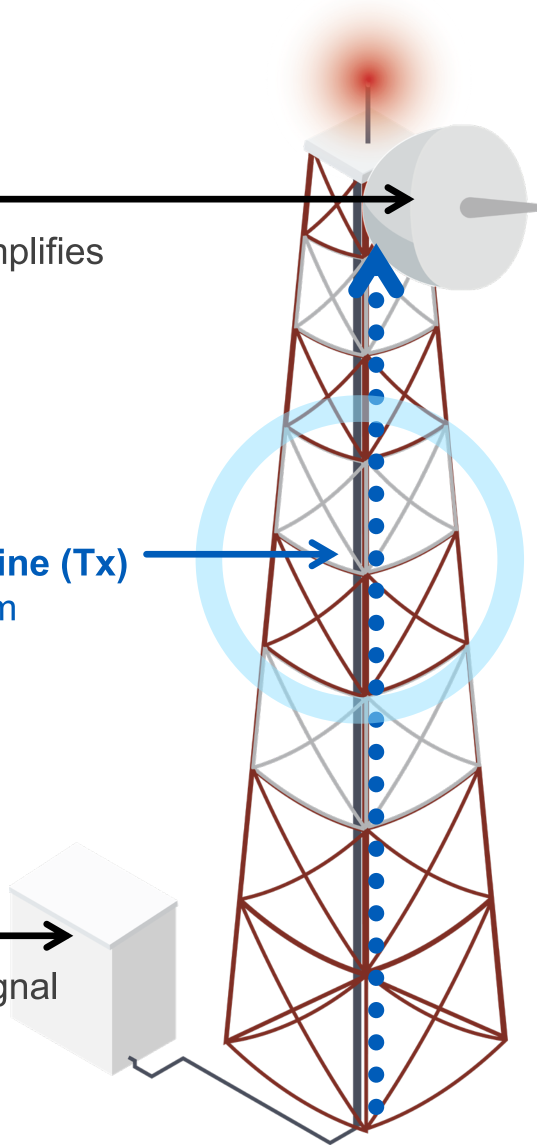


With auto-alignment

(=) the signal level is maintained as the antenna moves



TRANSMITTING END



Antenna (Tx)
transmits and amplifies the signal

Transmission Line (Tx)
brings signal from radio to antenna

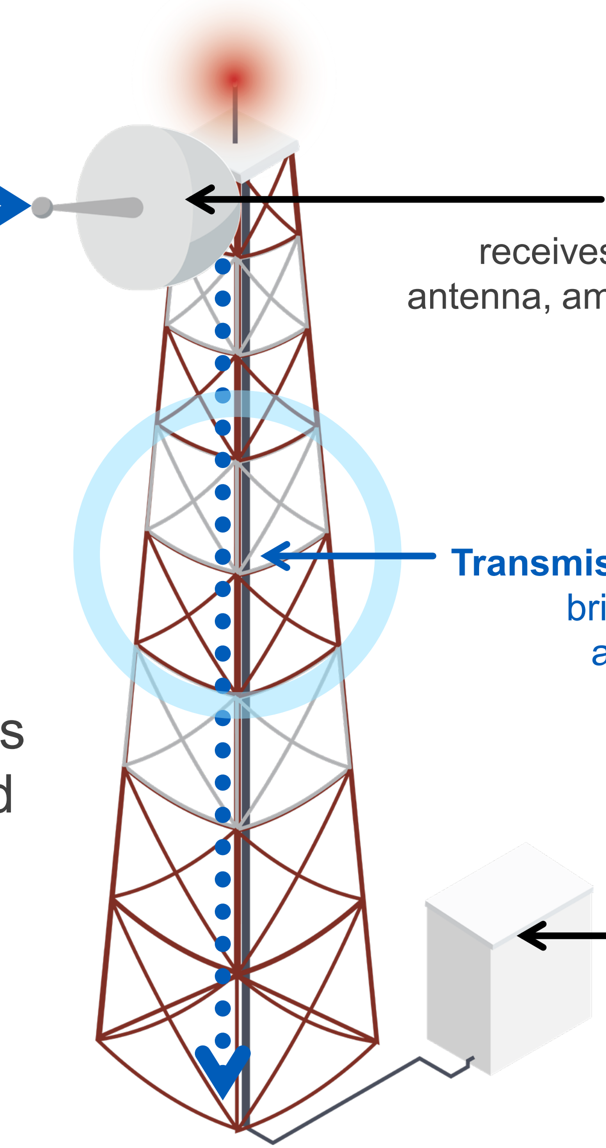
Radio (Tx)
generates the signal

SIGNAL

How are the antenna and radio connected?

The transmission line connects the two unless direct-mounted

RECEIVING END



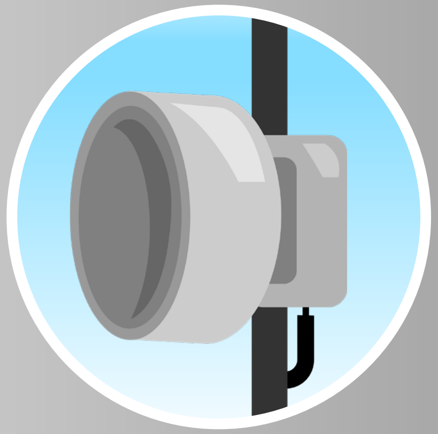
Antenna (Rx)
receives signal from Tx antenna, amplifying it again

Transmission Line (Rx)
brings signal from antenna to radio

Radio (Rx)
receives signal

Frequency Band	Elliptical Waveguide (dB / 100 ft)
6.1 GHz	**1.43**
11 GHz	**3.06**
18 GHz	5.91
23 GHz	8.34

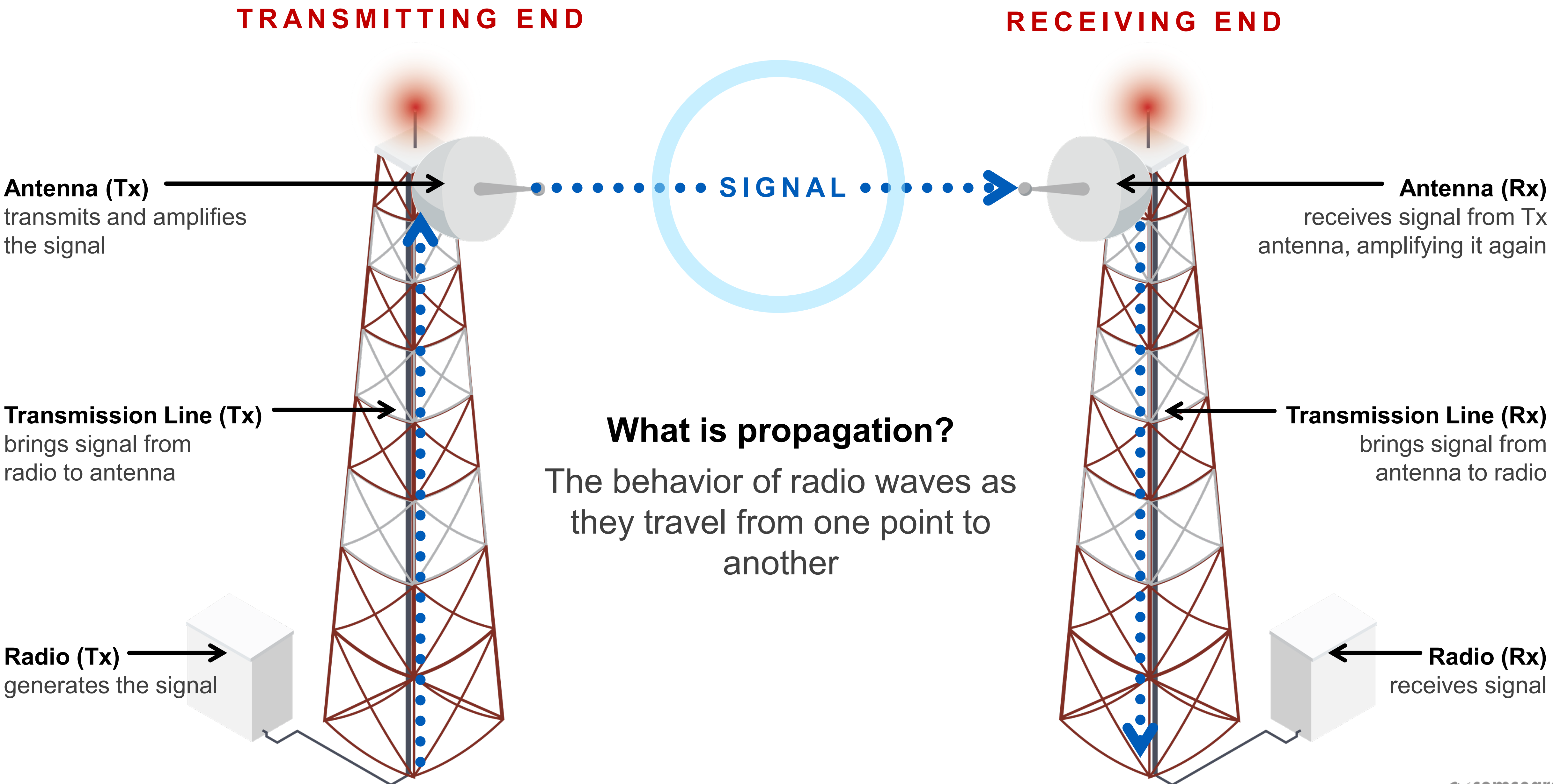
4-11 GHz



>11 GHz

Microwave Fundamentals—Part I

2. RF Propagation



What is propagation?

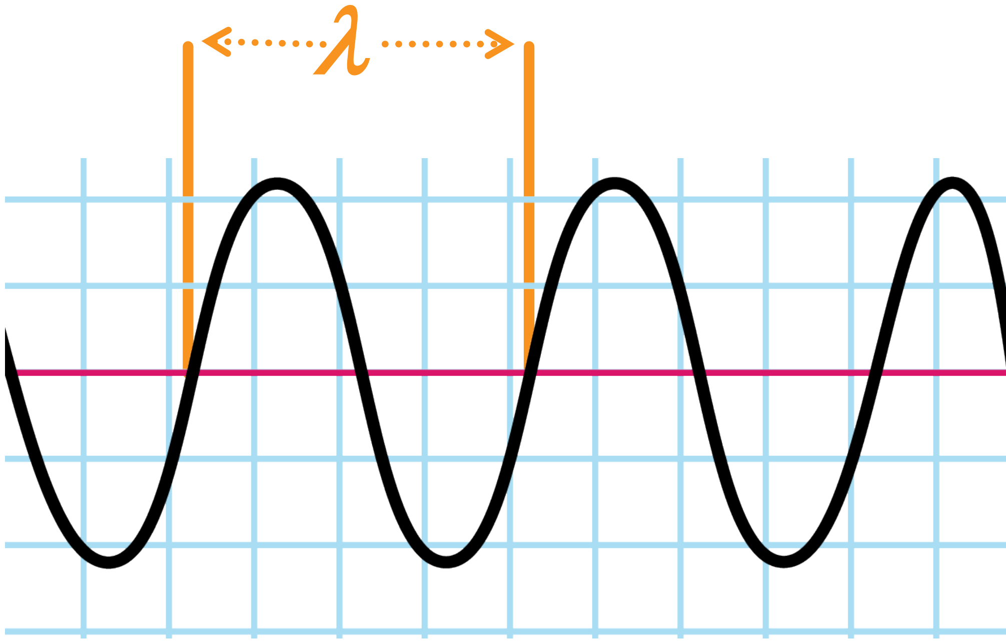
The behavior of radio waves as they travel from one point to another

Frequency (f)
Number of repetitions (cycles) per second (Hz)

Period (τ)
Duration of a Single Cycle (seconds)

Wavelength (λ)
Distance wave travels in one period

Speed of Light (c)
$= 2.99792458 \times 10^{8}$ m/s



$f = 1/\tau = c/\lambda$

The difference between **transmitted effective radiated power & received signal level** is called ***Path Loss***

Typical types of path loss:

1. **Free Space**
2. **Atmospheric Absorption**
3. **Diffraction**
4. **Refraction**

The portion of Path Loss attributed to the **spreading effect of a signal** is called

Free Space Path Loss

it increases for larger distances and higher frequencies

FREE SPACE PATH LOSS EQUATION

$FSPL_{dB} = 96.6 + 20\log(f_{GHz}) + 20\log(d_{mi})$ dB

EXAMPLE

What's the FSPL for a **20** mi path at **6.1** GHz?

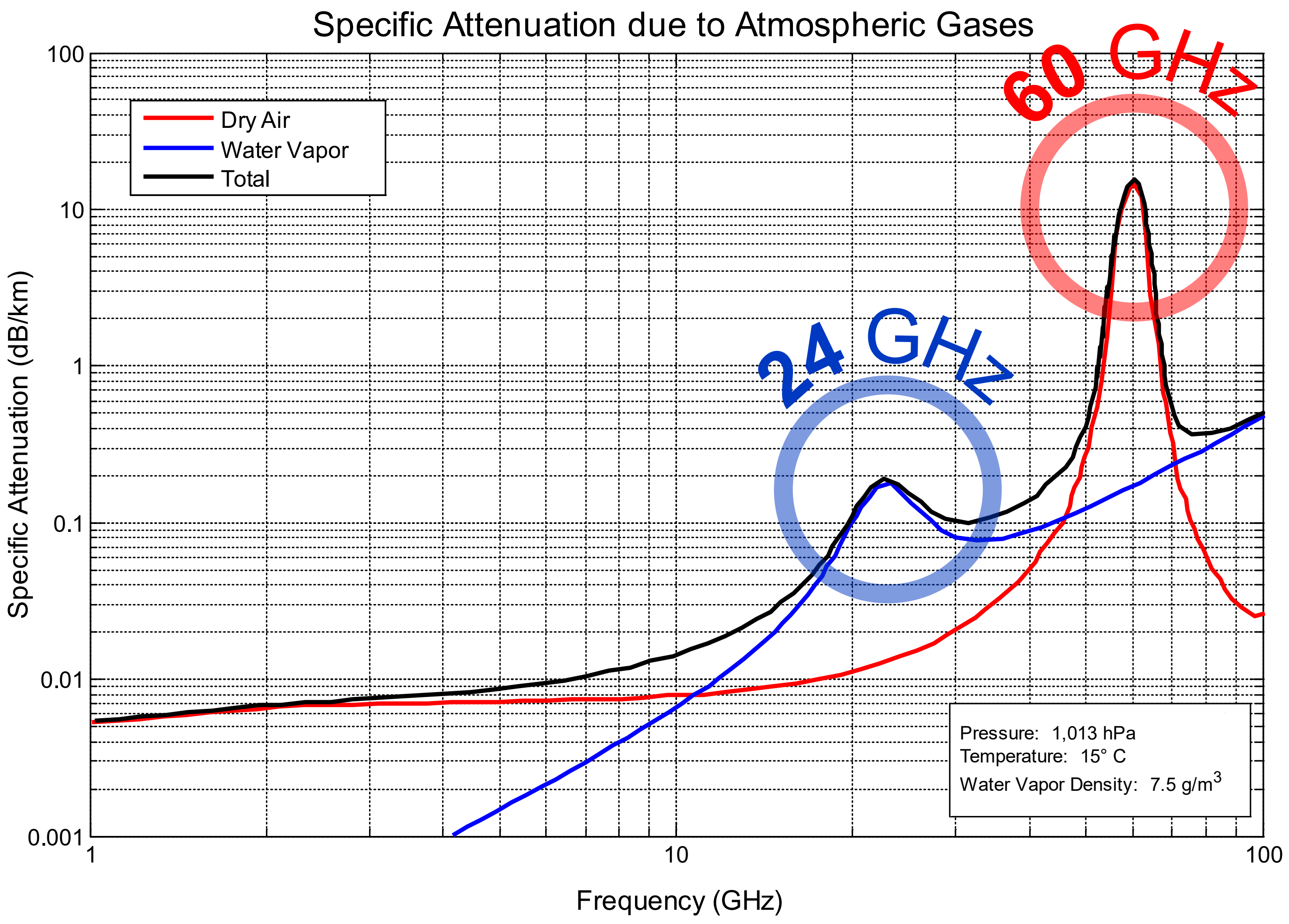
$FSPL = 96.6 + 20\log(6.1) + 20\log(20)$ dB = 138.3 dB

What's the FSPL at 10 mi? **132.3 dB**

What's the FSPL at 40 mi? **144.3 dB**

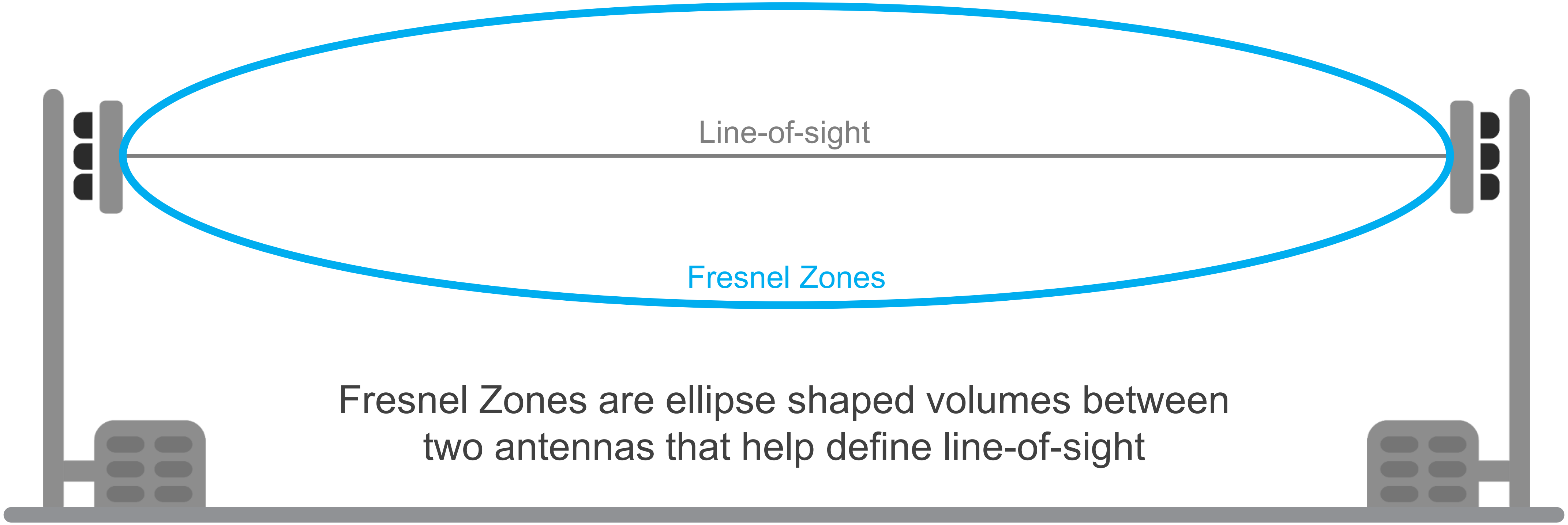
Path loss attributed to the properties of the medium that the signal traverses is **atmospheric absorption**

Some frequencies are affected more than others by **water vapor** or **oxygen**



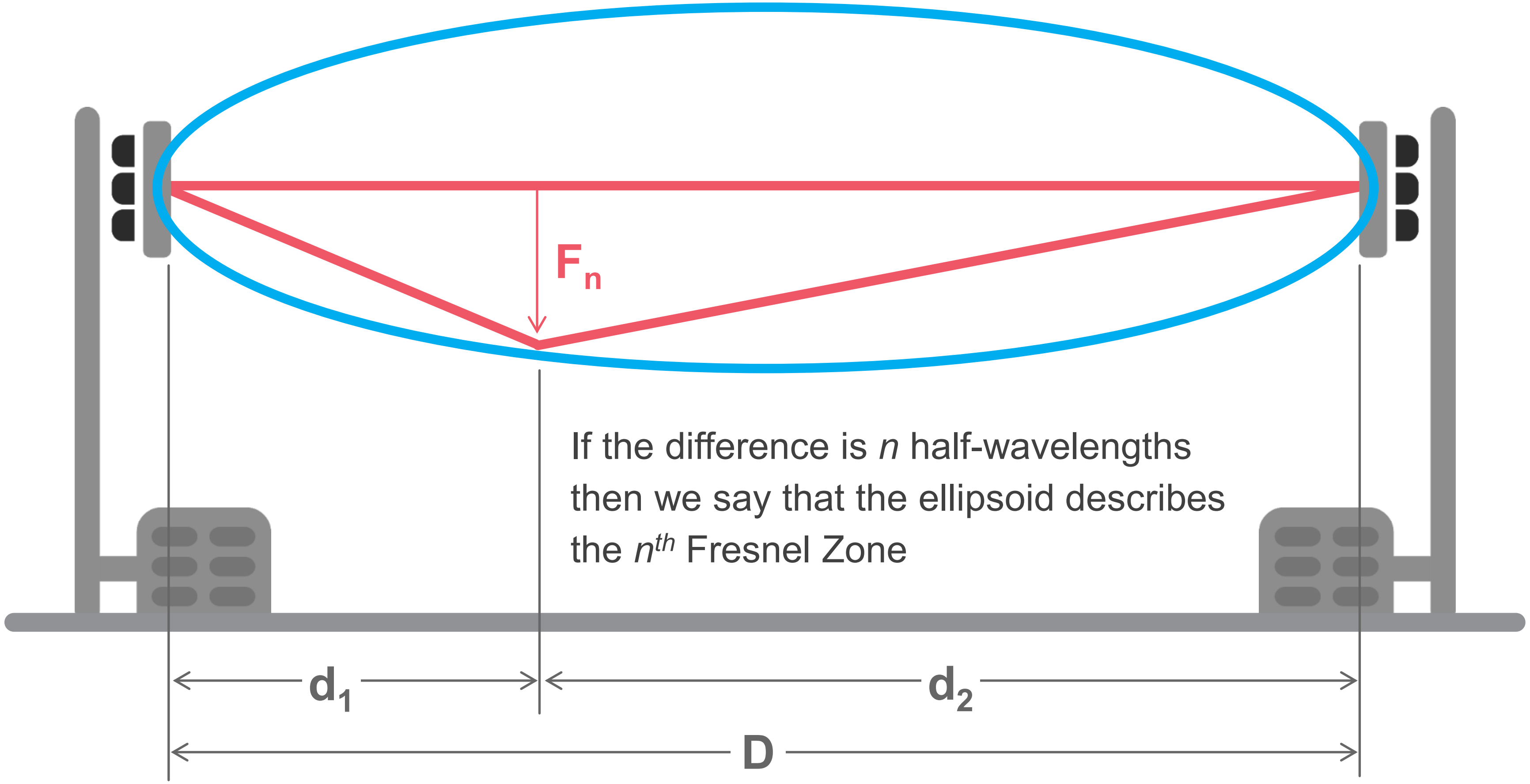
To evaluate effects of **refraction** and **diffraction**, we need to consider

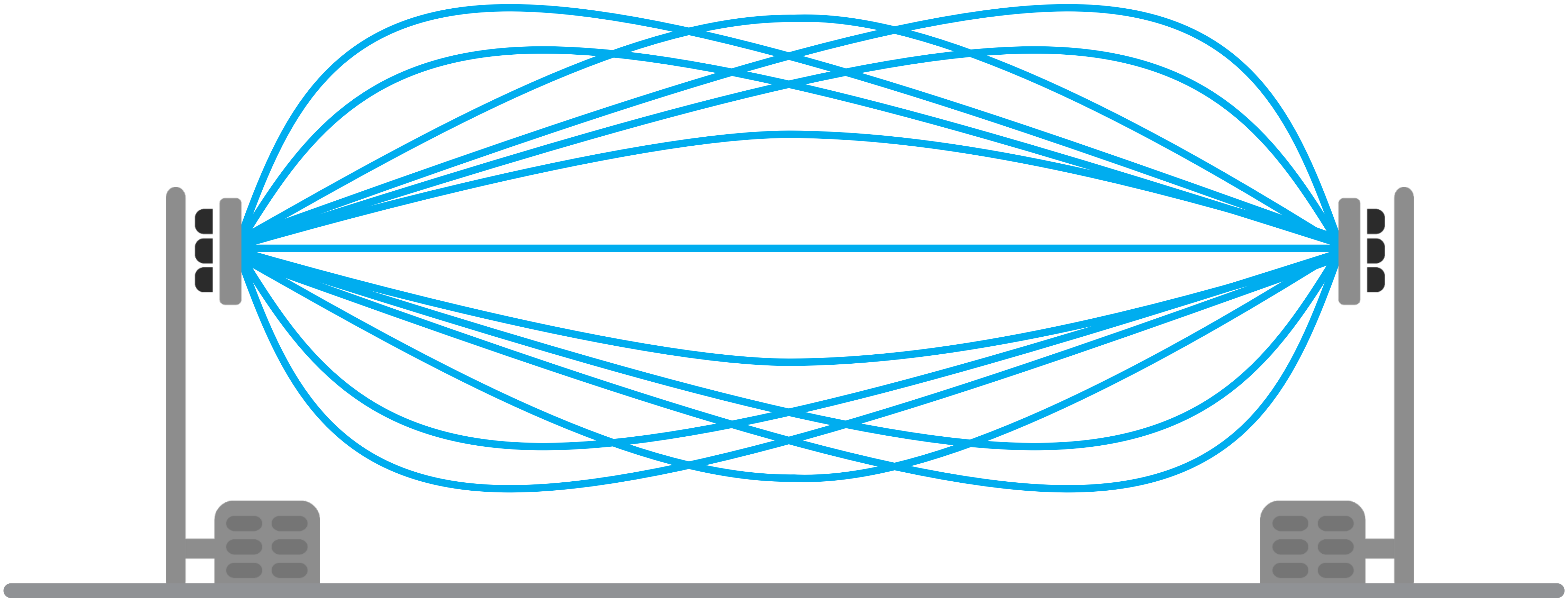
Fresnel Zones** and **K Factor



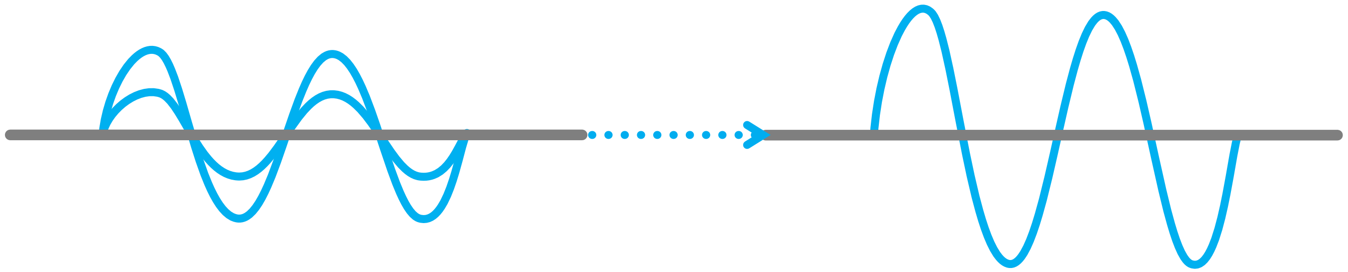
Fresnel Zones are ellipse shaped volumes between two antennas that help define line-of-sight

Fresnel's Ellipsoid: The set of points for which the difference in path distance between the direct and indirect rays is an *integer number of half-wavelengths*



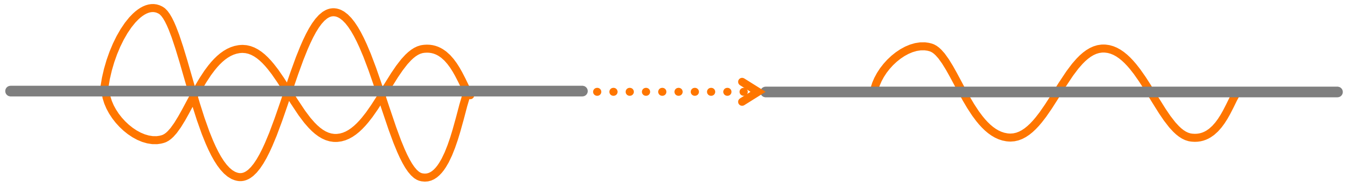


Signals may reach a receiver by multiple paths through the troposphere



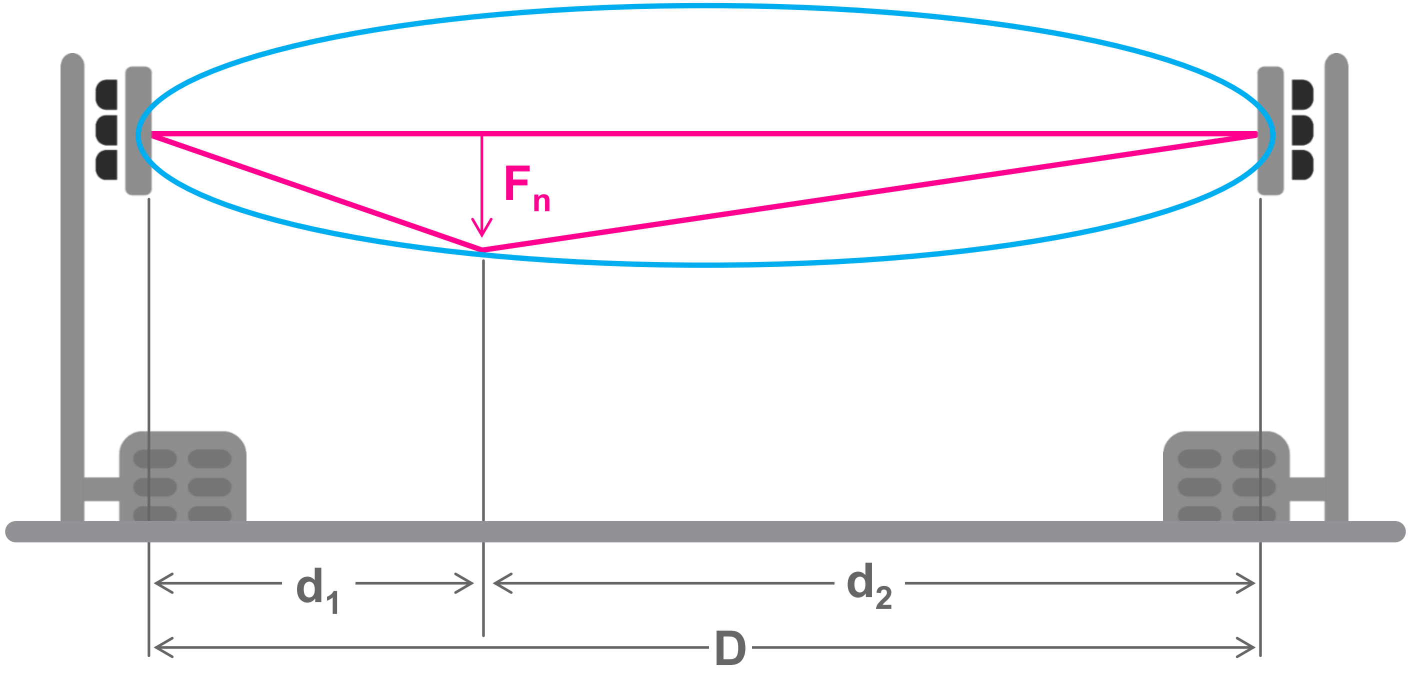
IN PHASE

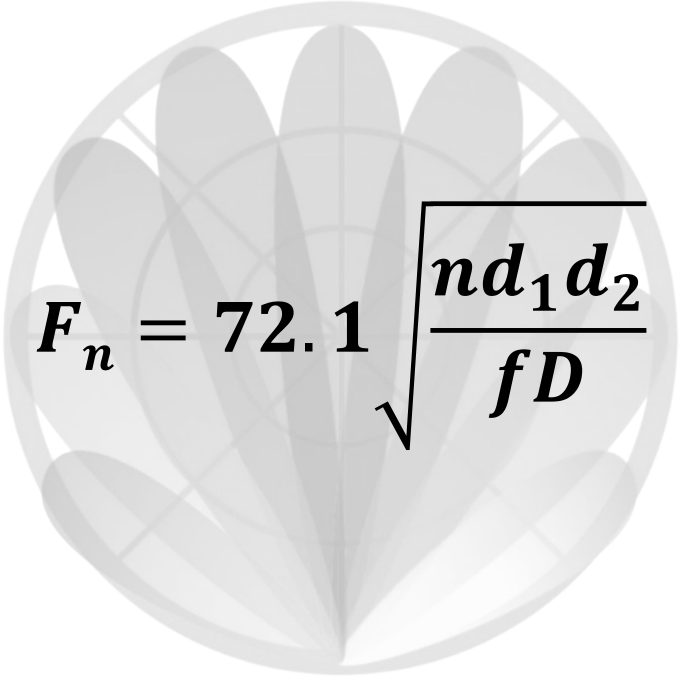
- Rays arrive at receiver in phase
- Improves the desired signal



OUT OF PHASE

- Rays that arrive out of phase (180º shift)
- Diminishes the desired signal





$$F_n = 72.1\sqrt{\frac{nd_1d_2}{fD}}$$

F_n = n^{th} Fresnel Zone radius in feet

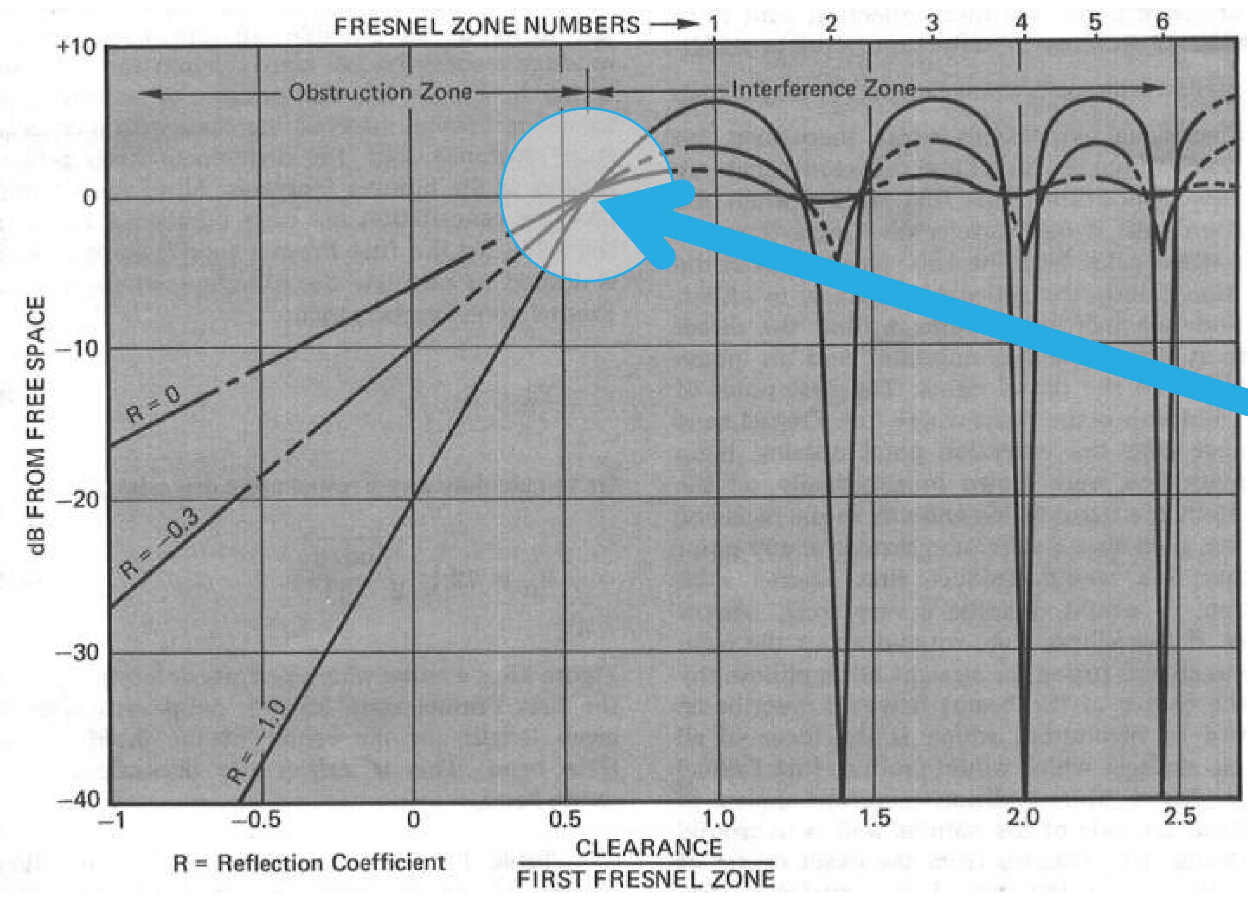
d_1 = Distance from one end of the path to the reflection point in miles

D = Total path length

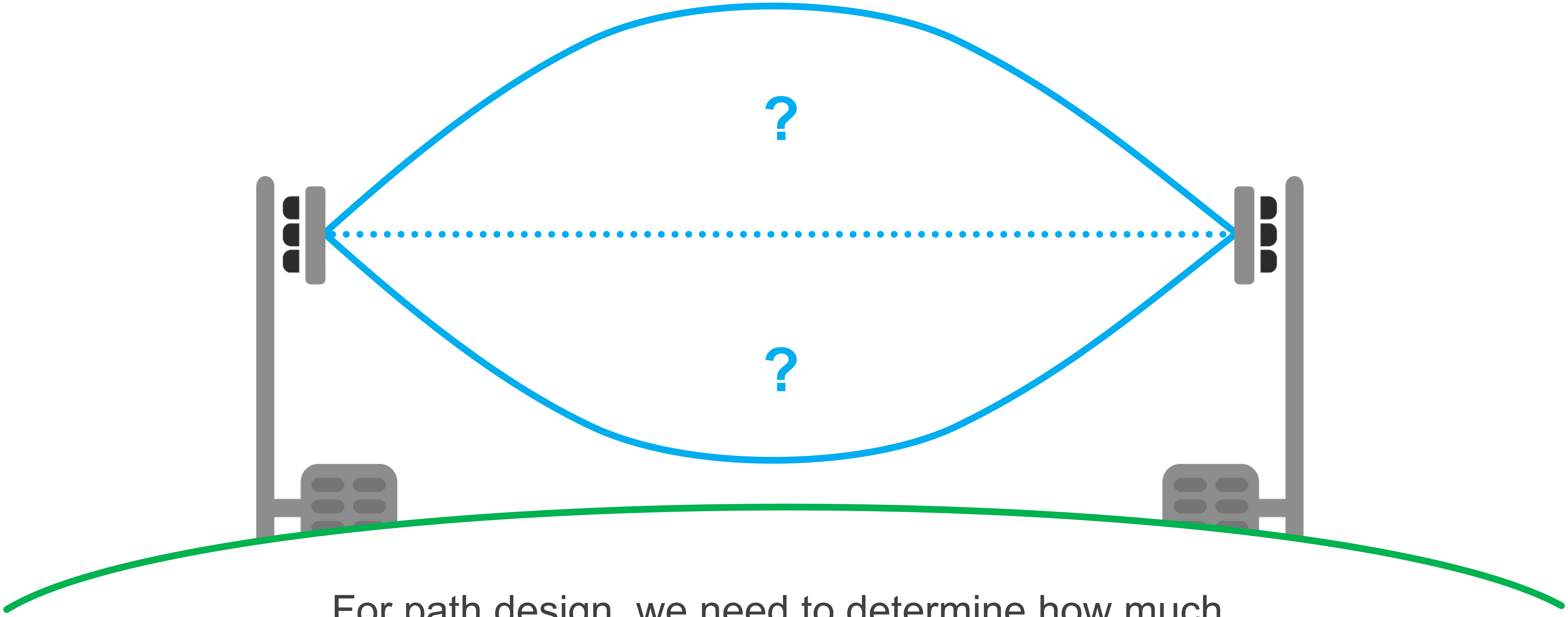
d_2 = D - d_1

f = Frequency in GHz

IF	D = 30 mi	D = 30 mi	D = 8 mi	D = 3 mi
	d1 = d2 = 15 mi	d1 = d2 = 15 mi	d1 = d2 = 4 mi	d1 = d2 = 1.5 mi
	f = 1.9 GHz	f = 6.7 GHz	f = 23 GHz	f = 38 GHz
THEN	F1 = 143.25 ft	F1 = 76.3 ft	F1 = 21.3 ft	F1 = 10.3 ft



Source: NAVAL SHORE ELECTRONICS CRITERIA LINE-OF-SIGHT MICROWAVE AND TROPOSPHERIC SCATTER COMMUNICATION SYSTEMS | NAVELEX 0101,112 (MAY 1972) | “Figure 2-17. Path Attenuation Versus Path Clearance” (pg. 2-24)



For path design, we need to determine how much the path is bent up or down due to **refraction**

K Factor is the
effective earth radius factor

Where

$\mathbf{a_e}$ = Ka

$\mathbf{a_e}$ = Effective earth radius

$\mathbf{a}$ = Actual earth radius (6,370 km)

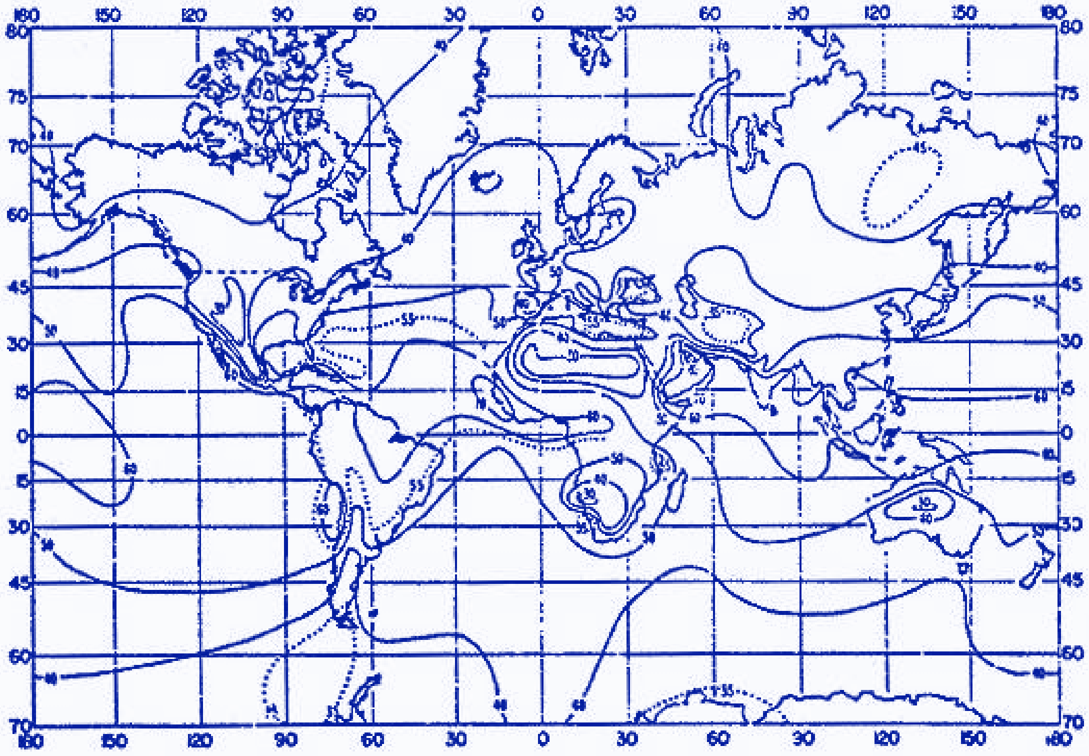


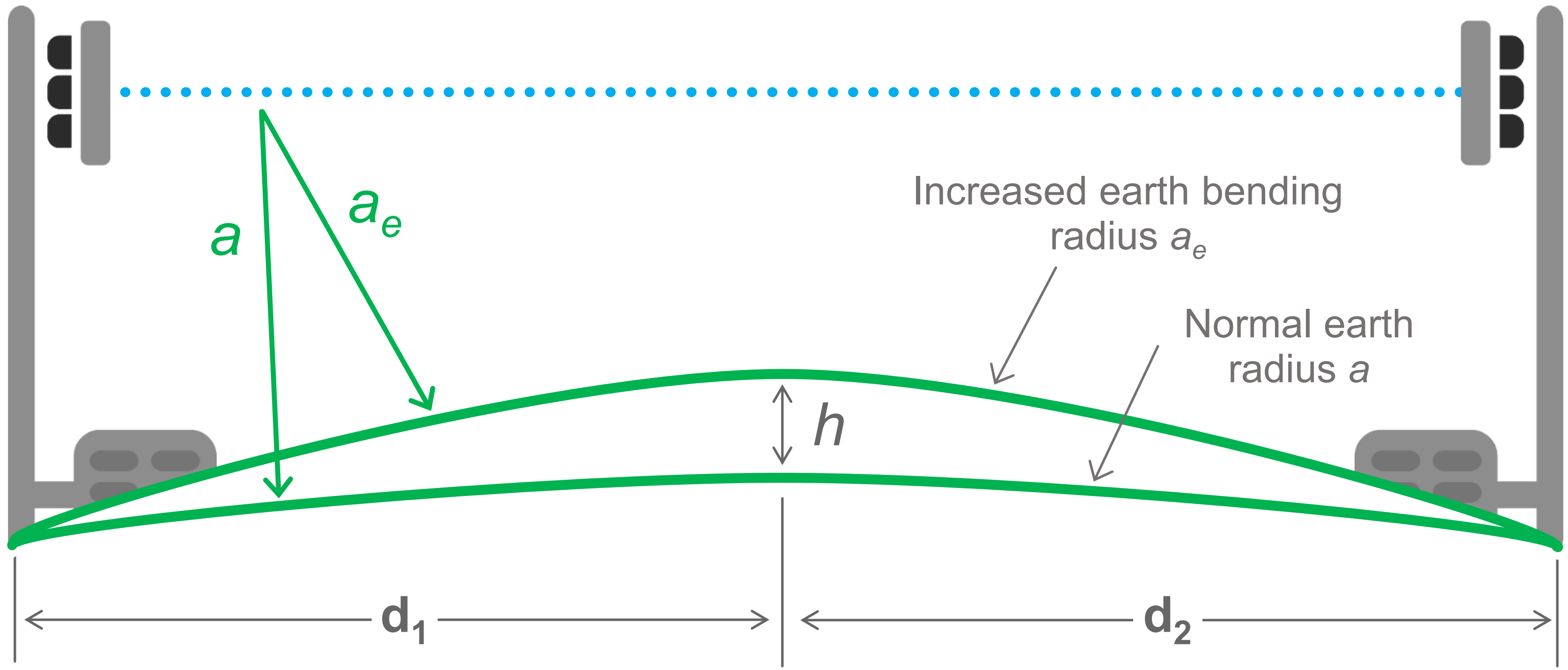
FIGURE B-15. Annual mean of refractivity gradient between surface and 1 km, ΔN.

Source: U.S. DEPARTMENT OF COMMERCE ENVIRONMENTAL SCIENCE SERVICES ADMINISTRATION | B. R. Bean, B. A. Cahoon, C. A. Samson, and G. D. Thayer | Institute for Telecommunication Sciences and Aeronomy Institutes for Environmental Research | Boulder, Colo. | “A World Atlas of Atmospheric Radio Refractivity” (1966) | “Figure B-15. Annual mean of refractivity gradient between surface and 1 km” (pg. 59). This work was supported in part by the U.S. Navy Weather Research Facility, Contract Number 7560 : NABUSTDS 65 Ser. 300 | Library of Congress Catalog Card Number : Map 66-74

$$K = 157 / (157 + dN/dh)$$

Refractivity gradient (dN/dh) is change of refractivity with height above ground

Measured value in the first km above the ground is about -40 N units/km



Earth Bulge (h):

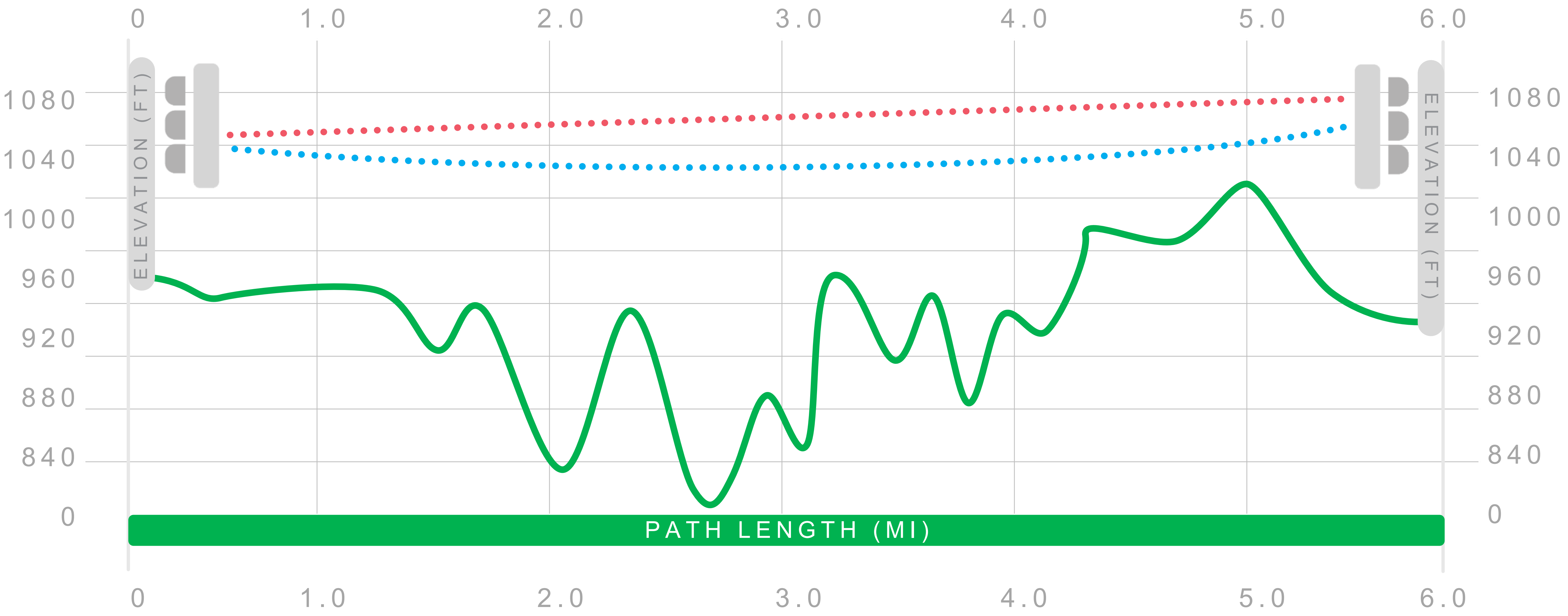
$\boldsymbol{h}$ = $d_{1(km)}d_{2(km)}$ /12.75k meters

$\boldsymbol{h}$ = 0 for

k = infinity

It is convenient to model the bending ray as an increase in the curvature of the earth, leaving the ray straight

RF PROPAGATION | PATH CLEARANCE



Microwave Fundamentals—Part I

3. Field Survey

Why do we perform microwave path surveys?

- Identify obstructions to determine antenna heights
- Locate reflection points/objects
- Audit site information for coordination and FCC licensing
- Recommend antenna mount locations for installation

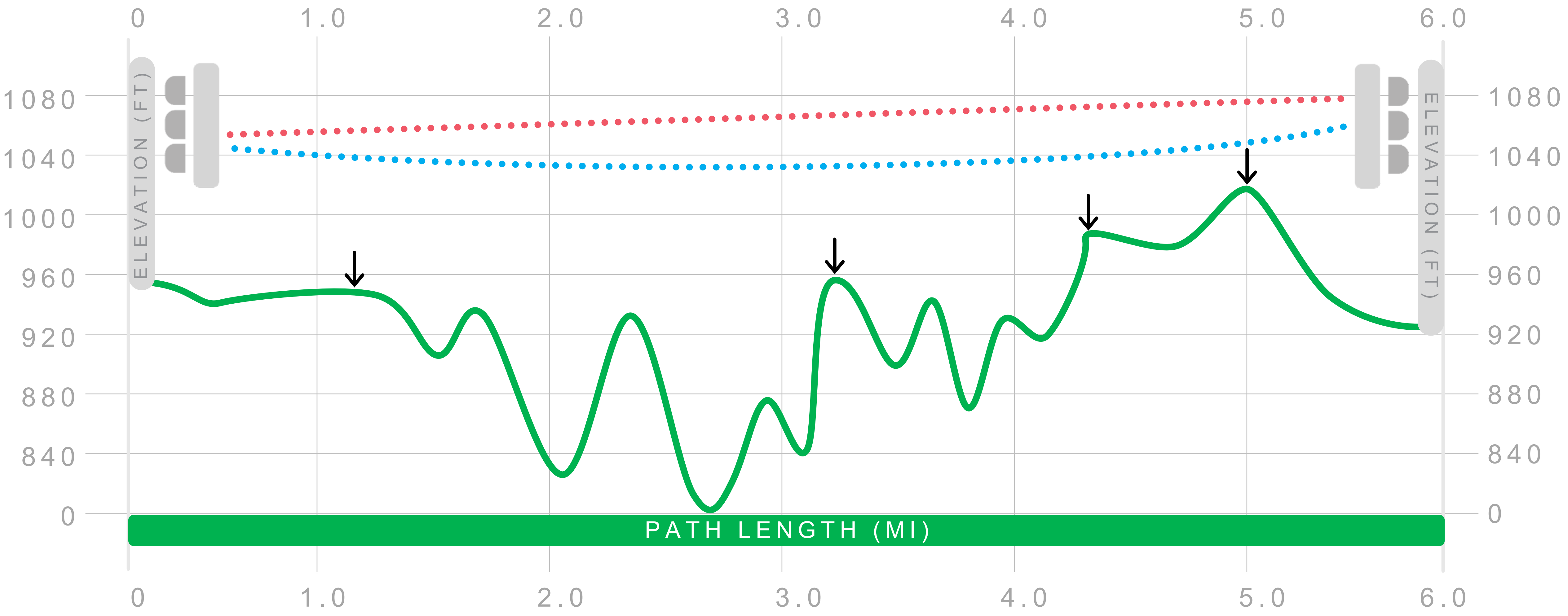
Preparing for a field survey

- Arrange for site access
- Review preliminary path design
- Examine path profile and locate critical points

Load up your survey gear

- Laptop w/ Mapping Software
- Laser Height Tool
- Compass
- Binoculars
- GPS

PATH SURVEY | CRITICAL POINTS



• Identify the critical points along path profile •

• Critical points are typically high elevation points where path clearance is the least •

What data do we collect at each site?

- ✓ Coordinates of site including reference datum
- ✓ Tower/rooftop heights
- ✓ Available antenna mounting locations
- ✓ Ground elevation using commercial grade instruments
- ✓ Photographs and site sketches

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PATH SURVEY | DRIVE PATH

- **Plot the path on a map** or mapping software
- **Drive along the path** focusing on the critical points
- **Record heights and locations** of obstructions on-path and off-path
- **Identify possible reflection points**

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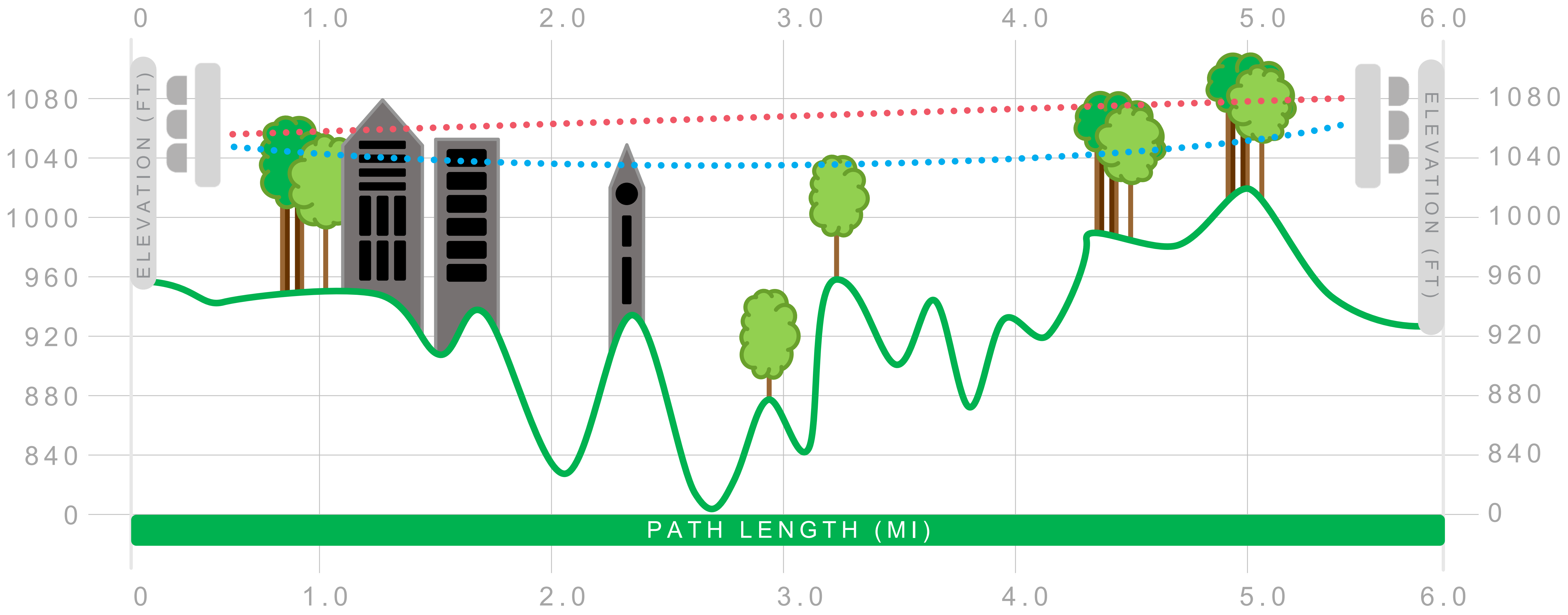
PATH SURVEY | UPDATE PROFILE



• Add measured obstructions to the path profile •

• This example shows that the original design centerlines are blocked •

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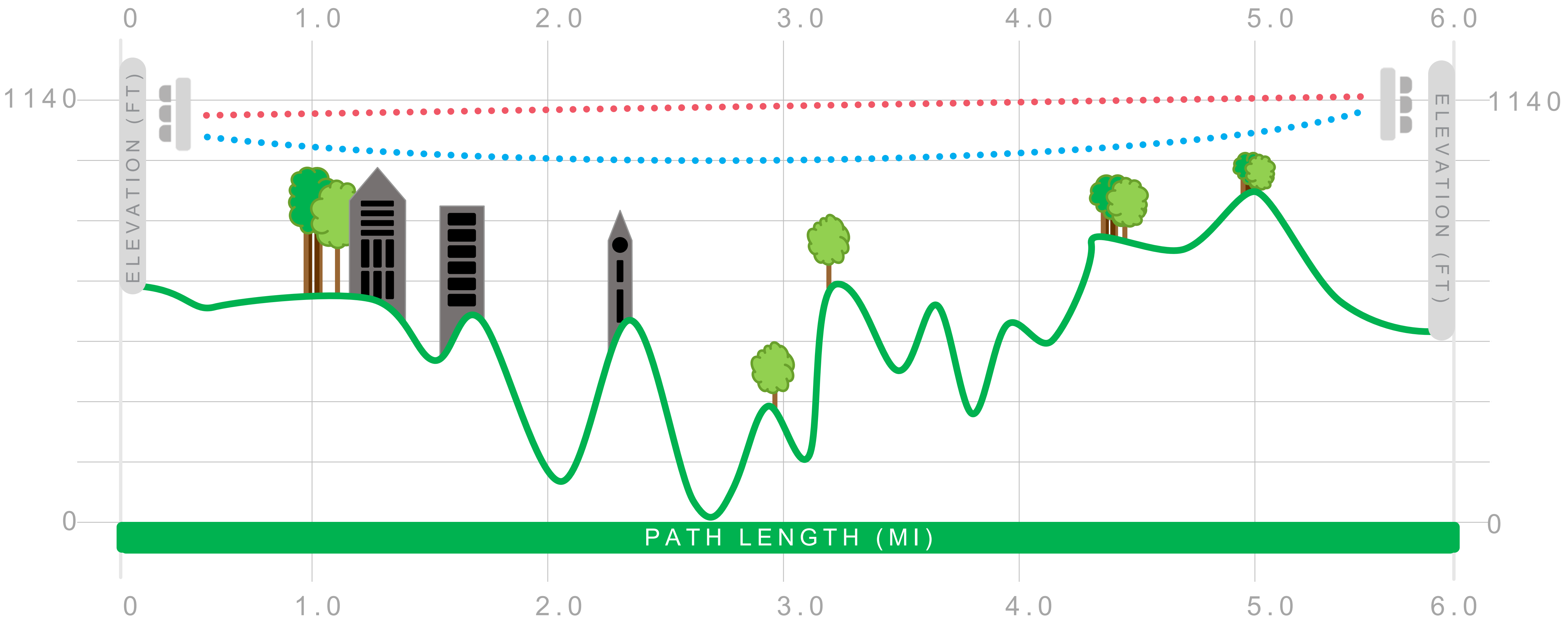
PATH SURVEY | OPTIMIZE & RE-EVALUATE



• Adjust antenna centerlines to clear obstructions •

• Be aware that raising antenna heights can increase fixed losses •

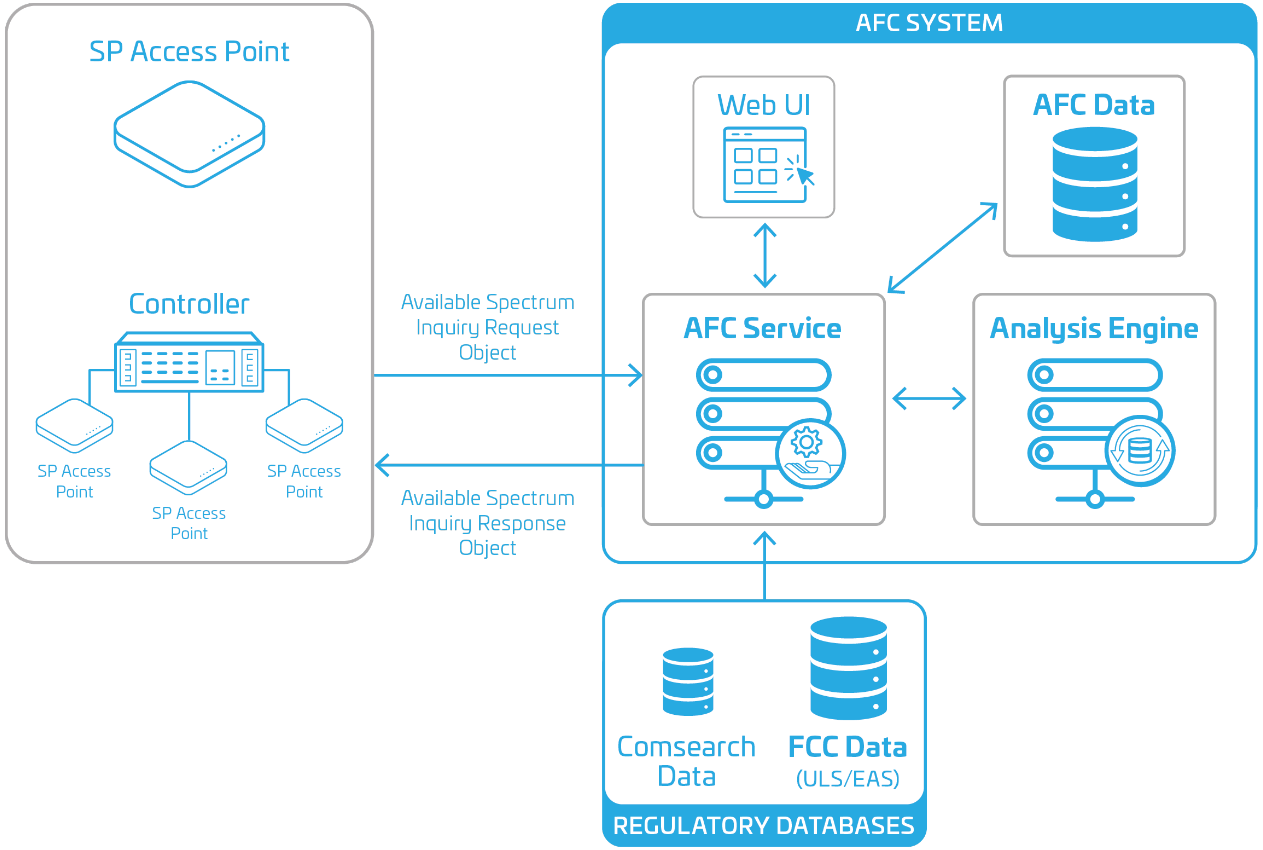
• Re-evaluate preliminary design using survey data to ensure it meets all design objectives •

Microwave Fundamentals—Part I

4. 6 GHz Microwave Assurance

- Concept proposed and advocated for by Apple, Broadcom, Cisco, Google, HPE, Intel, Meta, Microsoft, Qualcomm & Ruckus
- Established by FCC in 2020 via Order (ET 18-295)
- Based on TV White Space (2009) and CBRS/SAS (2015)
- AFC is a centralized database-enabled dynamic spectrum management system
- Allows standard power unlicensed devices (up to 4W/36 dBm) to operate in 6 GHz band and not cause harmful interference into incumbents
- Relies on FCC ULS as official database of licensed incumbent systems
  - ULS accuracy is critical to ensure protection (see FCC PN DA 22-236)
- AFC systems certified for commercial operation on Feb 24 (PN DA 24-166)
- AFC admins set up interference reporting portal (https://www.afcoperators.org/)

AFC Functional Architecture



GENERAL USE CASE EXAMPLES FOR 6 GHZ UNLICENSED

Wi-Fi®

Consumer & Enterprise Wi-Fi

FWA

MDU Applications

Whole Home Gigabit Coverage

Carrier Aggregation that can be Quickly Deployed

Municipal Wi-Fi

Factory & Warehouse IoT

Multi-gigabit Wi-Fi Venue Capacity

AFC OPERATION

Device Requirements

- Automatically geolocate
- Register with AFCs by sending basic information to AFC (including location)
- Provide updated information to AFC
- Check in with the AFC every 24 hours
  - If check in fails, device has until 11:59pm of following day to establish contact or it must shut down
- Use security methods to prevent accessing non-approved AFC systems and unauthorized modification of device
- Device controllers can act as device proxies when interacting with the AFC

AFC Requirements

- Use FCC databases (ULS & EAS) for information on protected/licensed incumbent systems
- Verify validity of device FCC ID
- Determine available frequencies and max permissible transmit EIRP using device registration query data
- Return lists of available spectrum/channels and max powers
  - In 3 dB steps between 21 dBm and 36 dBm
- Store registered information in a secure database until an SPAP or FCD ceases operation at a location
- Deregister device if no contact with AFC within 3 months

6 GHz Microwave Assurance
Basics of the FCC Rulemaking

6 GHz Report & Order (R&O) adopted on 4/24/2020

- Allocates 1200 MHz for unlicensed operation
- **Automated Frequency Coordination (AFC)** is a control mechanism to dynamically manage frequency assignment
- **Low Power Indoor (LPI)** devices can operate without AFC (5 dBm/MHz, capped at 30 dBm/320 MHz) in the **5925-7125 MHz** band
- **Standard Power** Access Points (APs) can operate both indoors and outdoors in the **U-NII-5 (5925-6425 MHz)** and **U-NII-7 (6525-6875 MHz)** bands and **must use AFC** (Automated Frequency Coordination). Max EIRP 36 dBm with AFC
- **Standard Power APs** must register with an AFC for authentication (serial number & FCC ID)
- **AFC** provides available frequencies/powers based on incumbent usage **(FCC ULS)**
- FCC released **PN (DA 22-236)** on 3/8/2022 reminding incumbent fixed MW operators in the 6 GHz band of the importance of maintaining accurate information in the ULS
- No **AFC-AFC** data sync
- APs must recheck with the AFCs **daily** for an updated list of frequencies and power levels
- **No mobility** is permitted for Standard Power or LPI devices

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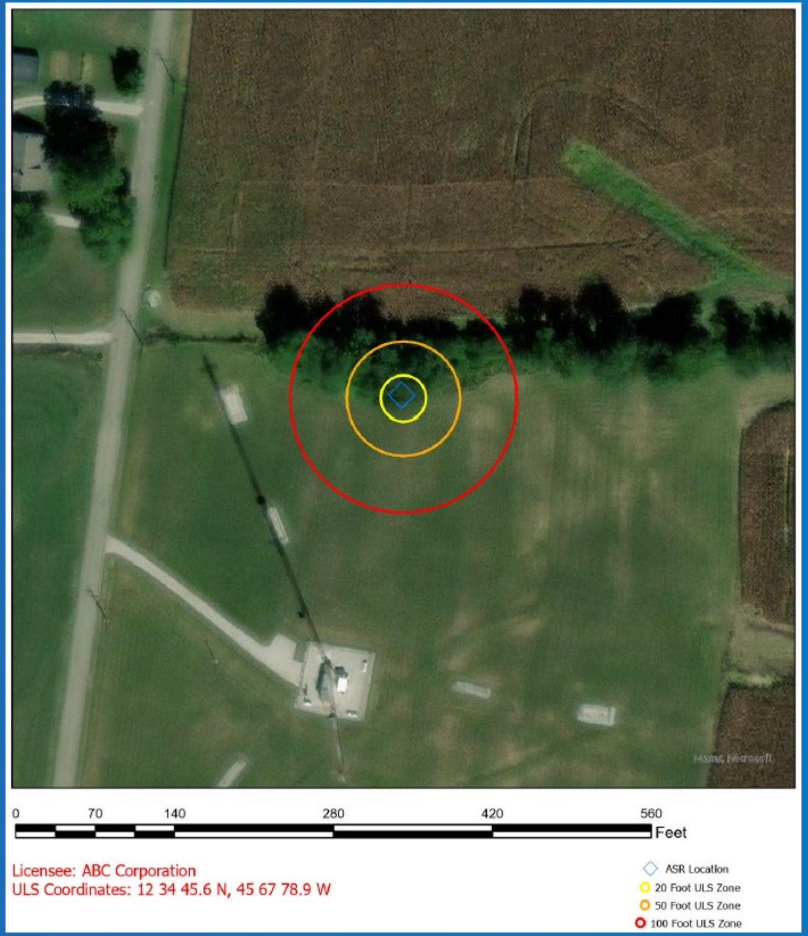
STEP 1: AUDITING

Desktop Verifications

- Analyze 6 GHz licensed data using all available sources including the ULS, the Comsearch database, and a variety of GIS tools to identify potential errors in coordinates and AMSL.
- Provide a clear list of what data is in error as well as expert advice on corrective action prioritization.
- Deliverables include a quick reference document with aerial images, an Excel file with coordinates from the GIS source including variance in the two data sources (GIS and ULS), and a Google Earth file with audited call signs.

Field Verifications

- On-site audit will be conducted using GNSS devices to document accurate coordinates, AMSL, and antenna heights. This information will be used to correct any erroneous license details on the ULS.



STEP 2: CORRECTIVE ACTIONS

Coordination & FCC Licensing Updates

Results from Step 1 will be used to prioritize and manage all corrective actions with the following services:

- PCN updates
- FCC licensing corrections, additions and deletions
- FAA Registration (Form 7460-1)
- Antenna Structure Registration (ASR Form 854)
- Local Notices
- Long-term network health with FCC License Management

STEP 3: MITIGATION

Interference Resolution

Identify and mitigate interference when it occurs

- Work with the AFCs to gather all available data for each interference case
- Deploy field team to track interference source
- Provide mitigation advice and ongoing support to resolve interference cases

Thank you!

Joe Marzin

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