Basic Communications-Electronics Principles And Systems

Michael Hicks
Air Force Spectrum Management Office
301-225-3721

Communications Terms

- **Bandwidth**—the portion of the frequency spectrum required to transmit the required information
- **Bel**—a unit used to express the ratio of two amounts of power in communications
- **Current**—the flow of electrical charge measure in amperes
- **Electromagnetic wave**—electromagnetic energy radiated from a conductor
- **Energy**—the ability to do work
- **Power**—the rate of doing work. Product of voltage times current
- **Velocity**—rate of change of position with respect to time

Communications Terms

- Energy waves
  - rock in a pond
  - sound waves
  - electromagnetic waves
- Power
  - Expression of the rate at which work is done
  - Spectrum Management purposes—generally measured in Watts
  - Power = I (amps) x E (volts)
  - 1 amp x 1 volt = 1 watt
- Circuit
  - the complete process of transmission through to reception
  - transmitter – antenna – medium – antenna – receiver

Communications Terms

- Effective Transmitted Power (ETP)
  - $ETP = P_t - L_t + G_t + G_r - L_r$

Where:

- Pt = Power of transmitter
- L_t = Line losses of transmitter
- G_t = Gain of transmitter antenna
- G_r = Gain of receiver antenna
- L_r = Line losses of receiver

Communications Terms

- Received Signal Level (RSL)
  - the calculation of power received
  - RSL = ETP – total path loss
- Logarithms
  - The logarithm of a quantity is the exponent (or the power) to which a given number (called the base) is raised to equal that quantity
    - $b^x = n$
    - $Log_b\ n = x$
    - $10^x = n$
    - $Log_{10}\ n = x$
    - $Log_{10}100 = 2$ $(10^2 = 100)$

Communications Terms

- Decibels (dB)
  - critical tools for spectrum managers
- Used like a ruler by a carpenter
  - Predict
  - Analyze
  - Identify problems
- Based on a discovery by telephone engineers that the human ear perceives sound levels on a logarithmic rather than a straight linear scale
- Bel is the name given to the unit which expresses the logarithm of this ratio

Communications Terms

- $\text{Bel} = \text{Log}_{10} \dfrac{P\,(\text{out})}{P\,(\text{in})}$
- $\text{Bel} = \text{Log}_{10} \dfrac{P_2}{P_1}$
- Decibel (dB) is a smaller unit of the Bel and is equal to one-tenth (.1) of a Bel.
- There are 10 Decibels in every Bel, therefore, we make a slight change in our formula:

$$10\,\text{Log}_{10} \frac{P\,(\text{out})}{P\,(\text{in})}$$

Communications Terms

- Example: A component in our transmitter takes a 10 Watt signal and boosts it to 20 Watts. What is the gain in dB?

$$dB = 10 \, Log_{10} \frac{P(out)}{P(in)}$$

  - dB = $10 \, Log_{10} \, 2$
  - dB = 10 (.30103)
  - dB = 3 (expressed as a gain of 3 dB)
  - note: A 3 dB gain is always represents a doubling of power

POWER-RELATED TERMS

- Power: energy (radiated by transmitter) per unit of time (watt = joule/sec)
- Intensity (illumination level): total radiated power flowing through a unit of area (watts/sq. meter)
- Power Flux Density: Intensity within a defined bandwidth (watts/sq. meter/4 kHz)
- EIRP (Effective Isotropic Radiated Power): Transmitter power inferred from measurements of intensity and distance between transmitter and measurement point (watts)
- EIRP = (intensity) x (surface area of a sphere)^2
- EIPR = $4 \pi r^2$ x (intensity)

LOGARITHM

- The exponent that indicates the power to which a number is raised to produce a given number
- For example: $10^2 = 100$
- The exponent 2 is called the logarithm of 100 To the base 10
- This relationship is usually written $Log_{10}100 = 2$

LOGARITHM

- Because we use only base 10 numbers, then notation can be changed from
- Log_{10} to Log
- Now, for example, the expression:
- $\mathrm{Log}_{10}\ 100 = 2$
- Can be written as: $\mathrm{Log}\ 100 = 2$ and mean exactly the same thing

LOGARITHM

- GIVEN that: $10^2 = 100$ and $10^3 = 1000$
- Can be written as Log 100 = 2 and Log 1000 = 3 without a change in meaning, the concept can be extended to allow evaluation of the logarithm of numbers such as:
- 500
- Since Log 100 = 2 and Log 1000 = 3
- It stands to reason that Log 500 = some value between 2 and 3.
- In fact, Log 500 = 2.6989
- Conceptually, this means that $10^{2.6989} = 500$

Logarithmically, 100 and 1000 as values between 2 and 3

Log 10000 = 4	since $10^4 = 10000$
Log 1000 = 3	since $10^3 = 1000$
Log 100 = 2	since $10^2 = 100$
Log 10 = 1	since $10^1 = 10$
Log 1 = 0	since $10^0 = 1$
Log .1 = -1	since $10^{-1} = .1$
Log .01 = -2	since $10^{-2} = .01$

Now it is seen that the numbers between 1000 and 10000 can be represented logarithmically as values between 3 and 4, numbers between 10 and 100 lie logarithmically between 1 and 2, etc.

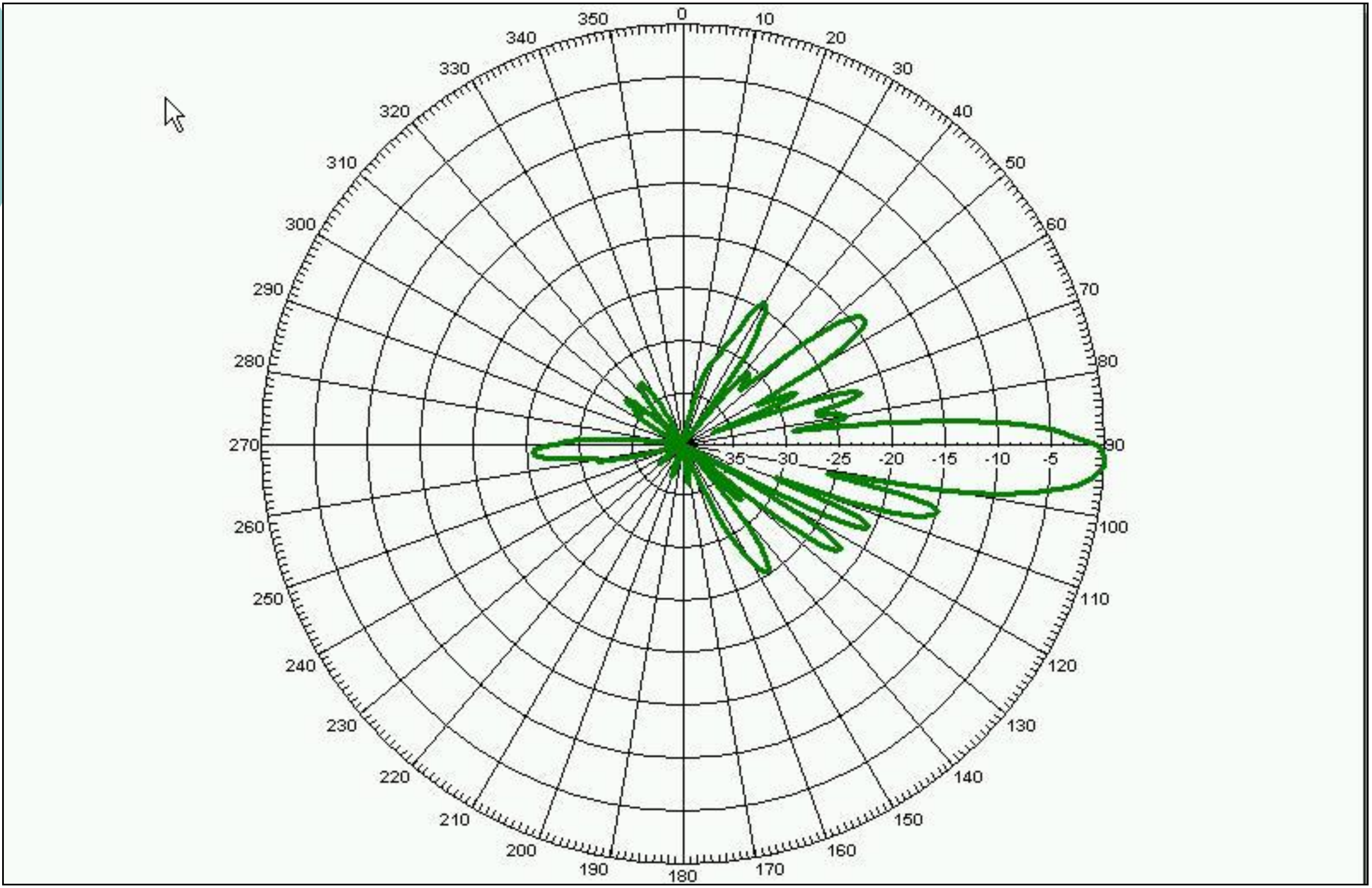
dB Equivalents for Selected Power Ratios

Power Ratio	Decibel Equivalent
10 000 000 000.00	100 dB
1 000 000 000.00	90 dB
100 000 000.00	80 dB
10 000 000.00	70 dB
1 000 000.00	60 dB
100 000.00	50 dB
10 000.00	40 dB
1 000.00	30 dB
100.00	20 dB
16.00	12 dB
10.00	10 dB
8.00	9 dB
6.30	8 dB
5.00	7 dB
4.00	6 dB
3.16	5 dB
2.50	4 dB
2 .00	3 dB
1.58	2 dB
1.26	1 dB
1.00	0 dB Unity Gain
0.79	-1 dB
0.63	-2 dB
0.50	-3 dB
0.40	-4 dB
0.32	-5 dB
0.25	-6 dB
0.2	-7 dB
0.16	-8 dB
0.13	-9 dB
0.1	-10 dB
0.01	-12 dB
0.001	-20 dB
0.000 1	-30 dB
0.000 01	-40 dB
0.000 001	-50 dB
0.000 0001	-60 dB
0.000 000 1	-70 dB
0. 000 000 01	-80 dB
0.000 000 001	- 90 dB
0.000 000 000 1	-100 dB

DECIBELS

- Express Gain Or Loss Of Signals And Relative Power Levels
  - Voltage: 20 Log10 $\frac{V_1}{V_2}$
  - Current: 20 Log10 $\frac{I_1}{I_2}$
  - Power: 10 Log10 $\frac{P_1}{P_2}$

A Microwave Antenna Pattern



Concepts of
Wavelength – Frequency – Velocity

- Electromagnetic Waves
  - 1887: Henirich Hertz discovered that electromagnetic energy could be sent into space in the form of radio waves.
  - Speed of Light = 186,000 miles/sec
  - Velocity of electromagnetic waves is constant
- Frequency
  - Number of times an action or occurrence is repeated during a specified time period.
  - For radio frequency, period of time used is as a reference is one second.

$$\frac{\text{Cycle}}{\text{Second}} = \textbf{Hertz (Hz)}$$

Concepts of Wavelength – Frequency – Velocity

- Distance = Velocity x Time
- Distance = Velocity x $\frac{\text{Second}}{\text{Cycle}}$

- Provides an expression of how far a wave travels in one cycle.

Concepts of Wavelength – Frequency – Velocity

- Wavelength (Lambda)
  - The physical distance from the occurrence of one positive peak of a wave to the next positive peak.
- Distance = Velocity $\times \dfrac{\text{Second}}{\text{Cycle}}$
- Frequency = $\dfrac{\text{Cycle}}{\text{Second}}$
- Distance = Velocity $\times \dfrac{1}{\text{Frequency}}$
- Lambda = $\dfrac{V}{\text{Frequency}}$
- As frequency *increases*, wavelength *decreases*
- Antenna sizes vary—majority are ½ wavelength

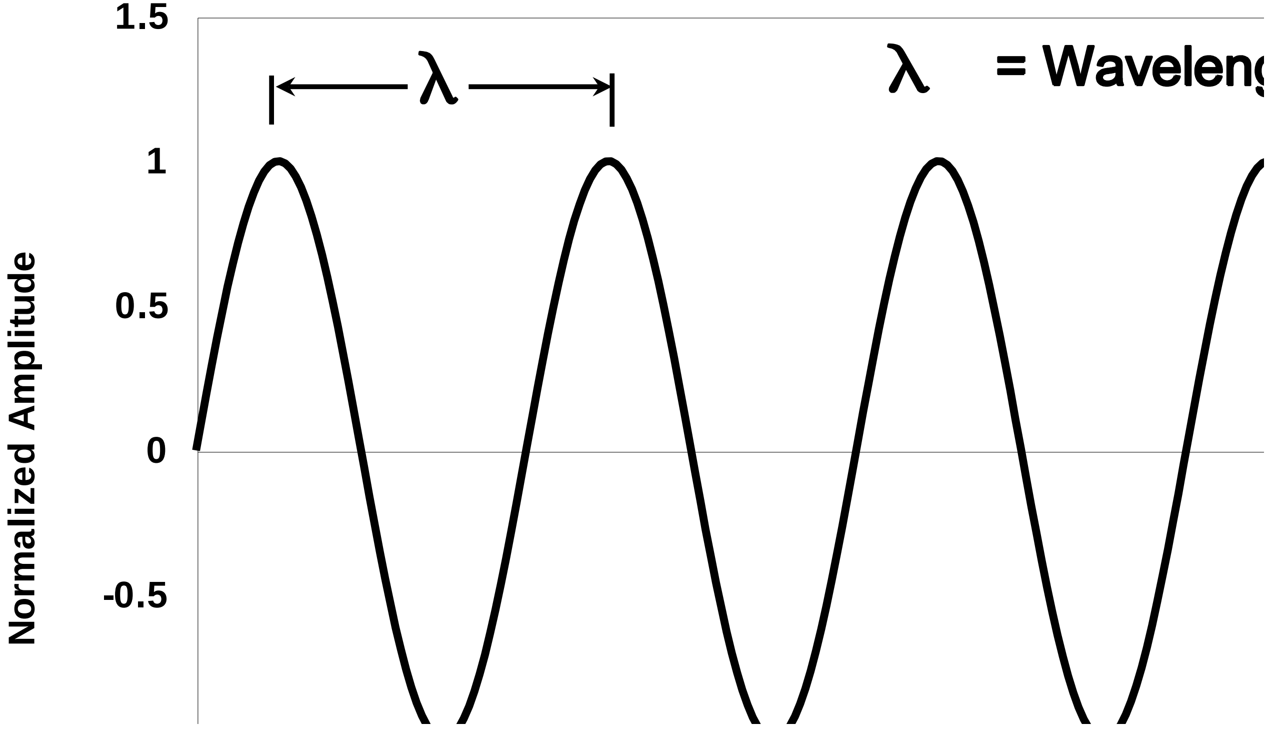
Concepts of Wavelength – Frequency – Velocity

- Speed of light : 186,000 mps or nearly 1 billion feet per second or 300,000,000 meters per second
- Radio waves oscillate or alternate from plus to minus and back
- Number of cycles per second – Hertz – determines the frequency
- Wavelengths are generally measured from one positive peak to the next positive peak.
- Frequency is the number of times any action or occurrence is repeated in a given period of time; or the number of vibrations or cycles per unit of time.
- The relationship between wavelength, frequency, and velocity is express by:

$f = v/\lambda$ where f = frequency, v = velocity, and λ = wavelength

Concepts of Wavelength – Frequency – Velocity

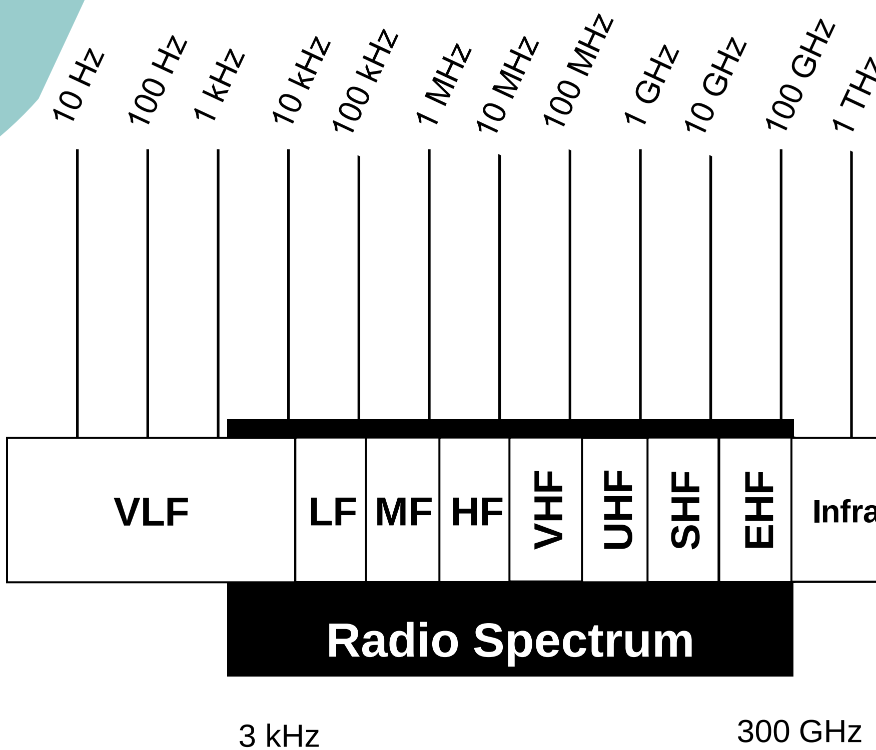
$$\text{Frequency} = f = \frac{V}{\lambda} \quad (\text{h}$$



Frequency Expressions

- 1 cps = 1 Hertz (Hz)
- 1,000 cps = 1 Kilohertz (kHz) (thousand)
- 1,000,000 cps = 1 Megahertz (MHz) (million)
- 1,000,000,000 cps = 1 Gigahertz (GHz) (billion)
- 1,000,000,000,000 cps = 1 Terahertz (THz) (trillion)

Electromagnetic Spectrum



Frequency−Wavelengths−Band Designations

Frequency	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz
Wavelength (meters)	10^5	10^4	10^3	10^2	10	1	10^{-1}	10^{-2}	10^{-3}

Band Designation							
Myria-Metric Wave	Kilo-Metric Wave	Hectro-Metric Wave	Deca-Metric Wave	Metric Wave	Deci-Metric Wave	Centi-Metric Wave	Milli-Metric Wave
VLF	LF	MF	HF	VHF	UHF	SHF	EHF

VLF: Data, Low Freq Broadcast, Radio Telegraphy

LF: Low Freq Broadcast, Markers, Low Freq Beacons

MF: Commercial Use, Scientific use, AM Broadcast

HF: Amateurs, Long Haul Comm, FM Broadcasts, Mobile, International Broadcast

VHF: Air/Ground Comm, Tactical Radio, LMR Radio, Taxi, TV Broadcast

UHF: Air/Ground Comm, SATCOM, LMR, Radars, TV Broadcasts, Low-Power Devices, Radio Astronomy

SHF: Radars, Microwaves, SATCOM, Satellite TV, Police Radars, Radio Astronomy, Earth-Exploration Satellites

EHF: LASERs, Satellite, Radio Astronomy, Earth-Exploration Satellites

Speed of Electromagnetic Waves

- In Free Space (Vacuum)

  C = 2.99 x 10^8 m/sec $\begin{cases} 3x10^8 \ m/\sec \\ 300 \ Mm/\sec \\ 300 \ m/micro\sec \\ 186{,}000 \ mi/\sec \end{cases}$

- In Other than Free Space (n = refractivity):

  v = c/n $\begin{cases} n \approx 1.0001 \ in \ air \\ n \approx 1.5 \ in \ cables, \ wire, \ etc. \\ n \approx 2.5-3 \ in \ glass \end{cases}$

- Wavelength is Distance Traveled During One Period

  wavelength = (speed) x (period) = (speed) / (frequency)

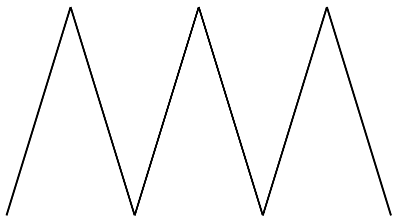
  λ = c/f f ·λ = c f = c/ λ

Modulation

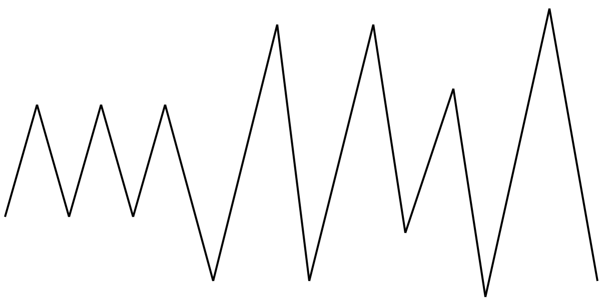
- Process of varying the amplitude, the frequency, or phase of a carrier or signal
- AM modulation
- FM modulation
- PM modulation

AM Modulation

The process by which the amplitude of the carrier is varied at the audio rate of the modulating signal.



Carrier

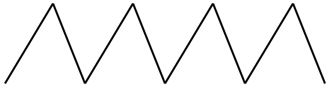


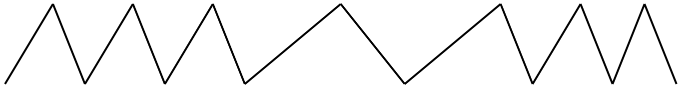
Amplitude Modulation

FM Modulation

The process by which the frequency of the carrier is varied at the audio rate of the modulating signal.

Carrier



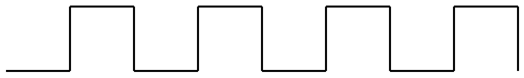


FM

Pulse Modulation-PM

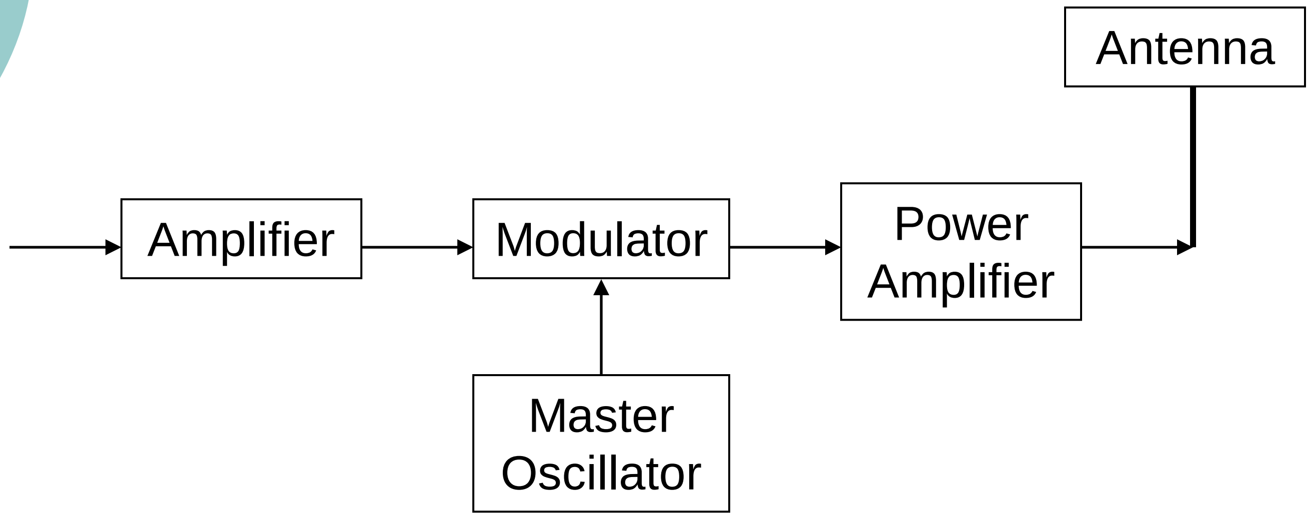
The modulation of a carrier by a pulse train. Commonly used in radar. Variation of pulse modulation may be used for communications purposes. Variations of PM include pulse frequency, pulse amplitude, pulse position, pulse phase, and pulse length (duration) modulation.

Resting Carrier

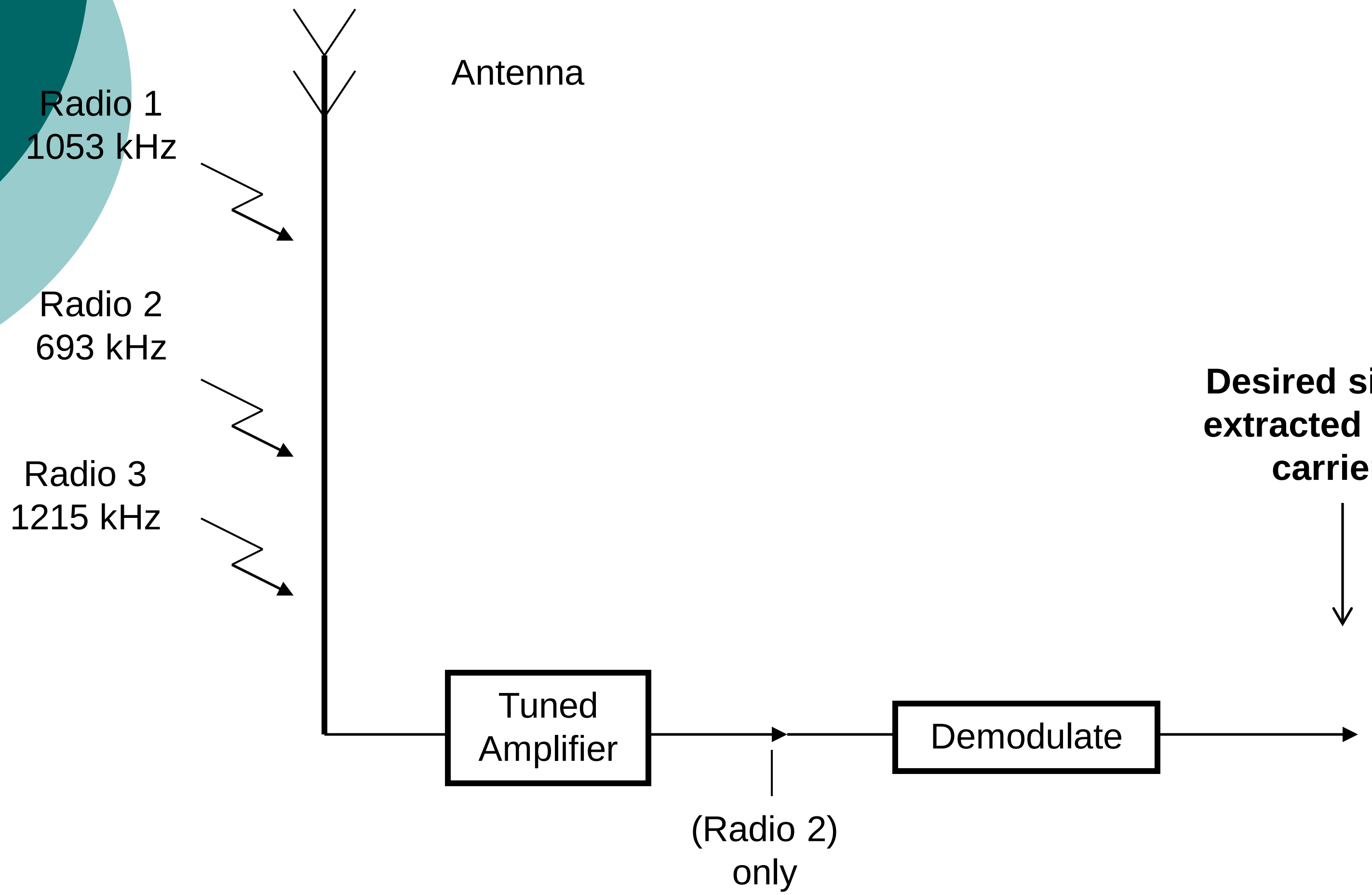


Pulse

Basic Transmitter



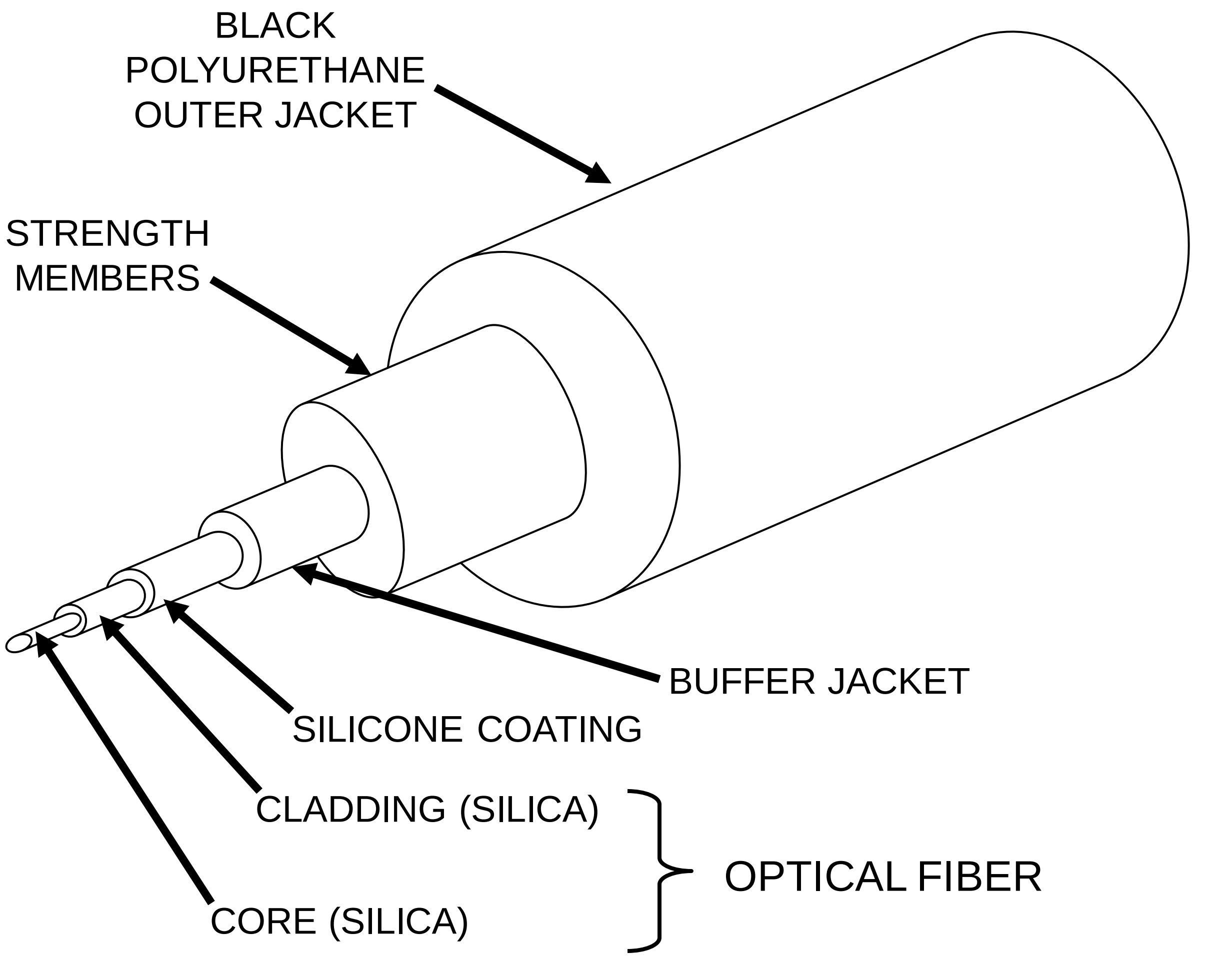
Basic Receiver



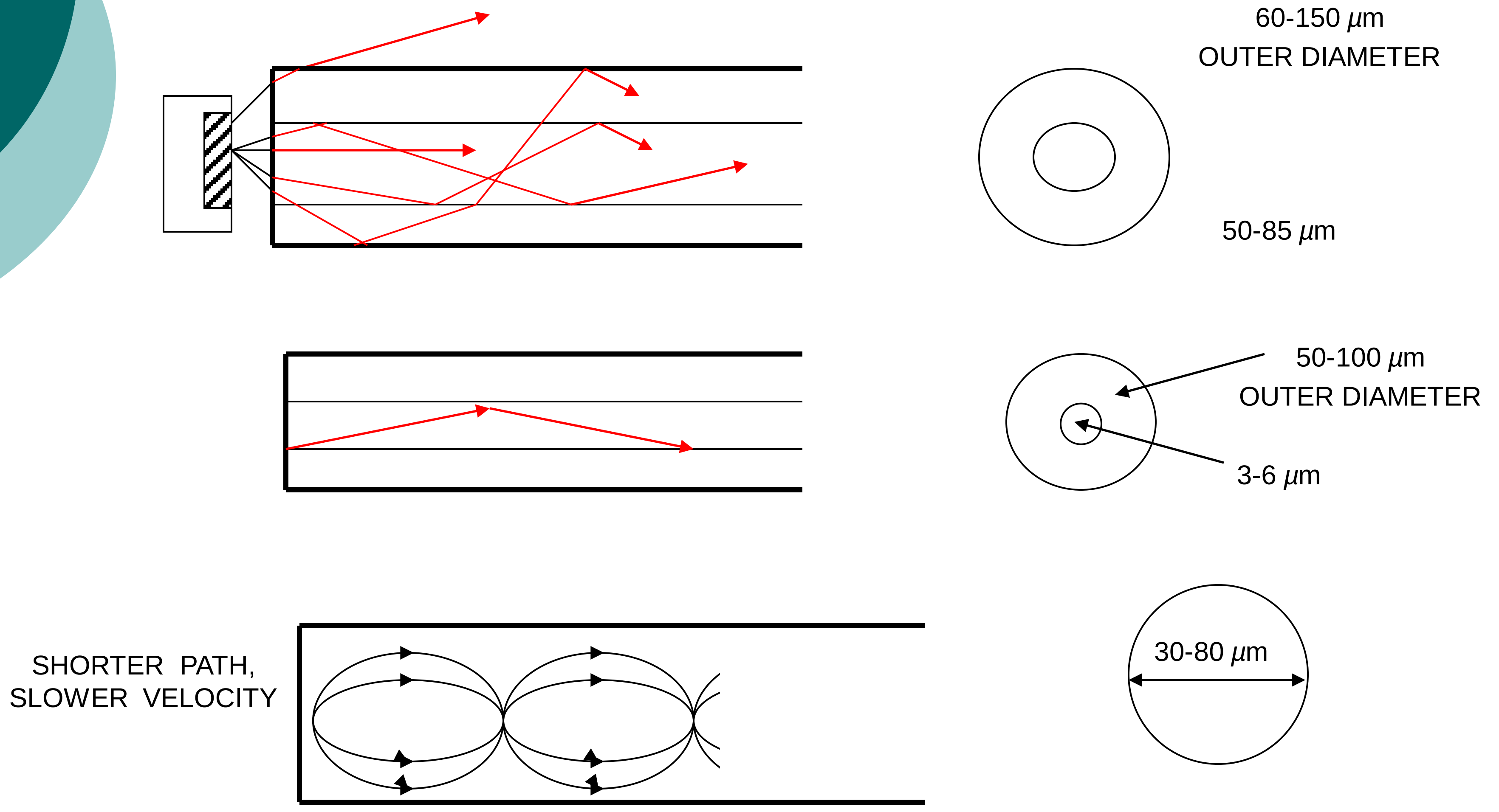
Communications Terms

- Bandwidth (Bw)
  - Establishing bandwidth is a process of determining the economics of transmitting something in terms of spectrum needed.
  - AM broadcast radio generally transmits a Bw of 5000 Hz
  - FM broadcast radio generally transmits a Bw of 18000 Hz
  - Bandwidth does not denote the frequency of the transmission, but indicates the size of the range of spectrum used for transmission.

Construction of a Single-Fiber Cable



Cross Sections–Typical Optical Fibers



Sources of Fiber Optic Communication

- LASERS
  - Higher Power
  - Narrow Spectral Bandwidth (few tenths of a %)
  - More Directional, Better Coupling
  - More Sensitivity to Temperature
  - More Complex Construction
  - Relatively Faster
- Light-Emitting Diodes
  - Lower Power
  - Broad Spectral Bandwidth (few %)
  - Low Coupling Efficiency for Low NA Fibers
  - Low Temperature Dependence of Emitted Power
  - Simple Construction
  - Relatively Slower

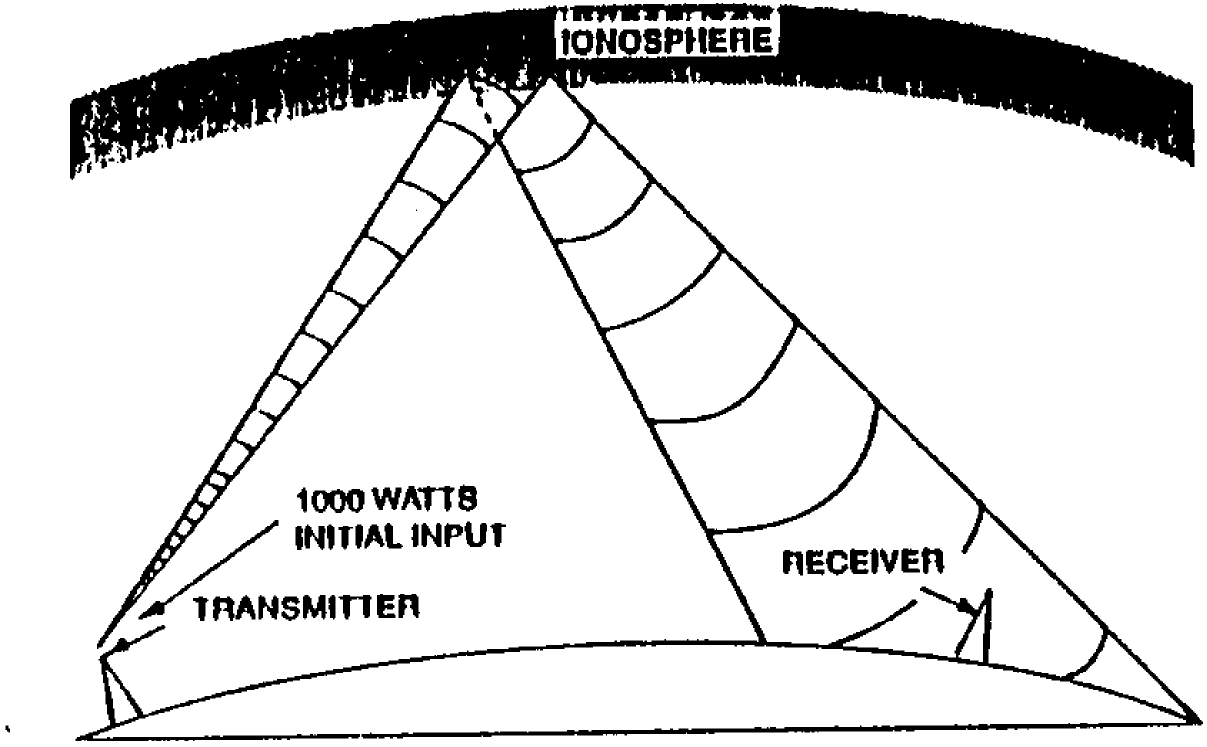
Radio Wave Propagation

- Path between transmitter and receiver
- Earth's atmosphere is not uniform
  - Height or geographical location
  - Change of time (day, night, season, year)
  - Air, moisture, ionization, and other atmospheric factors—propagation medium
  - Layers of the atmosphere (troposphere, stratosphere, ionosphere)

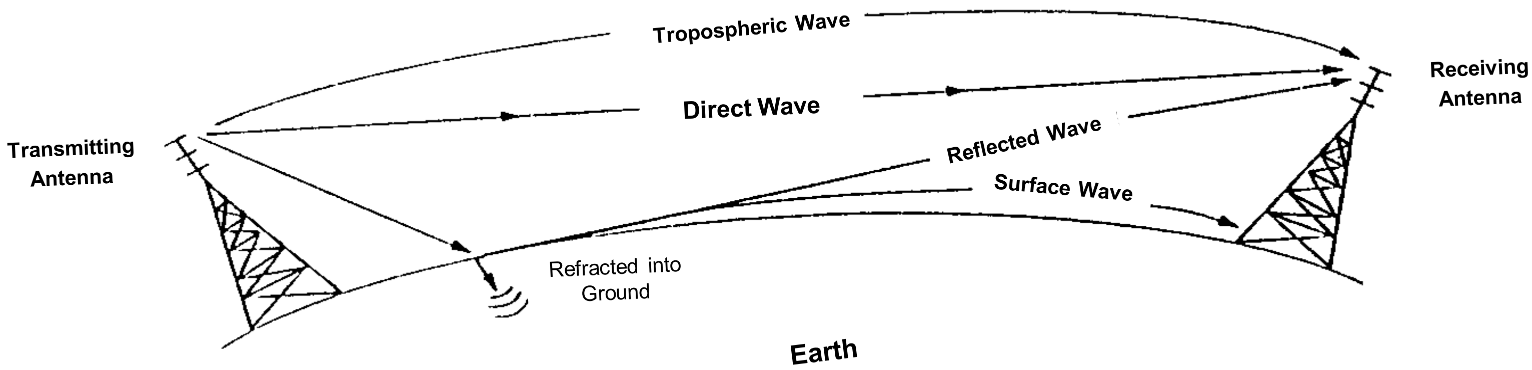
Propagation Paths

- Ground Wave
  - Direct wave
  - Reflected
  - Surface
  - Tropospheric
- Sky Wave
  - Makes use of Ionosphere
  - Refracts and reflects

Free Space Loss Principle

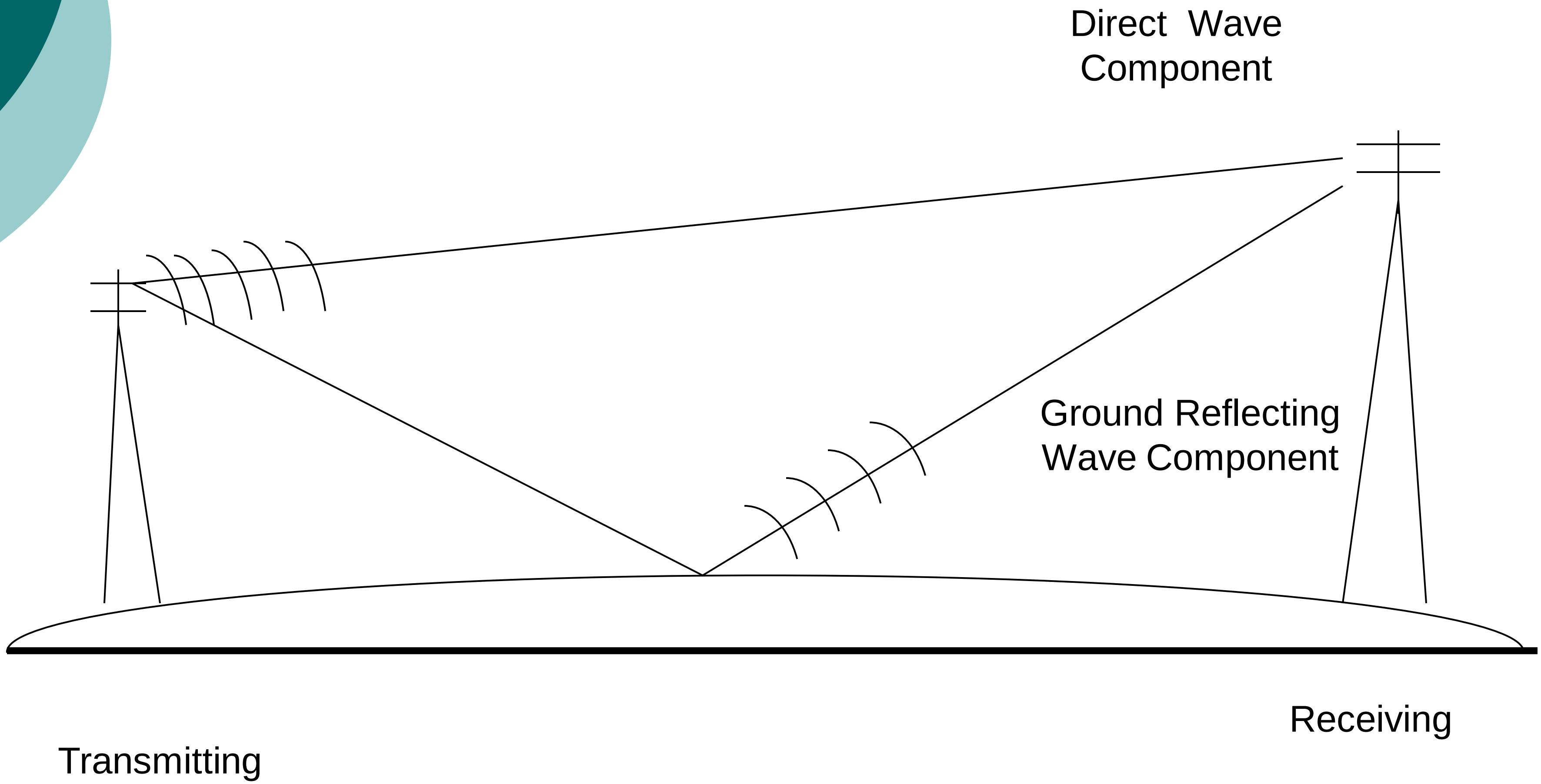


Ground Wave

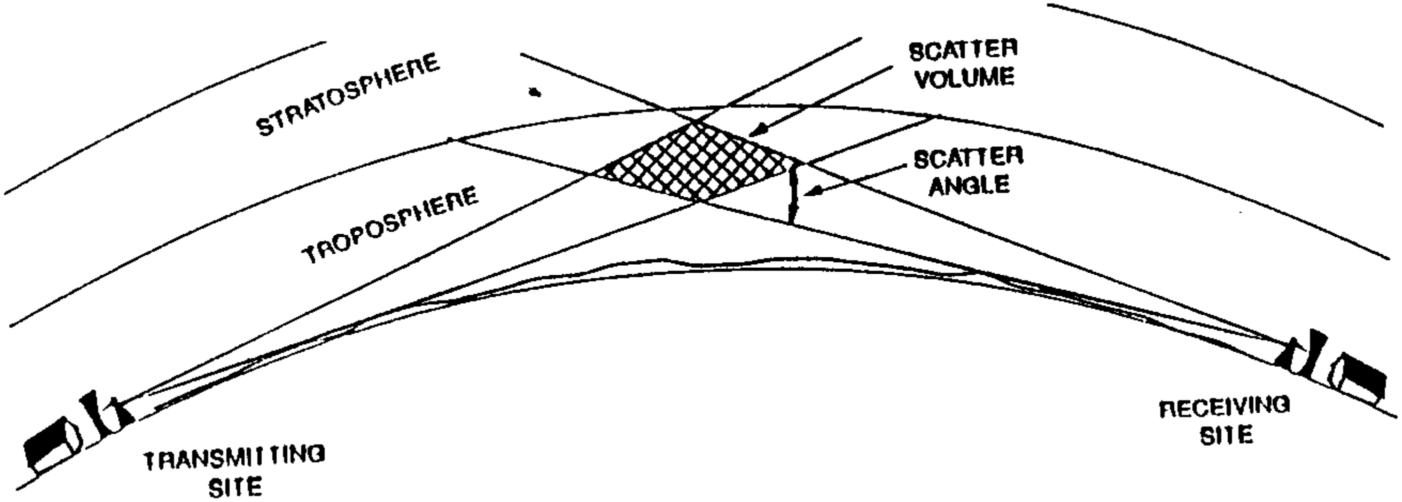


Ground-wave Propagation: any type of radio transmission that does not make use of the ionosphere.

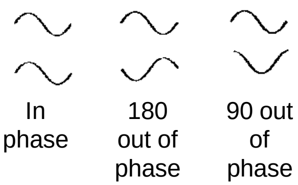
Direct and Reflected Wave Comparison—good and bad

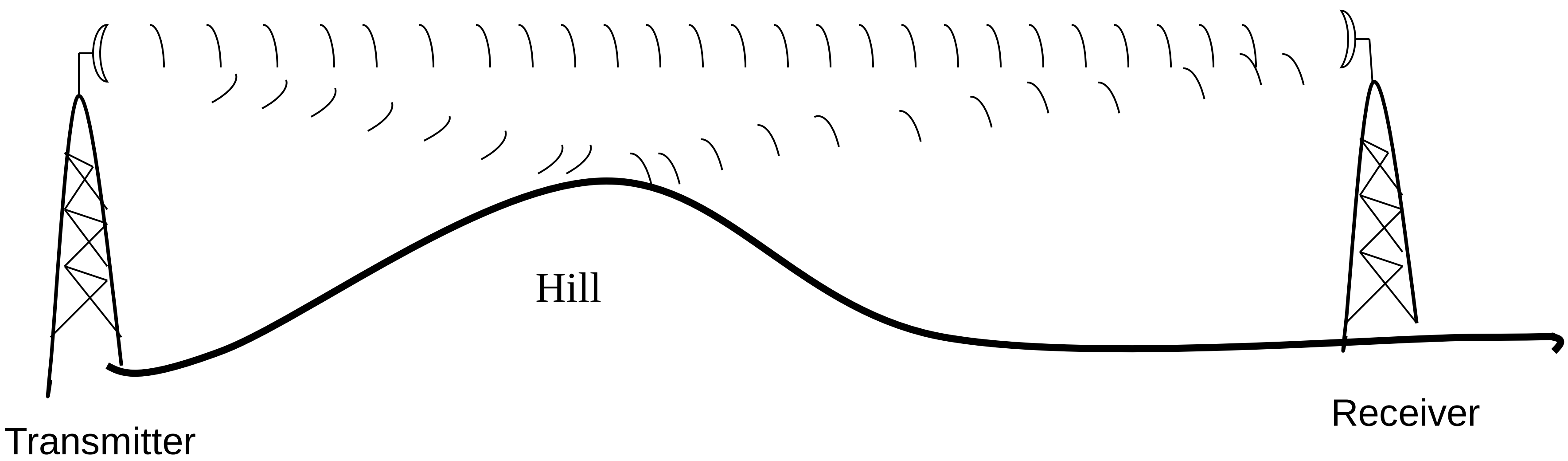


Tropospheric Scattering Propagation



Obstacle Gain or Loss

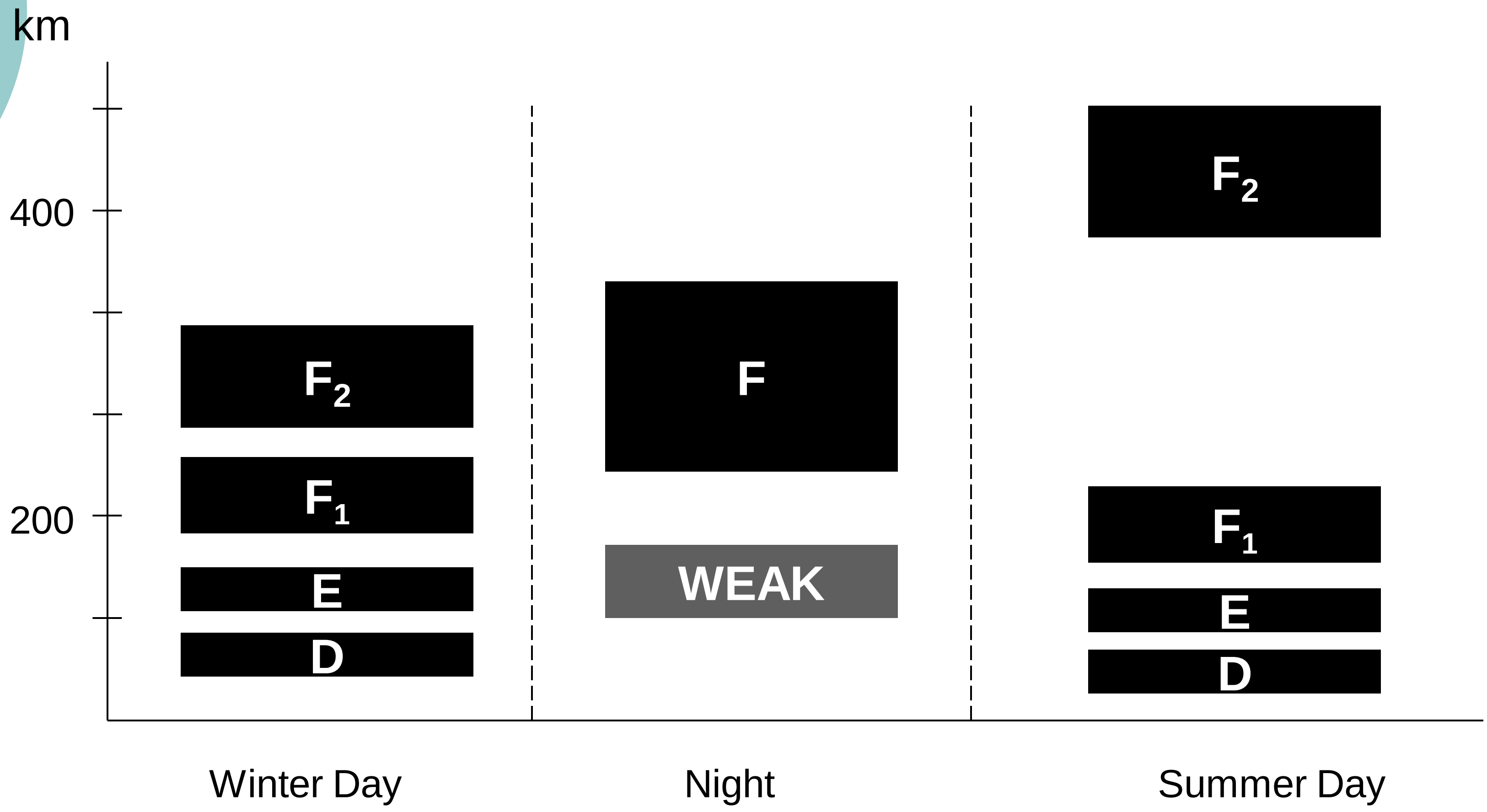




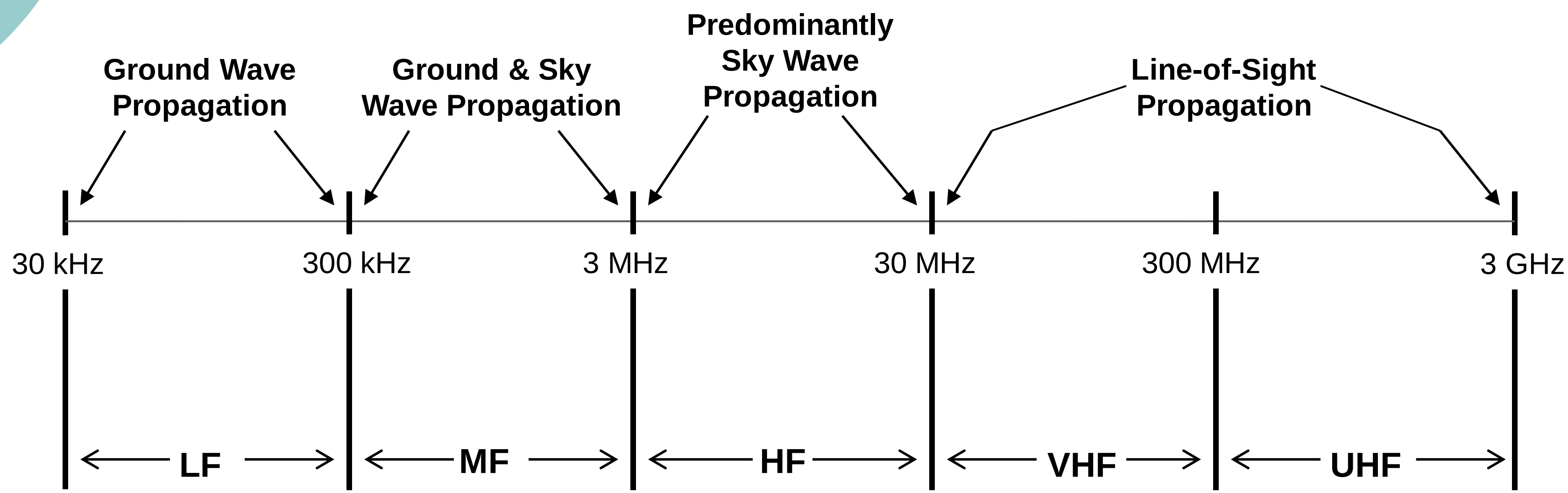
General Structure of the Ionosphere

Layer	Height (km)	Electron Density (e/cc)	Remarks
D Layer	≤ 90	10^2 at 70 km 10^3 at 80 km 10^4 at 90 km	Exists During Daytime Loss at High Frequency
E Layer	90–160	10^4–10^5	During Daylight Much Less Dense at Night Up to 2,000 km
F Layers F1 F2	160–250 250–450	10^4–10^6 10^6–10^7	Long Distance Circuits 4,000 km or More

Ionospheric Layers



Spectrum & Predominant Propagation



FREE SPACE ATTENUATION

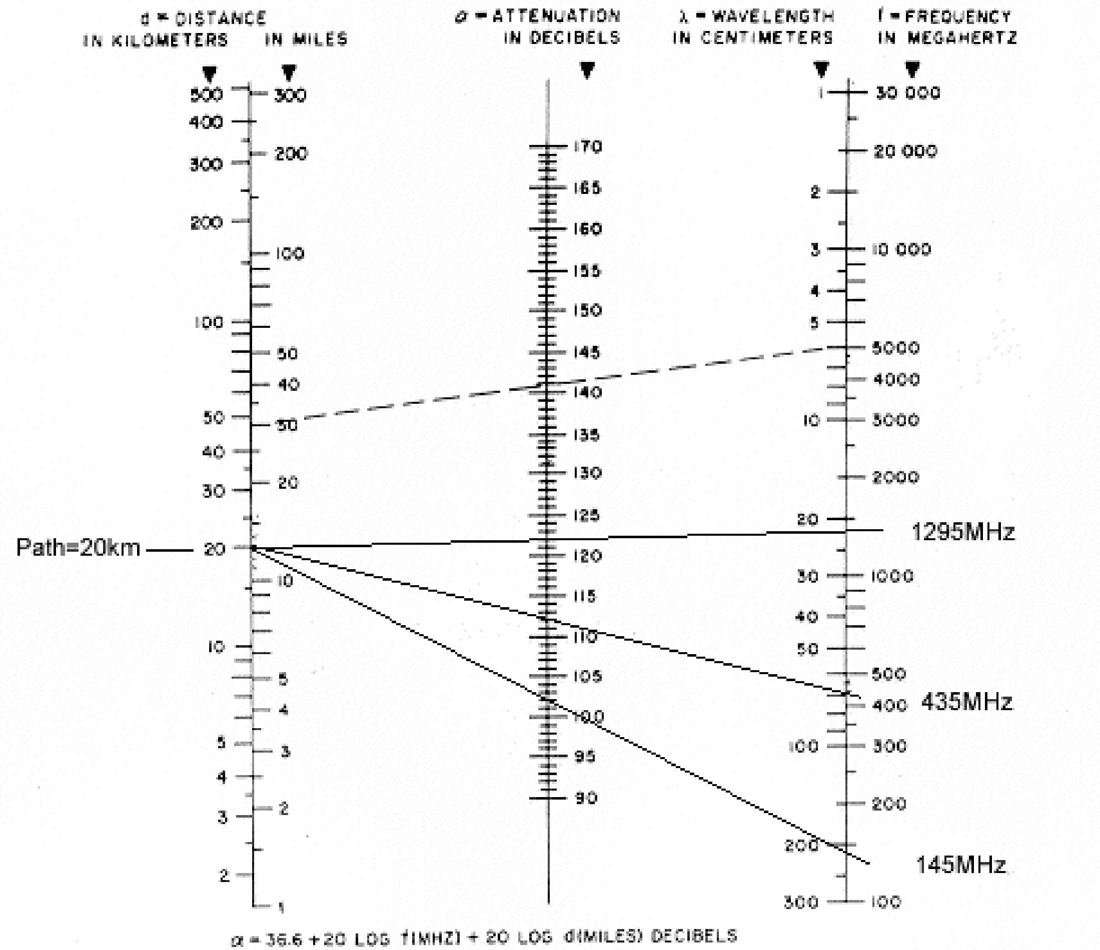


Fig. 24—Nomogram for solution of free-space path attenuation α between isotropic antennas. Example shown: distance 30 miles; frequency 5000 megahertz; attenuation = 141 decibels.