1.3 POWER LEVELS OF SIGNALS AND DECIBELS

The *decibel*, a measure of signal level and its change. We use this logarithmic measure or its variants in the telecommunications network for many purposes, for example, to express the voice level or the transmission and reception power of radio systems, such as mobile telephones, or an optical line system.

1.3.1 Decibel, Gain, and Loss

Along the long-distance communication connection or channel, the power of the signal is reduced and amplified over and over again. The signal power needs to be rigidly controlled to keep it high enough in relation to background noise and low enough to avoid system overload and resulting distortion.

The reduction of signal strength, loss or attenuation, is expressed in terms of *power loss*. When the signal is regained, this is expressed in terms of *power gain*. Thus, the absolute gain of ten corresponds to the loss of 1/10.

Alexander Graham Bell was the first to use logarithmic power measures. This was found to be handy and the unit for power gain was named in Bell's honor as decibel (dB). The gain in decibels is defined as follows:

$$\text{Gain or Loss} = \Psi = \frac{\text{Measured Power}}{\text{Reference Power}} = \frac{P_{\text{out}}}{P_{\text{in}}} = \frac{V_O^2 Z_O}{V_I^2 Z_I}$$

$$\Psi_{\text{dB}} = 10\log_{10}(\Psi)$$

- If $\Psi > 1$, it is gain, we label it as G.
- If $\Psi < 1$, it is loss, we label it as L.
- If $\Psi = 1$, i.e. the output = input powers, then G_{dB} and L_{dB} in decibels are each 0dB.

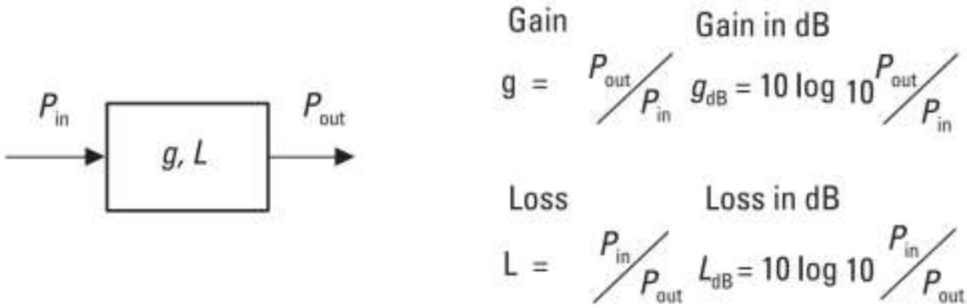
So, if an amplifier makes an output signal 100 times stronger than its input, then it has gain of:

$$G_{\text{dB}} = 10\log_{10}\left(\frac{100P_i}{P_i}\right) = 20\text{dB}$$

Also, if a signal reduced to 5% of original strength when passing through a cable, then this cable has dB loss (negative gain) of:

$$L_{\text{dB}} = 10\log_{10}\left(\frac{5}{100}\right) = -13\text{dB}$$

The Figure below presents an element in a telecommunications network with a certain input power and an output power. The formulas of loss (attenuation) and gain are given in the figure as well.



In telecommunications systems we usually have many elements in a chain.

Note that the decibel is the measure of power gain and, if we are interested in how voltage level changes, the impedances must be considered. The voltage and power gains are the same only if the impedances at the points where the power and voltage are measured are the same. The following formula gives the power gain if input and output voltages and impedance are known:

$$G_{\text{dB}} = 10\log_{10}\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right) = 20\log_{10}\left(\frac{V_{\text{out}}^2/Z_{\text{out}}}{V_{\text{in}}^2/Z_{\text{in}}}\right) = 20\log_{10}\left(\frac{V_{\text{out}}}{V_{\text{in}}}\right) + 10\log_{10}\left(\frac{Z_{\text{in}}}{Z_{\text{out}}}\right)$$

The impedances in the preceding equation are assumed to be real numbers.

1.3.2 Power Levels

Power levels in practical systems may vary from picowatts to tens of watts. Power measures based on decibels can be used to express this wide power range in an easy way. As:

$$P_{\text{dB}} = 10\log_{10}(P)$$

The level of absolute power is often expressed in dBm, where the actual power is compared to 1mW power. The power level in dBm is given by the expression:

$$P_{\text{dBm}} = 10\log_{10}\left(\frac{P}{1\text{mW}}\right)$$

For example, let the received power 2mW. Then $P_{\text{dB}} = -27\text{dB}$ and $P_{\text{dBm}} = 3\text{dBm}$.

Absolute power level dBm is commonly used instead of the absolute power in watts to express, for example, the optical output and received power of optical line systems or the received radio signal strength of a mobile telephone.

1.4 Communication Modes

In any communication link connecting two devices, data can be sent in one of three communication modes. These are:

A *simplex*: the communication flow can only occur in one direction. e.g. broadcast radio.

A *half-duplex*: communication in both directions, but not at the same time. e.g. 'walkie-talkies'.

A *full-duplex:* system can support simultaneous two-way communication. e.g. telephone.

1.5 Transmission Characteristics

1.5.1 Signaling Rate

The signaling rate of a communication link is a measure of how many times the physical signal changes per second and is expressed as the *baud rate*. An oscilloscope trace of the data transfer would show pulses at the baud rate.

1.5.2 Data Rate

The data rate or bit rate is expressed in bits per second (bps). This represents the actual number of data bits transferred per second.

1.5.3 Signal to Noise Ratio

The signal to noise (S/N) ratio of a communications link is an important limiting factor of the quality and rate of the communication. Noise sources may be external or internal, as discussed in Part 4 in this document.

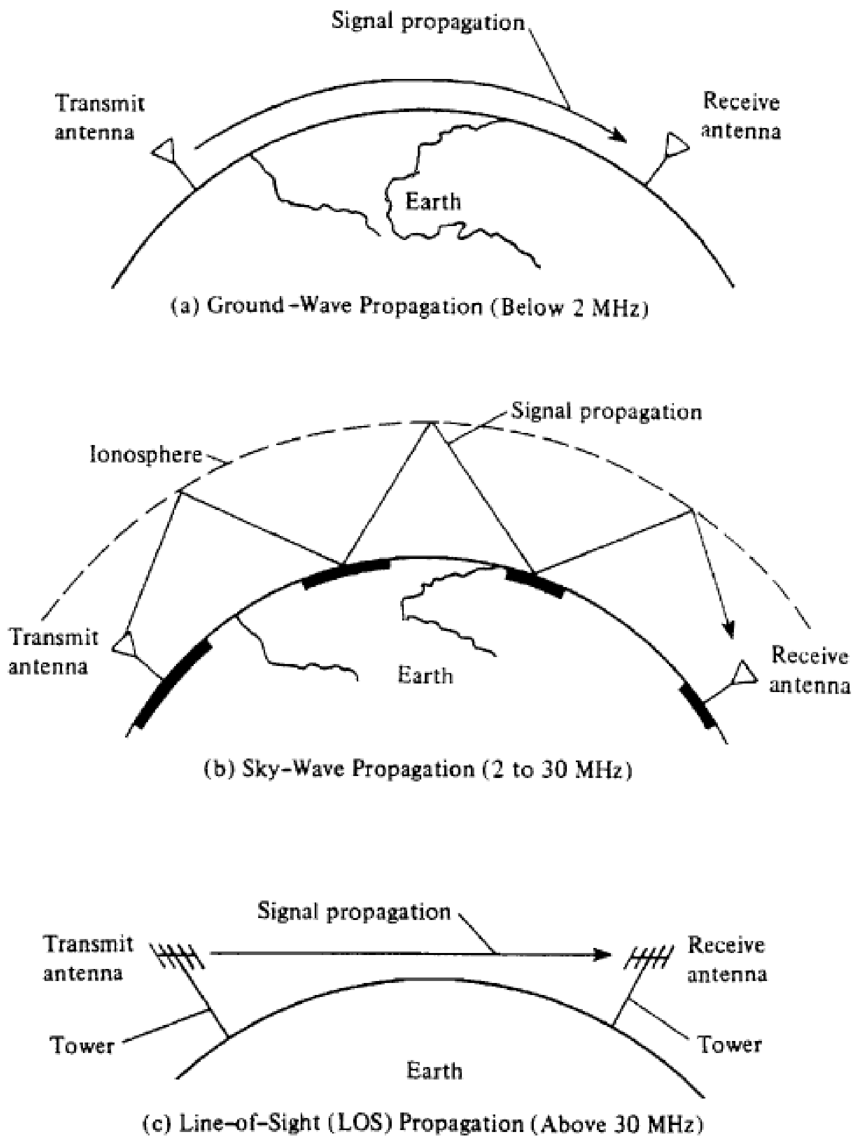
1.6 Wave Propagation

Generally, there are three types of traveling waves in wireless channels: the ground waves, the sky waves, and the Line-of-Sight (LoS).

The ground waves communication is efficient using LF band. While the sky waves communication is working only in the HF band. Higher frequency (VHF or higher) are not reflected by ionosphere and they pass directly to space, so they are used in the satellite communications.

The ionosphere is a region of ionized particles extends from 100km → 700km above the earth surface. The ionization is caused by the action of the sun's radiation on the upper atmosphere of the earth. The free electrons act as reflectors for HF radio waves, and their density varies with: height, period of the day and year. During day time, the reflection capability is strong, but it decreases during night. Most AM signals are transmitted over the HF band 3MHz → 30MHz. The transmitted HF signal reaches the receiver via the sky waves that have been reflected by the ionosphere.

While, the FM signals are transmitted over the VHF band which pass through the atmosphere layers (not reflected), hence the FM broadcasting coverage is limited. High frequencies, therefore, are transmitted through the LoS communication.

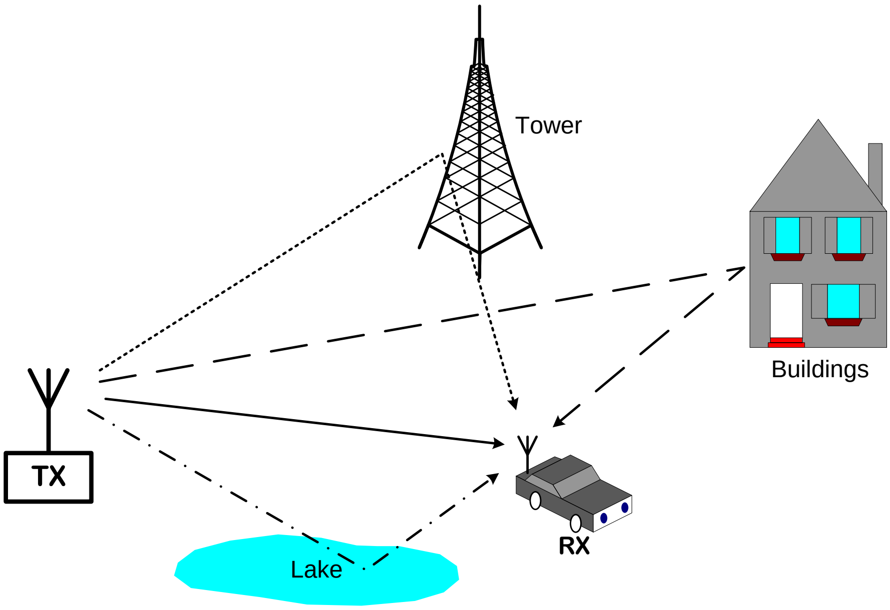


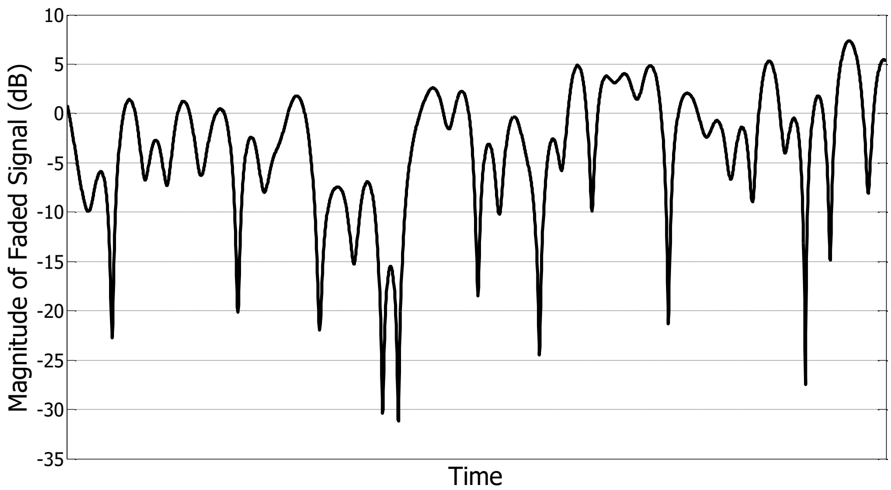
Propagation Types of Radio Frequencies

1.7 MULTIPATH EFFECT

When two or more radio waves arrive at the receiver point along different paths, their phases (and sometimes frequencies) are not the same, results in cancellation of one signal by the others, which results in a loss of the signal strength. This phenomenon is called '*fading*'.

The fading effect is usually divided into two types, namely *large-scale fading*, mainly due to path loss as a function of distance and shadowing by large objects such as mountains and tall buildings, and *small-scale fading* due to the constructive and destructive combination of randomly scattered, reflected, diffracted, and delayed multiple path signals.



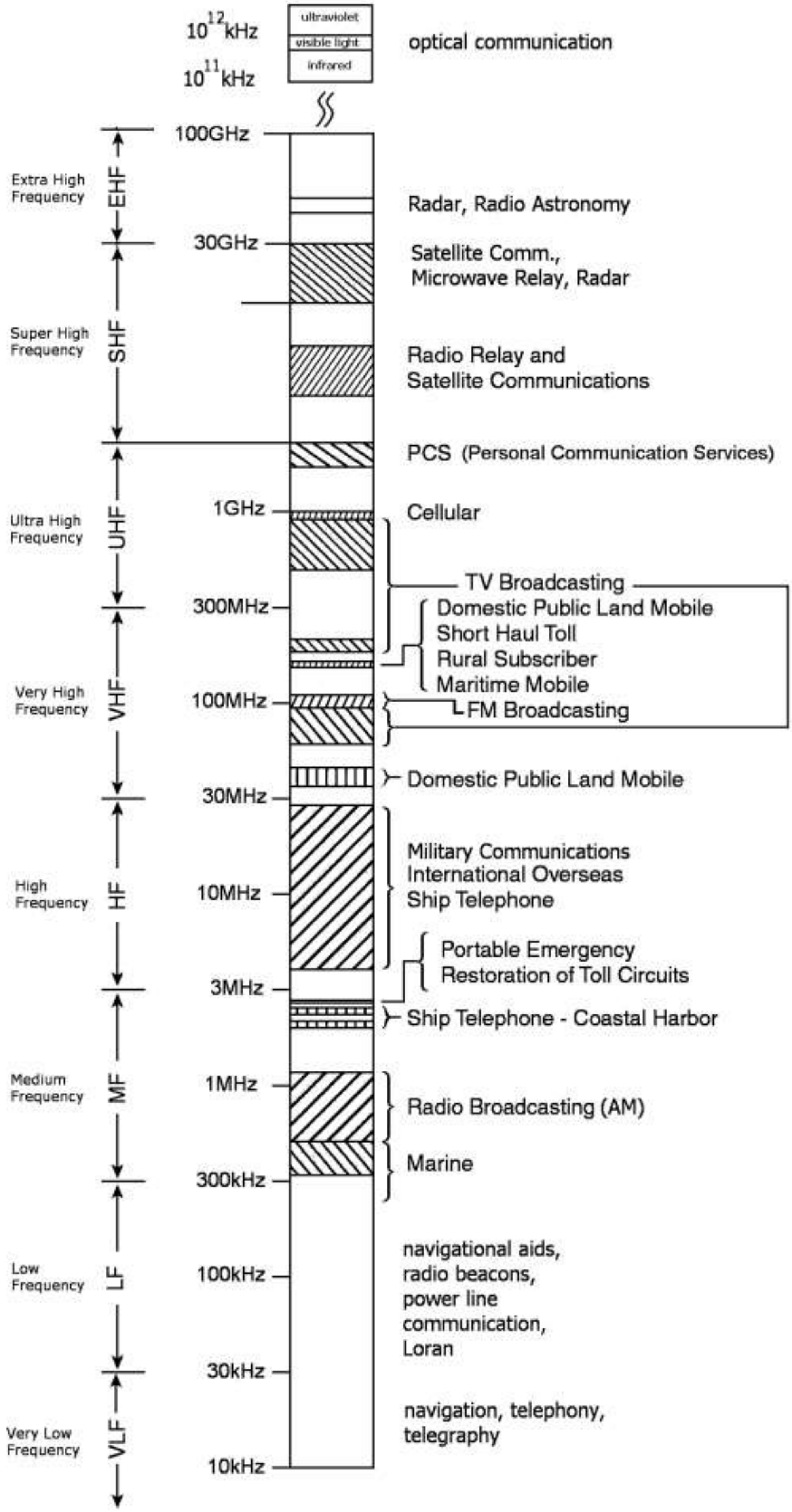


✍ *What is (are) the method(s) used to solve the Multipath problem?*

1.8 GOVERNMENT REGULATIONS AND STANDARDS

In communications, perhaps more than any other field, the need for standards to ensure correct interoperation of equipment is paramount. Communication systems are always interworking with other devices, possibly located on the other side of the world.

The drawing up of standards falls to a small number of national and international bodies, with, for example, ITU (International Telecommunications Union) being responsible for the drafting standards of most of the new wireless and wired communications.


10^12 kHz
10^11 kHz
ultraviolet
visible light
infrared
optical communication
100GHz
Extra High Frequency
EHF
Radar, Radio Astronomy
30GHz
Satellite Comm., Microwave Relay, Radar
Super High Frequency
SHF
Radio Relay and Satellite Communications
PCS (Personal Communication Services)
Ultra High Frequency
UHF
1GHz
Cellular
TV Broadcasting
300MHz
Domestic Public Land Mobile
Short Haul Toll
Rural Subscriber
Maritime Mobile
Very High Frequency
VHF
100MHz
FM Broadcasting
Domestic Public Land Mobile
30MHz
High Frequency
HF
10MHz
Military Communications
International Overseas
Ship Telephone
Portable Emergency
Restoration of Toll Circuits
3MHz
Ship Telephone - Coastal Harbor
Medium Frequency
MF
1MHz
Radio Broadcasting (AM)
Marine
300kHz
Low Frequency
LF
100kHz
navigational aids, radio beacons, power line communication, Loran
30kHz
Very Low Frequency
VLF
navigation, telephony, telegraphy
10kHz