Chapter 1 : Introduction to telecommunications

1 Human Communication Before Electricity

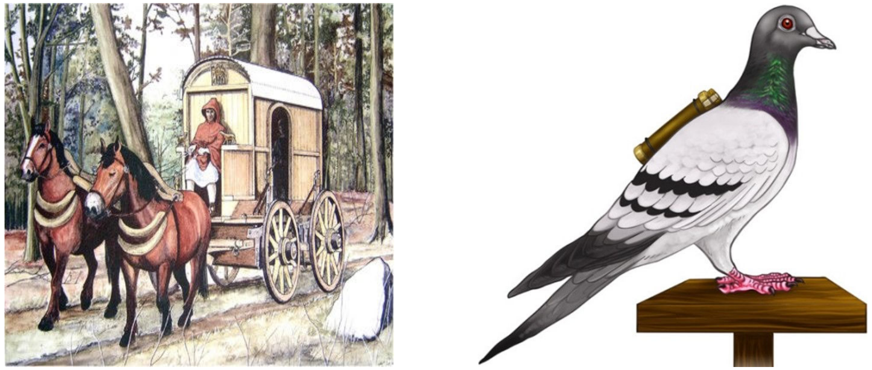
1.1 The Significance of Human Communication

Communication is the process of exchanging information between individuals. It allows people to interact with others. This process occurs in various forms, including verbal communication, nonverbal cues such as body language, and through writing, painting, print...

Figure 1: Exchange of Perspectives Between Two Individuals

1.2 Communicating over long distances

Early human communication was initially limited to face-to-face encounters. The written word extended the distance over which messages could be sent. For many years, long-distance communication relied on sending verbal or written messages through human runners, horseback riders, ships, and later, trains.



(a) Roman Mail Services *(b) carrier pigeon*

Figure 2: Communication by written messages

For faster communication, people used simple signals like drumbeats, horn blasts, smoke signals, and signal flags (semaphores). As messages were relayed from one location to another, these methods enabled the transmission of information over vast distances.

(a) Torches. *(b) Smoke Signals.* *(c) Aldis lamp.*

Figure 3: Examples of instant communication methods.

2 Modern Telecommunications

2.1 Historical Perspective of Telecommunication

Electricity gave birth to the first long-distance communication systems. The use of radio waves marked the beginning of wireless transmission systems, and advances in electronics enabled the creation of smaller and more complex circuits.

Key milestones in the evolution of telecommunication technology include:

- **1837**: Invention of the telegraph by Samuel Morse.
- **1864**: James Clerk Maxwell theoretically demonstrated radio wave propagation.
- **1876**: Alexander Graham Bell patents the telephone.
- **1887**: Heinrich Hertz confirms the existence of radio waves.
- **1888**: Guglielmo Marconi transmits the first radiotelegram.
- **1906**: Reginald Fessenden invents amplitude modulation; first electronic voice communication demonstrated.
- **1923**: Vladimir Zworykin invents and demonstrates television.
- **1940–1945**: Invention and development of radar.
- **1948**: Invention of the transistor at Bell Laboratories.
- **1958–1962**: First communication satellite tested by the United States.
- **1979**: First-generation cellular networks (1G) established in Japan.
- **1982**: TCP/IP protocol adopted, marking the beginning of the Internet.
- **1991**: Launch of second-generation cellular networks (2G).
- **1991**: The World Wide Web is launched to the public, marking the beginning of Internet commercialization.
- **1995**: Global Positioning System (GPS) becomes fully operational.
- **2009**: First 100 Gb/s fiber-optic networks implemented.
- **2019**: Introduction of fifth-generation cellular networks (5G).

2.2 Definition of Telecommunications

Telecommunications refers to the transmission of information over distances using electrical means for the purpose of communication.

3 An Overview of Communication Systems

3.1 Concepts of Information and Signal in Communication

Information: Information refers to any meaningful data or message conveyed from one entity to another. In communication systems, information can take various forms, including text, audio, video, or digital data.

Signal: A signal is an electrical representation of information that can be transmitted over a medium. Signals can vary in form, including analog and digital types.

3.2 Schematic diagram of a telecommunication system

A typical communication system consists of the following components:

Transmitter : The device or system responsible for sending information. It converts the information into a signal suitable for transmission over a given communication medium.

Communication channel: The medium through which the information is transmitted. This can be wired (like copper cables, Waveguides, fiber optics) or wireless (air, radio waves).

Receiver: The device that receives and decodes the transmitted information back into its original form.

Noise: Unwanted disturbances that may interfere with the transmission, reducing the quality of the received information.

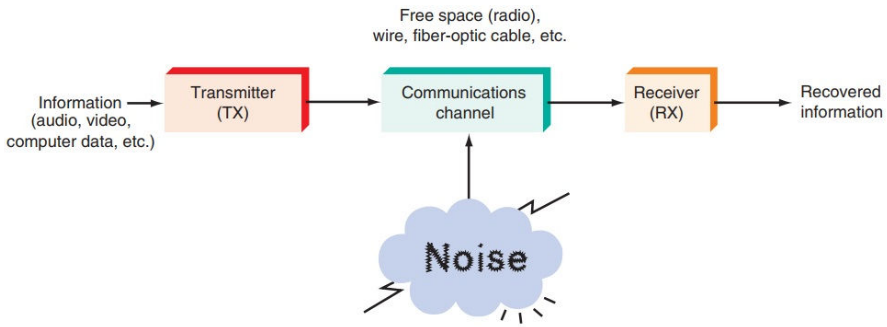


Figure 4: Schematic diagram of a telecommunication system

3.3 Transceivers

Most electronic communication is two-way, and so both parties must have both a transmitter and a receiver. These units are commonly referred to as transceivers.

For example : Telephones, handheld radios, cellular telephones, and computer modems.

3.4 Attenuation in Communication Channel

Signal attenuation, or degradation, is inevitable regardless of the transmission medium. Attenuation increases with the distance between the transmitter and receiver.

Communication channels are also frequency-selective, distorting the transmitted signal.

3.5 Analog vs. Digital Communication

Communication systems can be classified into:

Analog Communication Systems: These systems transmit information using continuous signals. It is more prone to noise and signal degradation over long distances. Examples include traditional radio, television broadcasts, and landline telephones.

Digital Communication Systems: These systems use discrete signals to represent data, providing better noise resistance, signal clarity, and error detection mechanisms.e. Examples include digital television, mobile communication, and computer networks.

3.6 Communication Modes

Telecommunication links can be classified based on the communication direction between two terminals: one-way or both ways.

Simplex Systems: Unidirectional communication where data flows in one direction only (e.g., TV broadcast, remote control).

Half-Duplex Systems: Communication where both parties can transmit and receive, but not simultaneously (e.g., walkie-talkies).

Full-Duplex Systems: Both parties can communicate simultaneously (e.g., telephone conversations).

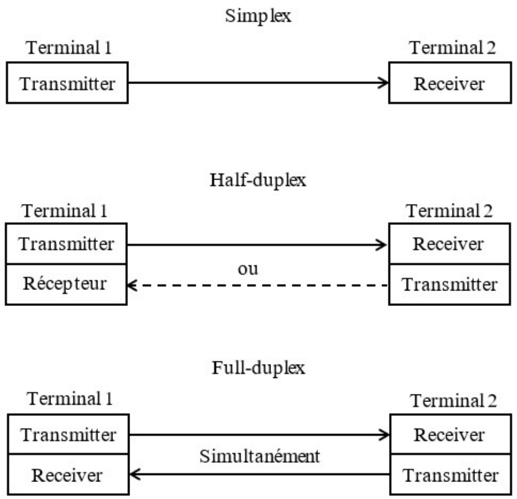


Figure 5: Communication Modes

3.7 Baseband Transmission

Baseband transmission involves converting information into an electronic signal suitable for the transmission medium, which is referred to as a baseband signal. These signals will be transmitted as they are, maintaining their original form.

For example, in many telephone and intercom systems, it is the voice itself that is placed on the wires and transmitted over some distance to the receiver.

3.8 Modulation Techniques

In many instances, baseband signals are incompatible with the transmission medium. Directly transmitting these baseband signals can result in significant signal loss and distortion. Although it is theoretically possible to transmit voice signals directly by radio, in practice, this approach is often impractical.

Modulation techniques address this issue by encoding the information onto a carrier wave with a higher, suitable frequency. This allows the information to be transmitted more efficiently and with greater resilience against noise and interference.

4 Concepts of a Signal

4.1 An Overview of Signals

4.1.1 Definition of a Signal

A signal is any physical quantity that varies with time. It is characterized by its temporal expression, which describes how its amplitude changes over time.

4.1.2 Periodic Signal

A signal is called periodic if its variation pattern repeats regularly after a constant period T. Mathematically, a signal $x(t)$ is periodic if for all t there exists a period T such that:

$$x(t+T) = x(t)$$

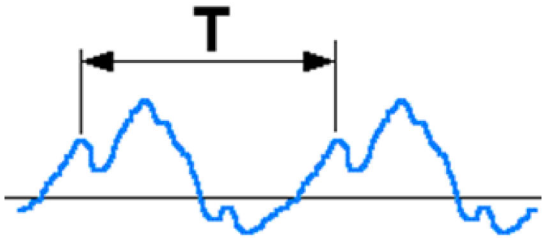


Figure 6: Example of a periodic signal

The **frequency** of a periodic signal is defined as the number of periods in one second, expressed in Hertz.

$$f = \frac{1}{T}\,[Hz]$$

Frequency Units:

- KHz = Kilohertz = 10^3 Hz
- MHz = Megahertz = 10^6 Hz
- GHz = Gigahertz = 10^9 Hz
- THz = Terahertz = 10^{12} Hz

4.1.3 Sine Wave Signal

A **sinusoidal signal** is a type of continuous-time signal whose amplitude varies as a function of time, following a sinusoidal pattern. It is mathematically expressed as:

$$s(t) = A\sin(2\pi f_0 t + \phi_0)$$

where:

- A is the **amplitude**, representing the peak value of the signal.
- f_0 is the **frequency** in Hertz (Hz), which indicates how many cycles occur per second, and is related to the period T by $f_0 = \frac{1}{T}$.
- $\omega_0 = 2\pi f_0$ is the **angular frequency** in radians per second, representing the rate
- ϕ_0 is the **initial phase** in radians, specifying the signal's phase shift at $t = 0$.

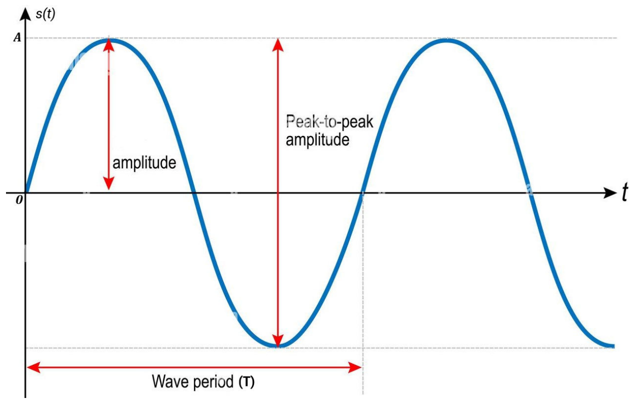


Figure 7: Amplitude variations of a sinusoidal signal over time.

4.1.4 Random Signal

A **random signal** is a signal that exhibits unpredictable variations over time. Random signals are characterized by their statistical properties and are often analyzed using probability theory.

4.1.5 Analog Signal

An **analog signal** is an electrical variable (e.g., voltage, current, electromagnetic field) that varies continuously, analogous to the variation of the physical quantity it represents.

Example: A temperature sensor is an electronic circuit that converts temperature variations in its environment into electrical voltage.

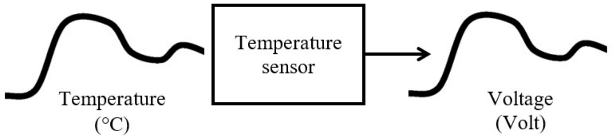


Figure 8: Variation of the output voltage (Volts) from a temperature sensor relative to the environmental temperature (°C)

The variation of voltage, expressed in volts, follows the same pattern as the variation of temperature in °C over time. Therefore, this voltage is considered analog.

4.1.6 Digital Signal

A **digital signal** is a discrete-time signal that represents information in a binary format, consisting of distinct values typically represented as 0s and 1s. This type of signal does not exist in nature, and its form is unrelated to the source physical phenomenon.

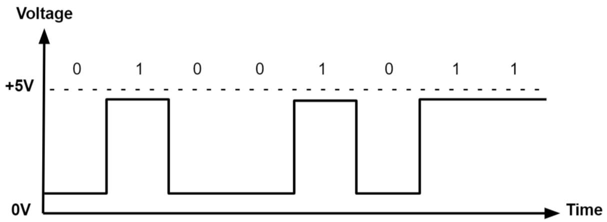


Figure 9: Example of a digital signal

A digital signal is obtained from an analog signal using an analog-to-digital converter (ADC). To convert back from a digital signal to an analog signal, a digital-to-analog converter (DAC) is used.

Figure 10: Analog-to-digital converter

4.1.7 Noise Signal

A **noise signal** is an unwanted or undesirable signal that interferes with the desired signal in a communication system. Noise can originate from various sources, including electrical interference, thermal fluctuations, and environmental factors. It is typically characterized by its random nature, which makes it difficult to predict or control.

4.2 Signal Power

4.2.1 Definition of Signal Power

Signal power refers to the average power carried by a signal over a given time period. It is a measure of the energy per unit time transmitted by the signal and is a crucial factor in determining the performance of communication systems.

Signal power is often measured in watts (W) or decibels (dB).

4.2.2 Instantaneous Power

Instantaneous power is defined as the power at a specific moment in time in an electrical circuit. It is given by the product of the instantaneous voltage across an element and the instantaneous current flowing through it. Instantaneous power $p(t)$ can be expressed as:

$$p(t) = v(t) \cdot i(t)$$

where:

- $p(t)$ is the instantaneous power at time t,
- $v(t)$ is the instantaneous voltage across the load,
- $i(t)$ is the instantaneous current flowing through the load.

4.2.3 Average Power

Average power is defined as the total energy consumed or transferred over a given period of time in an electrical circuit. It is calculated as the mean of instantaneous power over one complete cycle. Mathematically, the average power P can be expressed as:

$$P = \frac{1}{T}\int_0^T p(t)\,dt$$

where:

- P is the average power,
- T is the period of the signal,
- $p(t)$ is the instantaneous power at time t.

4.2.4 Average Power of a Sine Wave Signal in a Resistor

The average power P absorbed by a resistor R when a sinusoidal voltage $V(t)$ is applied across it can be expressed as:

$$P = \frac{V_{\text{rms}}^2}{R}$$

For a sinusoidal voltage, the relationship between the peak voltage V_p and the RMS voltage is given by:

$$V_{\text{rms}} = \frac{V_p}{\sqrt{2}}$$

Thus, the average power can also be expressed as:

$$P = \frac{V_p^2}{2R}$$

4.2.5 Electrical Power in Decibel

In telecommunications, power is often used as an informative measure. This power can vary from a few picowatts to several kilowatts. To simplify calculations, power is often expressed in a relative unit called decibel (dB).

The decibel is a logarithmic unit used to express the ratio of two values, typically power or intensity. It is defined as:

$$P_{\text{dB}} = 10\log_{10}\left(\frac{P}{P_0}\right)$$

where:

- P_{dB} is the power level in decibels,
- P is the measured power,
- P_0 is the reference power chosen as 1W .

$$P_{dB} = 10\log(P\,[W]) \quad \text{thus :} \quad 1W = 0dB$$

This logarithmic scale allows for easier comparison of power levels that can span many orders of magnitude. For example, an increase of 10 dB represents a tenfold increase in power.

For very low powers, the unit dBm, which references a power of 1mW, is used:

$$P_{dBm} = 10\log(P\,[mW]) \quad \text{thus :} \quad 1mW = 0dBm$$

Assuming the power is 1mW:

$$P_{dB} = 10\log(10^{-3}) = -30dB \quad \text{thus :} \quad 0dBm = -30dB$$

Power Conversion

- From dB to dBm : $P_{dBm} = P_{dB} + 30dB$
- From dBm to dB : $P_{dB} = P_{dBm} - 30dB$

Power Gain in Decibel

To express a power gain in decibels:

$$G_{dB} = 10\log(G) = 10\log\left(\frac{P_2\,[W]}{P_1\,[W]}\right) = 10\log\left(\frac{P_2\,[mW]}{P_1\,[mW]}\right)$$

If powers are expressed in decibels:

$$G_{dB} = (P_2)_{dB} - (P_1)_{dB} = (P_2)_{dBm} - (P_1)_{dBm}$$

4.3 Spectral Analysis of Signals

Spectral analysis is a technique used to analyze the frequency content of signals. It provides insights into how the power of a signal is distributed across different frequencies.

This analysis is particularly important in telecommunications, where understanding the frequency characteristics of a signal can lead to better system design and performance optimization.

4.3.1 Fourier Transform

The most common tool for spectral analysis is the Fourier Transform, which converts a time-domain signal into its frequency components. The Continuous Fourier Transform (CFT) is defined as:

$$X(f) = \int_{-\infty}^{\infty} x(t)e^{-j2\pi ft}dt$$

where:

- $X(f)$ is the Fourier Transform of the signal $x(t)$,
- f is the frequency,
- j is the imaginary unit.

4.3.2 Power Spectral Density (PSD)

The Power Spectral Density quantifies the power of a signal as a function of frequency. It is calculated as the square of the magnitude of the Fourier Transform, normalized by the bandwidth. The PSD provides a measure of how the power of the signal is distributed with frequency:

$$S(f) = |X(f)|^2$$

4.3.3 Sine Wave Spectrum

A **sine wave** is one of the simplest forms of signals and is defined by its smooth periodic oscillation. A pure sine wave contains only a single frequency component and can be represented in the frequency domain as a delta function at frequency f_0:

$$S(f) = A \cdot \delta(f - f_0)$$

Here, $S(f)$ is the Fourier transform of $s(t)$, and $\delta(f - f_0)$ denotes the Dirac delta function centered at the frequency f_0. This indicates that all the signal's energy is concentrated at a single frequency, f_0.

In the frequency domain, the sine wave appears as a vertical line at f_0 with a height proportional to the amplitude A. This representation illustrates that a pure sine wave is a monochromatic signal, having no harmonic frequencies or additional components.

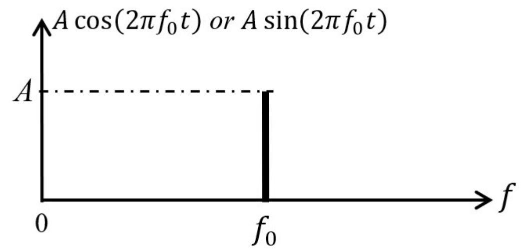


Figure 11: The frequency-domain plots of $A\sin(2\pi f_0 t)$ and $A\cos(2\pi f_0 t)$..

4.3.4 Harmonic Composition of a Signal

A signal is made up of a combination of frequencies.

The signal can be represented as a sum of the following components:

$$s(t) = \text{DC} + \text{fundamental frequency} + \text{2nd harmonic} + \text{3rd harmonic} + \cdots + \text{n-th harmonic}$$

- The essential component of the signal is a sine wave of the fundamental frequency. This is the minimum frequency necessary to represent a waveform.
- The subsequent components are integer multiples of the fundamental frequency, known as harmonics.
- The second multiple of the fundamental frequency is called the second harmonic, the third multiple is called the third harmonic, and so on.

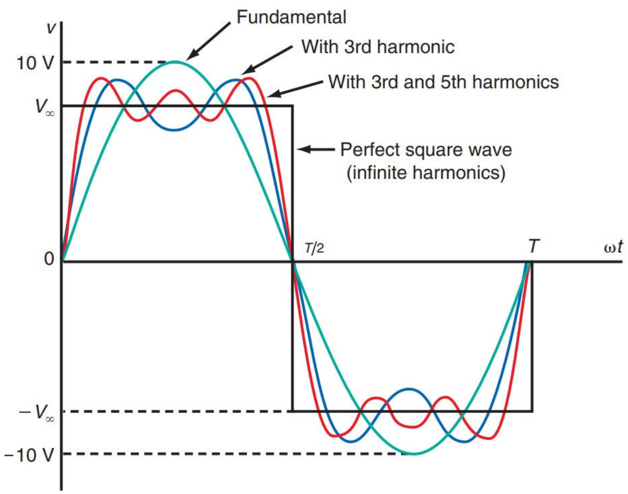


Figure 12: A square wave is made up of a fundamental sine wave and an infinite number of odd harmonics.

After decomposing a signal into its harmonics, each harmonic is represented in the spectrum by a Dirac impulse at the corresponding frequency.

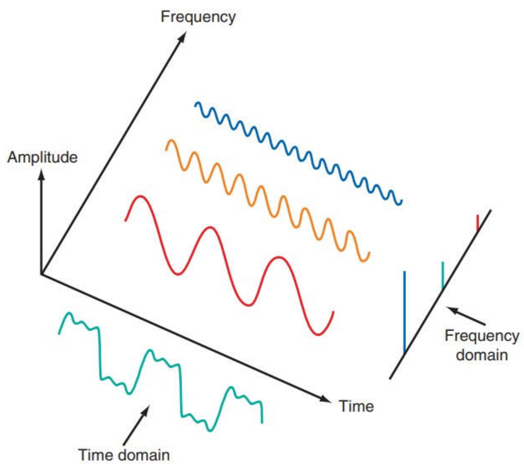


Figure 13: The relationship between time and frequency domains

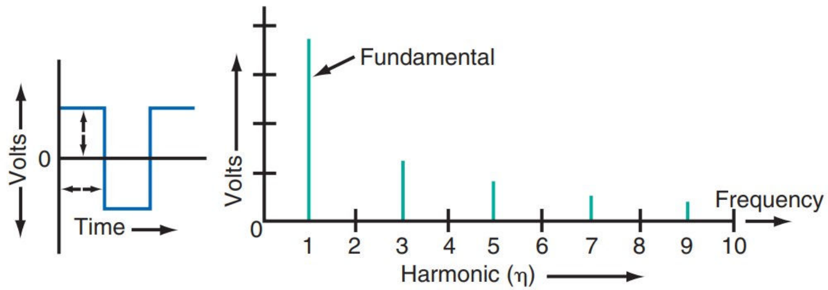


Figure 14: The frequency-domain plots of Square wave.

4.3.5 Signal Bandwidth

Bandwidth (BW) is that portion of the frequency spectrum occupied by a signal. It is also the frequency range over which a receiver or other electronic circuit operates.

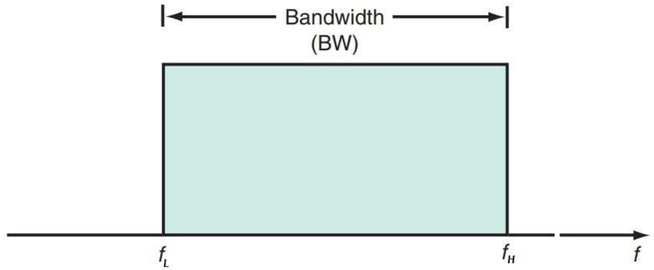


Figure 15: Signal Bandwidth.

More specifically, bandwidth is the difference between the upper and lower frequency limits of a signal or the operating range of equipment.

The bandwidth BW is calculated as the difference between the highest and lowest frequencies of the signal:

$$BW = f_{\mathrm{H}} - f_{\mathrm{L}}$$

where:

- f_{H} is the highest frequency component of the signal,
- f_{L} is the lowest frequency component of the signal.

4.3.6 Relative Bandwidth

The relative bandwidth BW_r is given by the ratio of the bandwidth to the center frequency f_0:

$$BW_r = \frac{BW}{f_0} \times 100\%$$

where: f_0 is the center frequency.

5 The Electromagnetic Spectrum

For classification purposes, the electromagnetic frequency spectrum is divided into distinct segments, each with unique characteristics and practical applications

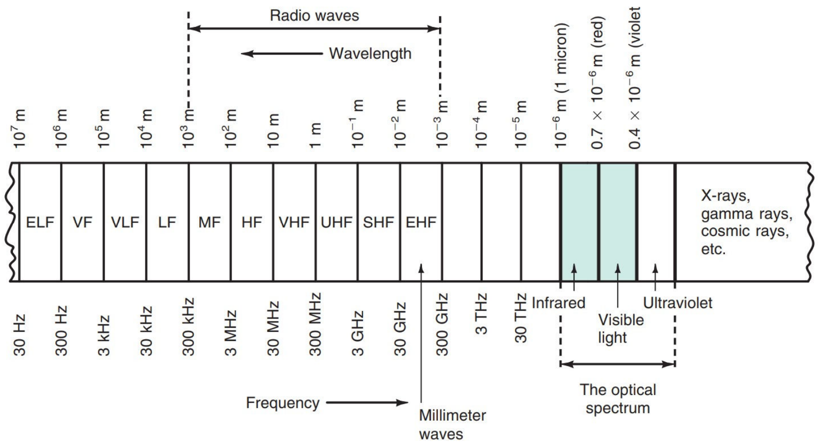


Figure 16: The electromagnetic spectrum.

Below are the frequency bands with their main telecommunications applications:

- **VF (Voice Frequencies)** : Between 300 and 3000 Hz, covering the human voice frequency band.
- **VLF (Very Low Frequencies)**: Includes a part of the spectrum audible to humans between 20 to 20,000 Hz, used in submarine communications.
- **LF (Low Frequencies)**: Used for maritime and aeronautical radionavigation.

- **MF (Medium Frequencies)**: AM radio broadcasting, marine and amateur radio communication.
- **HF (High Frequencies, Shortwaves)**: AM radio broadcasting and amateur radio.
- **VHF (Very High Frequencies, Metric Waves)**: FM radio broadcasting, terrestrial television, portable radio, amateur radio, marine and aeronautical communications.
- **UHF (Ultra High Frequencies, Decimetric Waves)**: Terrestrial television, mobile networks, WIFI 2.4GHz, Bluetooth, military communications, radar, amateur radio.
- **SHF (Super High Frequencies, Centimetric Waves)**: Satellite links, WIFI 5GHz, radar, mobile networks.
- **EHF (Extremely High Frequencies, Millimetric Waves)**: Satellite communications, personal wireless local area networks, mobile networks (5G).
- **Infrared** : Infrared remote controls.
- **Visible Light**: Transmission on optical fibers.
- **Ultraviolet**: Not used for communication; its primary use is medical.
- **Cosmic rays ...**

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