Data Communication Unit II

Metallic Transmission Lines Overview

A **metallic transmission line** is a system of metallic conductors designed to transfer electrical energy efficiently between two points via electrical current flow. These lines are integral in various applications, ranging from low-frequency electrical power distribution to high-frequency microwave signal propagation.

Structure

- Consists of **two or more conductors** separated by a **nonconductive insulator (dielectric)**.
- Lengths can range from **a few inches to thousands of miles**, depending on the application.

Applications

- Used to propagate **direct current (DC)**, **low-frequency alternating current (AC)**, and **high-frequency signals**, including **microwave radio frequencie**

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Transverse Electromagnetic Waves (TEM)

Types of Waves

- **Longitudinal Waves**:
  - Displacement occurs **parallel** to the direction of wave propagation.
  - Examples: **Sound waves** or **surface waves**.
- **Transverse Waves**:
  - Displacement occurs **perpendicular** to the direction of propagation.
  - Examples: **Electromagnetic waves**.

Electromagnetic Wave Characteristics

- **TEM Waves**:
  - Propagate electrical power along transmission lines.
  - Exist primarily in the **non-conductive dielectric** separating the conductors.
  - **Electric Field (E)** and **Magnetic Field (H)** are:
    - Perpendicular to each other.
    - Perpendicular to the direction of wave propagation.

Wave Components in Transmission Lines

- **Incident Waves**: Travel from the source to the load.
- **Reflected Waves**: Travel from the load back towards the source.

- Reflection typically occurs when there is an impedance mismatch between the source and the load.

1. Wave Velocity

- **Definition**: The speed at which a wave travels through a medium.
- **Variation with Medium**:
  - **Sound Waves**: Travel at ~1100 feet/second in normal atmospheric conditions.
  - **Electromagnetic Waves**: Travel significantly faster:
    - In **free space (vacuum)**: Speed of light, c≈186,000 miles/secc \approx 186,000 \, \text{miles/sec}c≈186,000miles/sec (≈3×108 m/s\approx 3 \times 10^8 \, \text{m/s}≈3×108m/s).
    - In **air**: Slightly slower than ccc due to air resistance.
    - Along **transmission lines**: Substantially slower due to the dielectric and conductor properties.

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2. Frequency and Wavelength

- **Oscillatory Nature**: Electromagnetic waves are periodic and repetitive.
  - **Frequency (fff)**: The number of oscillations per second, measured in **Hertz (Hz)**.
  - **Wavelength (λ\lambdaλ)**: The spatial distance between two successive wave crests or troughs.
- **Relationship Between Wavelength, Velocity, and Frequency**:
  λ=v×T\lambda = v \times Tλ=v×T
  - vvv: Wave velocity.
  - TTT: Period of the wave (time for one complete oscillation).
- Since T=1fT = \frac{1}{f}T=f1, the formula can also be written as:
  λ=vf\lambda = \frac{v}{f}λ=fv
  This relationship shows that the wavelength is inversely proportional to the frequency for a given wave velocity.

Characteristics of Electromagnetic waves

The three main characteristics are wave velocity, frequency and wavelength.

Wave velocity: Waves travel at different speeds depending on the type of wave and the characteristics of the propagation medium. Sound travels at 1100 feet/second in normal atmosphere where electromagnetic waves travel much faster. In free space i.e. in vacuum, TEM waves travel at the speed of the light, **c** (approximately at 186,000 miles/sec) and slightly slower in air and considerably slower along a transmission line.

Frequency and Wavelength: The oscillations of an electromagnetic wave are periodic and repetitive. The rate at which the periodic wave repeats is its frequency. The distance of one cycle occurring in space is called the wavelength and is given by

Distance = velocity × time

If the time for one cycle is substituted above, we get the length of one cycle which is called wavelength and is given by

λ = velocity × period = $v \times T$, where λ is wavelength, v is velocity and T is period because $T = 1/f$, we can write $\lambda = v/f$

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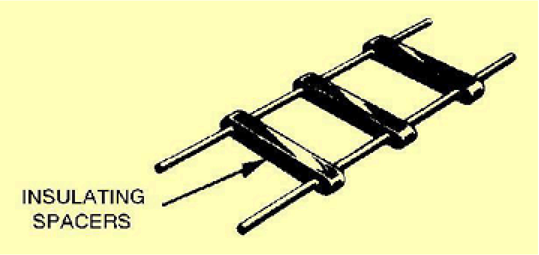
metallic transmission line types

Parallel-Conductor Transmission Lines

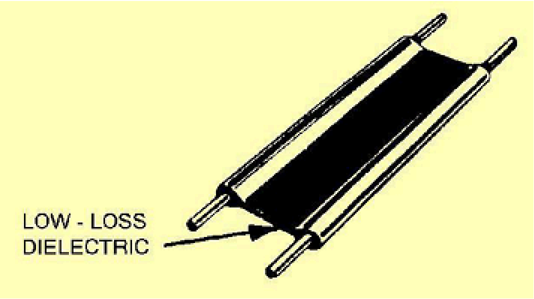
1. **Open-Wire Transmission Lines**:
    - Two parallel wires separated by air, supported by spacers.
    - **Advantages**: Simple construction.
    - **Disadvantages**: High radiation losses and susceptibility to crosstalk.
    - **Applications**: Standard voice-grade telephone lines.
2. **Twin-Lead Lines**:
    - Two parallel conductors separated by a continuous solid dielectric.
    - **Applications**: Connecting televisions to antennas

propagates in the air between the conductors, which acts as dielectric. The main advantage is its simple construction.



Since no shielding is present, the radiation losses are high and cable is susceptible to picking up signals through mutual induction, which produces crosstalk. The primary usage is in standard voice-grade telephone applications.

Twin lead: Twin-lead is essentially the same as open-wire transmission line except that the spacers between the two conductors are replaced with a continuous solid dielectric ensuring the uniform spacing along the entire cable.



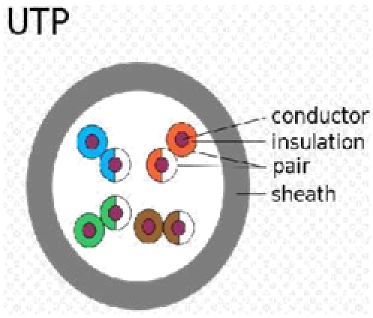
Types of Guided Transmission Media

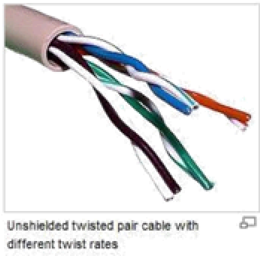
1. Twisted Pair Cable

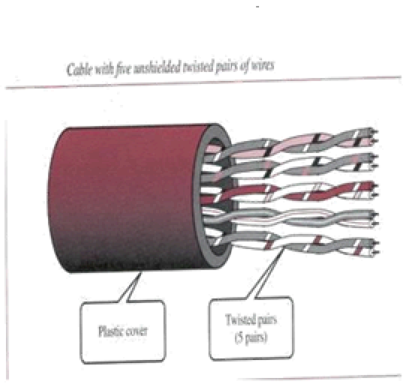
- **Description**: Made by twisting two insulated copper wires together to reduce electromagnetic interference.
- **Features**:
  - Lightweight, inexpensive, and easy to install.
  - Commonly used in LANs and telephone lines.
  - Comes in two types: **Unshielded Twisted Pair (UTP)** and **Shielded Twisted Pair (STP)**.
  - Noise reduction improves as the twists in the wire increase.

Unshielded Twisted Pair (UTP):

- Affordable and simple to install.
- Commonly used in high-speed LANs but only effective for short distances due to signal weakening (attenuation).







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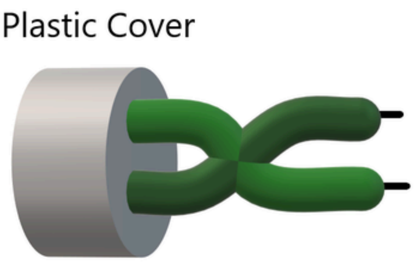

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Shielded Twisted Pair (STP):

- Better shielding than UTP, allowing for higher data rates.
- Slightly more expensive and heavier than UTP.

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2. Coaxial Cable

- **Description**: Consists of a copper core surrounded by insulation and shielding to block interference.
- **Features**:
  - Can carry data at higher frequencies than twisted pair cables.
  - Often used for TV connections and internet modems.

Types:

- **Baseband Transmission**: Sends one signal at a time.
- **Broadband Transmission**: Sends multiple signals simultaneously.

Advantages:

- High-speed data transmission.
- Better shielding and higher bandwidth than twisted pair cables
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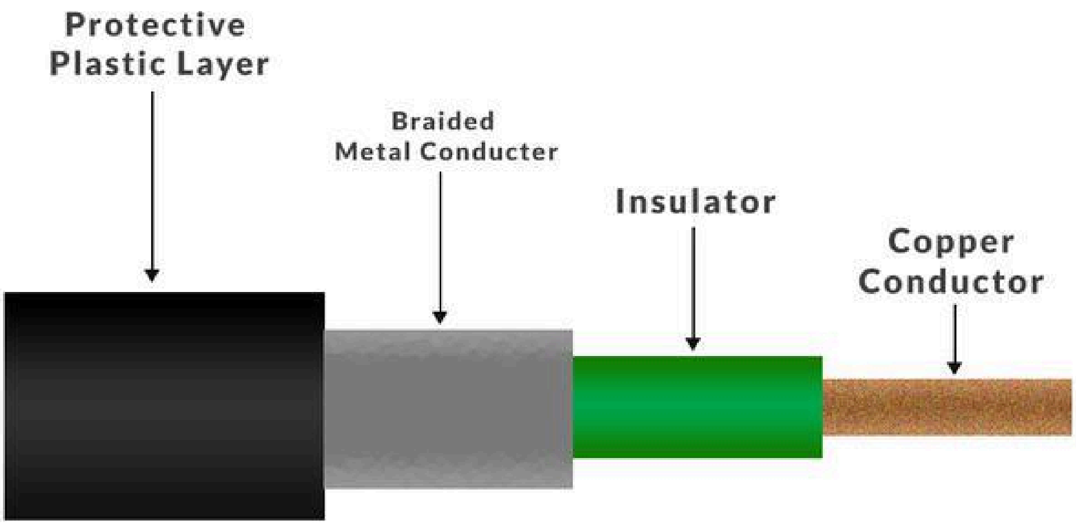

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Disadvantages:

- More expensive.
- A fault in the cable can disrupt the entire network.

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3. Fiber Optic Cable

- **Description**: Uses glass or plastic fibers to carry data as pulses of light, making it faster and more reliable than copper cables.
- **Features**:
  - **Core**: The center of the fiber that transmits light.
  - **Cladding**: Surrounds the core, reflecting light to keep it within the fiber.
  - **Jacket**: Protects the fiber from damage.

Advantages:

- Supports higher bandwidth and faster speeds.
- Can transmit data over longer distances with minimal signal loss.
- Immune to electromagnetic interference.

Disadvantages:

- Expensive to install.

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4. Connectors

- These join cables and ensure continuous communication. Examples include **RJ-45 connectors** for twisted pair cables and **BNC connectors** for coaxial cables.

Applications of Guided Transmission Media

1. **Local Area Networks (LANs)**: Commonly use twisted pair and coaxial cables to connect devices within a small area.
2. **Wide Area Networks (WANs)**: Fiber optic cables are used for long-distance data transfer with high speed.
3. **Internet Backbone Networks**: High-capacity fiber optics enable fast and reliable global data transmission.
4. **Telecommunication Networks**: Guided media are essential for stable and secure communication.

Advantages of Guided Transmission Media

1. **Reliability**: Provides stable and secure communication.
2. **Security**: Difficult to intercept compared to wireless media.
3. **Higher Bandwidth**: Especially with fiber optics, supports large data transfers.
4. **Less Interference**: Cables are less affected by external noise.
5. **Predictable Performance**: Offers consistent signal quality.
6. **Suitable for Long Distances**: Fiber optics work well over long ranges.
7. **Cost-Effective for Short Distances**: Twisted pair cables are affordable for local networks.

Disadvantages of Guided Transmission Media

1. **Limited Mobility**: Devices are physically connected, reducing flexibility.
2. **Physical Damage**: Cables can be cut or damaged, disrupting communication.
3. **High Cost for Long Distances**: Fiber optics are expensive to install over large areas.
4. **Limited Bandwidth in Some Types**: Twisted pair cables have lower bandwidth than fiber optics.
5. **Infrastructure Dependency**: Changes to the network require updates to physical cabling.
6. **Environmental Impact**: Manufacturing and disposal of cables can harm the environment.

Conclusion

Guided transmission media are the backbone of modern computer networks, providing reliable and secure communication channels. As technology advances, understanding these media is essential for building efficient and dependable networks.

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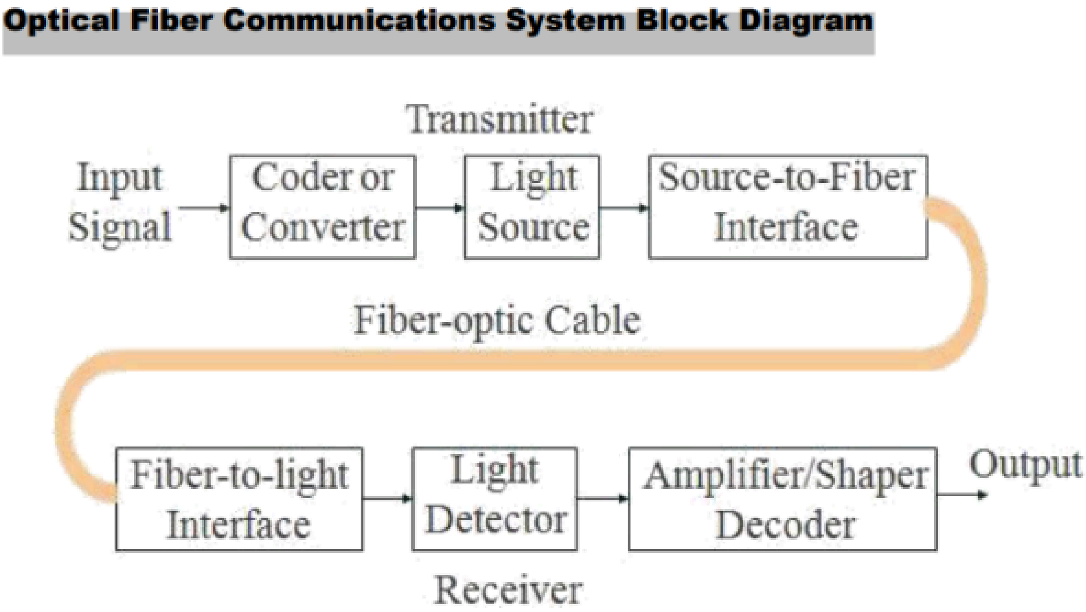
OPTICAL FIBER TRANSMISSION MEDIA :



Simplified Explanation of Optical Fiber Communication System

Optical fiber communication is a modern way of transmitting information using light signals instead of electrical signals. It is widely used for long-distance, high-speed data transmission because it offers better bandwidth and minimal signal loss compared to traditional copper cables.

Main Components of Optical Fiber Communication System:

1. **Transmitter:**
   - **Role:** Converts electrical signals (data like audio, video, or digital information) into light signals.
   - **Key Parts:**
     - **Light Source:** Lasers or LEDs generate the light pulses to carry the data.
     - **Driver Circuit:** Modulates (controls) the light source based on the electrical input.
2. **Optical Fiber:**
   - **Role:** The medium through which the light signals travel. It is a thin strand made of glass or plastic.
   - **Parts:**
     - **Core:** The center where light travels. It's made of pure glass with a high refractive index (helps reflect light inside).

        - **Cladding:** Surrounds the core and has a lower refractive index, which keeps the light inside the core using *total internal reflection*.
        - **Buffer Coating:** Protects the fiber from damage and environmental effects.
    - **Types:**
        - **Single-mode Fiber:** Best for long distances as it carries a single light signal with minimal distortion.
        - **Multi-mode Fiber:** Used for short distances, carrying multiple light signals.
3. **Optical Amplifier (Optional):**
    - **Role:** Strengthens weak light signals during transmission without converting them back to electrical form. Useful for very long distances like undersea cables.
4. **Receiver:**
    - **Role:** Converts light signals back into electrical signals.
    - **Key Parts:**
        - **Photodetector:** Detects light pulses and converts them into electrical signals.
        - **Amplifiers:** Boost the electrical signals to make them stronger.
        - **Signal Processor:** Reconstructs the original data from the electrical signal.
5. **Regenerators (Optional):**
    - **Role:** For very long distances, they clean up, amplify, and resend the signal to prevent loss or distortion.

How Optical Fiber Communication Works:

1. **Transmitter Stage:**
    - Data (e.g., audio, video, or digital) is converted into electrical signals.
    - These signals modulate a light source (laser or LED), creating light pulses representing binary data (1s and 0s).
    - The light pulses are sent into the optical fiber.
2. **Transmission Through Fiber:**
    - Light travels through the core of the fiber using *total internal reflection*, bouncing within the fiber walls to stay inside.
    - Optical fibers are immune to electromagnetic interference and have low signal loss, ensuring the data stays intact over long distances.
3. **Signal Amplification (Optional):**
    - For very long distances, optical amplifiers are used to boost the signal strength.
4. **Receiver Stage:**
    - The light signal reaches the receiver, where a photodetector converts it back into electrical form.
    - Amplifiers and signal processors enhance and decode the data.
5. **Output Stage:**

    ○ The electrical signal is processed back into its original form (e.g., audio, video, or digital data) and sent to the user’s device (TV, computer, etc.).

Advantages of Optical Fiber Communication:

1. **High Bandwidth:** Can carry a large amount of data.
2. **Faster Speeds:** Transmits data at the speed of light.
3. **Long Distances:** Signals can travel farther without losing strength.
4. **Less Interference:** Immune to electromagnetic interference.
5. **Reliable:** Resistant to temperature changes and physical damage.

This system revolutionized communication by enabling faster, more reliable data transfer for applications like internet backbones, telecommunications, and undersea data cables

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Optical fiber and metallic cables (e.g., copper cables) are commonly used for data transmission, but they differ significantly in terms of properties, performance, and applications. Here's a detailed comparison:

1. Transmission Speed

- **Optical Fiber**: Extremely high-speed transmission due to the use of light signals. Can support data rates in the range of terabits per second.
- **Metallic Cable**: Slower in comparison, limited by electrical signal speeds and susceptible to signal degradation over long distances.

2. Bandwidth

- **Optical Fiber**: Much higher bandwidth, capable of handling large volumes of data, ideal for high-demand applications like internet backbones and video streaming.
- **Metallic Cable**: Limited bandwidth; suitable for lower-demand applications like basic telephone and LAN connections.

3. Distance

- **Optical Fiber**: Can transmit signals over several kilometers without significant signal loss (low attenuation).
- **Metallic Cable**: Signal strength diminishes over shorter distances, requiring repeaters or amplifiers.

4. Interference and Noise

- **Optical Fiber**: Immune to electromagnetic interference (EMI) and radio frequency interference (RFI) since it uses light rather than electricity.
- **Metallic Cable**: Susceptible to EMI and RFI, especially in environments with high electrical noise.

5. Security

- **Optical Fiber**: More secure as it is difficult to tap or intercept light signals without being detected.
- **Metallic Cable**: Easier to tap, posing a higher risk of eavesdropping and signal interception.

6. Durability and Environment

- **Optical Fiber**: Less prone to corrosion; more resistant to environmental factors like moisture but can be fragile and prone to bending damage.
- **Metallic Cable**: More robust physically, but prone to corrosion and degradation over time.

7. Cost

- **Optical Fiber**: Higher initial installation cost due to expensive materials and equipment, but long-term maintenance costs are lower.
- **Metallic Cable**: Lower initial costs, but maintenance and replacement costs can add up over time.

8. Weight and Size

- **Optical Fiber**: Lightweight and thinner, making it easier to handle and install in dense cable arrangements.
- **Metallic Cable**: Heavier and bulkier, which can be a disadvantage in large installations.

9. Applications

- **Optical Fiber**: Used in high-speed internet, telecommunications, cable TV, medical imaging, and long-distance communication.
- **Metallic Cable**: Common in residential wiring, telephone networks, and traditional LANs.

10. Reliability

- **Optical Fiber**: More reliable in extreme environmental conditions and long-term use.
- **Metallic Cable**: More likely to fail under adverse environmental condition

Optical Fiber vs. Metallic Cable: Key Differences

Feature	Optical Fiber	Metallic Cable
Speed	Very high (light signals)	Slower (electric signals)
Bandwidth	Higher, supports massive data	Limited
Distance	Long without signal loss	Short, needs amplifiers
Interference	Immune to EMI/RFI	Susceptible
Security	Hard to tap, more secure	Easier to tap
Durability	Resistant to corrosion, fragile to bends	Robust but corrodes over time
Cost	Higher initial cost, lower maintenance	Cheaper initially, more upkeep
Size	Lightweight and thin	Heavier and bulkier
Applications	High-speed internet, telecom	Home wiring, basic LAN

Summary: Optical fiber is faster, more secure, and better for long distances, while metallic cables are cheaper and easier for short, simple setups.

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Transmission Line Classifications

Transmission lines can be broadly classified into **Balanced** and **Unbalanced** types based on the way they handle signals and ground connections.

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1. Balanced Transmission Line

- **Description**: Both conductors carry equal and opposite currents with respect to electrical ground.
    - One conductor carries the **signal**.
    - The other conductor carries the **return signal**.
    - Known as **differential signal transmission**.
- **Currents**:
    - **Metallic Circuit Currents**: Opposite directions in the pair.
    - **Longitudinal Currents**: Same direction in the pair (undesirable).
- **Advantage**:
    - Excellent noise rejection because external noise affects both conductors equally, and the differential signal cancels it out.
- **Common Types**:
    - **Twin-Lead**: Used in radio frequency signals.
    - **Twisted Pair**: Used for lower-frequency signals like in Ethernet cables.
- **Key Feature**: Requires both conductors to be symmetrical and identical for optimal performance.

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2. Unbalanced Transmission Line

- **Description**: One conductor is at **ground potential**, while the other carries the signal.
  - Known as **single-ended signal transmission**.
- **Advantage**:
  - Simpler wiring as only one signal wire and one shared ground wire are required.
- **Common Types**:
  - **Coaxial Cable**: Widely used in RF, TV, and internet connections.
- **Note**:
  - Unbalanced lines are less immune to external noise compared to balanced lines.

Connecting Balanced and Unbalanced Lines

- Special transformers called **baluns** (short for **balanced to unbalanced**) are used to connect balanced lines to unbalanced lines, ensuring proper impedance matching and signal integrit

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1. Metallic Transmission Line Equivalent Circuit

A metallic transmission line (e.g., coaxial cables, parallel-wire lines) is typically modeled using an equivalent circuit to represent the electrical properties of the line. The basic components of the equivalent circuit are:

- **Series Resistance (R)**: This represents the resistive losses in the conductors of the transmission line, which are primarily due to the finite conductivity of the metal. It is dependent on the material of the conductor and the frequency of the signal.
- **Inductance (L)**: The inductance accounts for the magnetic field generated by the current flowing through the transmission line. The inductance is proportional to the length of the line and the geometry of the conductors (spacing and radius).
- **Shunt Capacitance (C)**: This represents the electric field between the conductors, which stores energy in the dielectric medium between them. Capacitance depends on the distance between the conductors and the dielectric material properties.
- **Conductance (G)**: This represents the leakage current through the dielectric medium. In a metallic transmission line, this is typically very small, but it becomes significant for high-frequency signals or poor-quality insulation.

The equivalent circuit of a metallic transmission line can be described as an **LC or RLC network**, depending on whether losses are considered. The per-unit-length parameters (R, L, C, and G) are defined for the line and are used to model the propagation of waves along the transmission line.

2. Wave Propagation on Metallic Transmission Lines

When an electrical signal propagates along a metallic transmission line, the voltage and current waves travel at a characteristic speed determined by the transmission line's inductance and capacitance. The general form of wave propagation is described by the telegrapher's equations:

- **Voltage wave equation**:

$$\frac{\partial^2 V}{\partial x^2} - LC\frac{\partial^2 V}{\partial t^2} = 0$$

- **Current wave equation**:

$$\frac{\partial^2 I}{\partial x^2} - LC\frac{\partial^2 I}{\partial t^2} = 0$$

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Where LLL is the inductance per unit length, CCC is the capacitance per unit length, and xxx and ttt are the spatial and time coordinates, respectively.

The wave propagation speed vvv on a metallic transmission line is given by:

$$v = \frac{1}{\sqrt{LC}}$$

For a transmission line with low loss (ideal case), the voltage and current waves travel without significant attenuation. However, losses in the conductors and dielectric material can cause attenuation, reducing the amplitude of the wave over distance.

3. Metallic Transmission Line Losses

The losses in metallic transmission lines can be categorized into:

- **Conductor Losses (Resistive Losses)**: These occur due to the resistance of the conductors, which dissipate energy in the form of heat. The conductor resistance increases with frequency due to the skin effect, which causes the current to flow primarily on the surface of the conductor at higher frequencies. This increases the effective resistance and the power losses.

- **Dielectric Losses**: These losses occur in the insulating material (dielectric) between the conductors. At higher frequencies, the dielectric material may exhibit resistive losses due to its finite conductivity, causing energy dissipation.
- **Radiation Losses**: In some configurations, especially for high-frequency signals, part of the energy may be radiated away from the transmission line in the form of electromagnetic waves. This is more common in open-wire lines or poorly shielded cables.
- **Reflection Losses**: These occur when there is a mismatch in impedance between the transmission line and the load. This leads to partial reflection of the wave, which causes loss in power transfer efficiency.

The total loss α\alphaα (attenuation constant) of the line can be expressed as:

$$\alpha = \sqrt{RG + \frac{\omega^2 LC}{4}}$$

Where:

- RRR is the resistance per unit length
- GGG is the conductance per unit length
- LLL is the inductance per unit length
- CCC is the capacitance per unit length
- ω\omegaω is the angular frequency (ω=2πf\omega = 2\pi fω=2πf)

As frequency increases, both conductor losses (due to the skin effect) and dielectric losses typically increase, leading to greater attenuation of the signal.