Chapter 3: Cable Characteristics

Data with information moves from one network device to another device through networking cable. Networking cable is the transmission medium to transmit data from one end to another end. Different types of cables are available, which are commonly used with LANs. Selection of the type of cable for a network depends upon the network’s topology, size, protocol and expenditure also. For developing a successful network, it is important to understand the different characteristics of all types of cables and how they are related to a particular type of network.

3.1 Components of Twisted Pair cable

A twisted pair cable is made from bundled twisted pairs [1] as shown in the fig 3.1.

![Twisted-pair construction](image)

Fig 3.1: Twisted-pair construction

The components of a twisted pair cable are:

- **Conductor wires**

  The twisted signal wires are normally solid copper conductors but can be stranded. A twisted pair cable may contain multiple twisted pairs. Common
sizes are 2, 4, 7, 15, 25, 50, 100, 200, 300 or 400 pairs. Several pairs twisted around each other with color coded binder tapes form a cable unit or a binder group. A cable is made of numbers of binder groups wrapped around each other. The size of the cable determines the total number of groups and the number of pairs in each binder group.

- **Insulation**

Each of the conductors in a twisted pair cable is surrounded by a color coded insulating layer. Color coded insulation helps to identify the pair and to ensure the correct polarity. The A-leg is marked White, Red, Black, Yellow or Violet in sequence to identify which group of five pairs. The B-leg is consecutively coded Blue, Orange, Green, Brown and Slate.

- **Sheath**

The sheath of the cable is made of polyvinylchloride (PVC) or polyethylene (PE), in which the wire cables are encased.

### 3.2 Co-axial cable components

A co-axial cable has the following concentric or co-axial components [1] as shown in the fig 3.2.

- **Carrier wire**

A carrier wire or signal wire usually made of copper is in the center of the cable. The wire is normally solid but may be stranded. The diameter of the wire
is an important factor which determines the attenuation of the signal over distances.

![Co-axial cable components](image)

**Fig 3.2: Co-axial cable components**

- **Insulation**

  There is an insulation layer consisting of a dielectric material around the signal wire.

- **Foil shield**

  There is a thin foil shield around the dielectric. Normally, the foil shield consists of aluminum bonded to both sides of a mylar tape.

- **Braid shield**

  The insulation and foil shield are surrounded by a braid or mesh conductor which is made of copper or aluminum. The braid conductor is normally
connected to ground. The earthed braid shield together with any foil shield protects the signal wire from EMI and RFI.

- **Sheath**

  The outermost cover which provides the physical protection for the cable is usually made of polyethylene (PE) and polyvinyl chloride (PVC).

### 3.3 Fiber Optic cable components

A fiber optic cable has the following components [1]:

- **Core**

  The core is that part of an optical fiber which carries the light signal. For multimode cable, the most common core sizes are 50µm and 62.5µm. For single mode cable, core size is 8.5µm.

- **Cladding**

  The part cladding is a protective layer of optical fiber surrounding the core with a slightly lower refractive index than of the cladding. Typical cladding diameter is 125µm.

- **Fiber-optic coating**

  The coating is a plastic layer surrounding the cladding, which helps to increase the cable strength, thereby decreasing likelihood of breaking the fiber. This layer protects the core and the cladding in the operating environment.
• **Buffer**

A buffer can protect the fiber from all the stresses applied to the cable, isolating the fiber from these stresses. A buffer can be of two types: loose buffer and tight buffer.

• **Strength members**

Strength members of an optical fiber are strands of some very tough materials which provide tensile strength for the cable. Examples of such materials are steel, fiberglass or Kevlar with their own advantages and disadvantages.

• **Cable sheath**

The outer casing of a fiber-optic cable is called the sheath providing primary mechanical protection.

### 3.4 General Cable characteristics

There are two general cable characteristics, which are of most interest. They are *attenuation* and *bandwidth* [2].

• **Attenuation**

Attenuation means a loss of energy. When a signal travels through a medium, it loses some of its energy in overcoming the resistance of the medium. The longer the signal travels, the more energy it loses.
The unit used to calculate the loss (or gain) of power during the transmission of a signal is **decibel (dB)**.

\[
\text{dB} = 10 \log_{10}(P_r / P_s) \quad (3.1)
\]

where, \( P_r \) is received signal power

\[ P_s \] is transmitted signal power

Since, \( P \propto V^2 \), \( \text{dB} = 20 \log_{10}(V_2 / V_1) \quad (3.2) \) also.

The dB will be negative if we lost power, positive if we gained power and exactly the same if there is no change of power.

- **Bandwidth**

**Bandwidth** is a measure of network performance. In networking, the term bandwidth is used in two contexts.

- **Bandwidth in hertz**, which refers to the range of frequencies contained in a composite signal or the range of frequencies that a channel can pass. It is generally expressed in KHz (kilohertz), MHz (megahertz).

- **Bandwidth in bits per second**, which refers to the speed of transmission of bits in a channel. It is generally expressed in Kbps (kilo bits per second), Mbps (mega bits per second), Gbps (giga bits per second).

Different types of cables support different bandwidths.
3.5 Copper Cable Characteristics

3.5.1 Transmission line theory for copper cable

The transmission characteristics of copper cable can be understood by using transmission line theory. According to transmission line theory, any copper cable has four basic parameters [3]. These four basic parameters are also called primary line constants. The primary line constants describe the characteristics of copper cable in terms of the electrical properties of the copper lines. All other parameters can be derived from the primary line constants and they are called secondary line constants and are more generally applicable.

The following table 3.1 gives the four primary line constants with their symbols and units.

Table 3.1: Four primary line constants

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Unit</th>
<th>Unit symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance</td>
<td>R</td>
<td>ohm per meter</td>
<td>Ω/m</td>
</tr>
<tr>
<td>Inductance</td>
<td>L</td>
<td>henries per meter</td>
<td>H/m</td>
</tr>
<tr>
<td>Capacitance</td>
<td>C</td>
<td>farads per meter</td>
<td>F/m</td>
</tr>
<tr>
<td>conductance</td>
<td>G</td>
<td>Siemens per meter</td>
<td>S/m</td>
</tr>
</tbody>
</table>
Resistance and inductance are properties of the copper conductor and both of them are series elements of the line. Capacitance and Conductance are properties of the dielectric material and they are shunt element of the line.

To give a true representation of a circuit, the four line constants can not be simply represented as lumped elements, they must be described as distributed elements. For that the elements must be made infinitesimally small so that each element is distributed along the line as shown in the fig. The infinitesimal elements in an infinitesimal distance \(dx\) are given by,

\[
dL = \lim_{\delta x \to 0}(L\delta x) = Ldx \quad (3.3)
\]

\[
dR = \lim_{\delta x \to 0}(R\delta x) = Rdx \quad (3.4)
\]

\[
dC = \lim_{\delta x \to 0}(C\delta x) = Cdx \quad (3.5)
\]

\[
dG = \lim_{\delta x \to 0}(G\delta x) = Gdx \quad (3.6)
\]

Fig 3.3(a) represents the equivalent circuit of a transmission line using distributed elements.

Now series impedance \(Z\) and shunt admittance \(Y\) elements are represented as,

\[
dZ = (R + j\omega L)dx = Zdx \quad (3.7)
\]

\[
dY = (G + j\omega C)dx = Ydx \quad (3.8)
\]

Fig 3.3(b) represents a transmission line using generalized distributed impedance and admittance elements.
3.5.2 Secondary line constants

Secondary line constants are derived from primary line constants [3]. They are:

- **Characteristic impedance**

  The most important electrical characteristic of a copper cable is its characteristic impedance ($Z_0$). $Z_0$ is the input impedance considering the length of the cable as infinite. It is a complex quantity. Mathematically, characteristic impedance is expressed as
Cable Characteristics

\[ Z_0 = \sqrt{Z/Y} \]

Or, \[ Z_0 = \sqrt{(R + j\omega L)/(G + j\omega C)} \quad (3.9) \]

where, \( Z = R + j\omega L \) (\( \Omega/m \)) = series impedance per unit length

\( Y = G + j\omega C \) (\( S/m \)) = shunt admittance per unit length

- **Propagation Constant**

  The propagation constant is another important characteristic of a copper cable. It is also a complex quantity. It is mathematically expressed as,

  \[ \gamma = \sqrt{YZ} \quad (3.10) \]

  The real part of propagation constant is called the *attenuation constant* \( \alpha \) and is measured in nepers per length. The quadrature part is called the phase constant \( \beta \) and is measured in radians per unit length. Thus,

  \[ \gamma = \alpha + j\beta \quad (3.11) \]

  For Twisted Pair Cable,

  \[ \gamma \approx \sqrt{j\omega CR} \quad (3.12) \]

  \[ \alpha \approx \sqrt{\frac{\omega CR}{2}} \quad (3.13) \]

  \[ \beta \approx \sqrt{\frac{\omega CR}{2}} \quad (3.14) \]

  \[ Z_0 \approx \sqrt{\frac{R}{j\omega C}} = \sqrt{\frac{R}{2\omega C}} - i \sqrt{\frac{R}{2\omega C}} \quad (3.15) \]
For co-axial cable,

\[ y \approx i \omega \sqrt{LC} \quad (3.16) \]

\[ \alpha \approx \frac{Lg + Rc}{2 \sqrt{LC}} = \frac{1}{2} \left( Z_0 G + \frac{R}{Z_0} \right) \approx \frac{R}{2Z_0} \quad (3.17) \]

\[ \beta \approx \omega \sqrt{LC} \quad (3.18) \]

\[ Z_0 \approx \sqrt{\frac{L}{c}} \quad (3.19) \]

### 3.5.3 Cross-talk

Cross-talk is the interference produced by the signal of one wire on the signal of another wire [4]. Cross-talk is produced through capacitive, inductive couplings between wires. It is measured in decibels (dB). Different types of cross-talk are defined below:

- **NEXT**: When cross-talk is measured at the end closest to the transmitter, it is called the NEXT (Near End Cross-talk).

- **FEXT**: When cross-talk is measured at the end farthest from the transmitter, it is called the FEXT (Far End Cross-talk).

- **PS**: When all possible combinations of interference from adjacent cable pairs are added up, it is called PS (Power Sum).

- **ELFEXT**: ELEXT is Equal Level Far End Cross-talk. It is subtracted attenuation of a signal due to cable length.
3.5.4 Return Loss

When a signal travels down a cable and there is an impedance mismatch between the cable and its connecting hardware, noise occurs and it is called Return Loss [4]. The greater is the impedance mismatch, the more is the noise. When the cable and the connecting hardware have the same impedance, there is no return loss. It is expressed in decibels (dB).

3.5.5 Delay Skew

A copper cable consists of 4 pairs of twisted wires, which may have a slight difference in length. For this reason, the time taken by a signal to travel down a copper cable’s wires may be different. The time difference between the fastest and slowest pairs is known as delay skew [4]. Delay skew is undesirable, because too great delay skew can create errors.

3.6 Twisted pair cable parameters

- **Loop resistance**

  Loop resistance is the total resistance of the conductors for a particular length. It is twice the resistance of one individual conductor. Cable diameters are generally expressed in millimeters or American Wire Gage (AWG).

- **Mutual capacitance**

  The mutual conductance of the cable depends upon the conductor geometry and the dielectric constant of the insulation.
• Characteristic impedance

The characteristic impedance of the twisted pair cable is given by the formula [1],

\[
Z_0 = \frac{276}{\sqrt{k}} \log \frac{2s}{d} \quad (3.20)
\]

Where, 'k' is the dielectric constant of the insulation, 's' is the conductor spacing and 'd' is the conductor diameter.

3.7 Co-axial cable parameters

• Characteristic impedance

The most common electrical property of co-axial cable is characteristic impedance. The mathematical formula for determining the characteristic impedance of co-axial cable is [5],

\[
Z_0 = 138 \times V_p \times \log_{10}\left(\frac{D}{d}\right) \quad (3.21)
\]

Where, \(V_p\) = velocity of propagation

\(D = \) Diameter of the dielectric

\(d = \) Diameter of the conductor

Co-axial cables are typically designed as 50Ω, 75Ω and 93Ω depending upon applications.
• **Capacitance**

Capacitance is the ability of the cable to hold a charge. The mathematical formula for the capacitance of a co-axial cable is [5],

\[
C = \frac{7.36 \times \varepsilon_r D}{10^{10} A} \quad \text{(3.22)}
\]

Where, \( \varepsilon_r = \) dielectric constant

The value of the capacitance is length dependent and is expressed in pF/m.

• **Power rating**

The power rating of a co-axial cable is proportional to the cable diameter [5]. Power rating increases with the increase of the diameter and decreases with the decrease of the diameter.

### 3.8 Fiber Cable characteristics

Some of the important optical fiber characteristics are described briefly:

• **Numerical Aperture (NA)**

Mathematically, *Numerical Aperture* of an optical fiber is defined as [6],

\[
NA = \sin \theta_0 \text{ (max)} = \sqrt{\left(\mu_1^2 - \mu_2^2\right)/\mu_0} \quad \text{(3.23)}
\]

Where, \( \theta_0 = \) the acceptance angle of the fiber

\( \mu_1 = \) refractive index of the core

\( \mu_2 = \) refractive index of the cladding
If the fiber is surrounded by air ($\mu_0=1$),

then $NA = \sqrt{(\mu_1^2-\mu_2^2)}$ ------ (3.24)

**Acceptance Cone and Acceptance Angle of a Fiber**

The fundamental property of light propagation in a fiber is the light which travels within a cone defined by the acceptance angle is trapped and guided. That cone is referred to as acceptance cone.

Any light wave impinging on the core within the maximum external incident angle $\theta_0$ corresponding to the critical angle of incidence $\theta_c$ at the core-cladding interface of the fiber is coupled into the fiber and will propagate. This angle is called the acceptance angle and is different for different fibers. Acceptance angle depends on the fiber material and core diameter.

**V-number of a fiber**

The number of modes supported by a fiber is determined by its $V$-number. $V$-number is also called “cut-off parameter” or “normalized frequency of cut-off”.

The mathematical expression for the $V$-number [6] is

$$V \cong (\pi d)\lambda_0 NA$$ ------ (3.25)

Where, $d$= core diameter

$\lambda_0$ = wavelength of the incident light

The approximate number of modes supported by a fiber is $Number of modes \cong \frac{1}{2} V^2$, provided the $V$-number is considerably larger than unity.
• Modal dispersion

In multimode fiber, different modes travelling with different velocities may result in modal dispersion at the destination. There is no modal dispersion in single mode fibers, because they support only one mode. Modal dispersion is measured in nanoseconds per kilometer (ns/km). There are two types of multimode fiber: Step-index fiber and graded–index fiber. Modal dispersion is reduced in graded-index fiber than step–index fiber.

3.9 Shielding of a cable

Shielding is placed over the conductors and under the cable jacket and typically it is a metallic layer. Shielding protects the cable from outside EMI and also prevents cross-talk between cable conductors [7].

Common Types of Shielding are:

• Foil / myler shield: This type of shielding provides a good resistance to EMI and is common for most serial and printer cables.

• Foil / myler plus braid (Double shield): This type of shielding is an excellent resistance to EMI and common for VSB, Firewire and high end serial and parallel cables. A braid shield is finely stranded wires interwoven in a cylindrical form.

• Spiral shield: This type shielding also provides excellent resistance to EMI and typically found in highly flexible cables. Spiral shield is similar to a braid shield, the only difference is that the finely stranded wires are applied spirally instead of interwoven.
3.10 Cable Jacket

Cable Jacket is the outermost protective covering of a cable over the shielding and/or inner conductors [7]. Different cable materials include:

- **Polyvinylchloride (PVC):** PVC is the most common material used for cable jacket with low cost. It is typically rated for temperature ranges of $-20^\circ C$ to $80^\circ C$.

- **Teflon:** Teflon is expensive, but it is good electrical insulator. It provides resistance to chemical splash and high heat conditions. Typical temperature rating is $-70^\circ C$ to $200^\circ C$.

- **Low Smoke Zero Halogen (LSZH):** LSZH is a thermoplastic compound. It reduces the amount of toxic gases and corrosive gases emitted during combustion. It is generally used in poorly ventilated areas. Typical temperature rating is $-20^\circ C$ to $80^\circ C$.

- **Plenum:** Plenum has highest flame resistance, but it can emit toxic and corrosive gases during combustion. Plenum can be made from materials including Teflon and specially treated PVC. Depending upon the used material, the temperature ranges vary.

3.11 Physical characteristics of a cable

Physical characteristics of a cable basically include Physical Dimensions, Temperature Rating, Bend Radius, Flex Radius, Pulling Tension. Physical dimensions are diameters of the wire conductors, jackets.
3.11.1 Wire (Conductor) Size

**Wire size** is normally expressed as AWG (American Wire Gauge) numbers. As the AWG number gets larger, the wire diameter gets smaller [7]. For example, 22 AWG wire has large diameter than 24 AWG wire.

3.11.2 Wire Current Carrying Capacity

The current carrying capacity of a wire mainly depends upon wire AWG, temperature, insulating material and the number of bundled wires in a cable [7]. The following table 3.2(a) gives an idea to calculate the current rating of a cable. In the table, figures are based on 30°C ambient temperature and ‘X’ is the Current Reduction Factor.

Reduction Factors apply when conductors are bundled. The following table 3.2(b) gives the reduction factor for bundled conductors.

<table>
<thead>
<tr>
<th>Insulation Material</th>
<th>Wire Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>2X, 3X, 4X, 6X, 8X, 10X, 15X</td>
</tr>
<tr>
<td>LSZH</td>
<td>3X, 4X, 5X, 7X, 9X, 12X, 17X</td>
</tr>
<tr>
<td>Plenum</td>
<td>3X, 5X, 6X, 8X, 11X, 14X, 20X</td>
</tr>
</tbody>
</table>
Table 3.2(b)

<table>
<thead>
<tr>
<th>Bundled conductors</th>
<th>Reduction factor(X)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-5</td>
<td>0.8</td>
</tr>
<tr>
<td>6-15</td>
<td>0.7</td>
</tr>
<tr>
<td>16-30</td>
<td>0.5</td>
</tr>
</tbody>
</table>

**Formula:** \( \text{Wire Size/Insulation material value} \times \text{current reduction factor}(X) \)

\[=\text{Current in amperes per conductor.}\]

For example, if the cable is a 24 AWG, PVC cable with 9 conductors, then the current rating = 6×0.7=3.2 amp/conductor.

3.11.3 Temperature Rating

Temperature Rating is the safe range of temperature for a cable, which is based upon the thermal properties of the dielectric and jacket material [5]. It gives the limitations on temperature extremes that a cable structure can handle without any deformation, melting or fracture of it.

3.11.4 Bend radius and Flex radius

Bend radius for permanent install and flex radius for flexing [5].

3.11.5 Pulling Tension

Pulling Tension gives the maximum load bearing weight of a cable. Its value is well below the break strength of the cable [5].
References


