

# Coaxial Cables and Applications

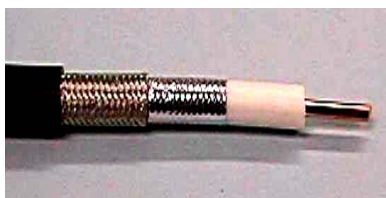
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**Overview:** Coaxial cables are perhaps the most common, basic, and easy to understand cables of common transmission line designs. Basically, they are used to transmit electrical energy, or signals, from one location to another: to connect a source to a load, such as a transmitter to an antenna. This is accomplished with a transverse electromagnetic (TEM) wave field distribution propagation within the transmission line, or coaxial cable, and is governed by transmission line theory.

Coaxial Cable (coax) is typically identified or classified according to its impedance or RG-type. For example, a 50-ohm coax or an RG-8 type coax. This chapter will examine flexible coax cable in more detail and explain the basic construction, electrical, and application characteristics.

A coax cable consists of two conductors separated by a dielectric material. The center conductor and the outer conductor, or shield, are configured in such a way that they form concentric cylinders with a common axis. Hence the term and name co-axial.



**Construction:** The center conductor may be made of various materials and constructions. Most common constructions are solid or seven-strand conductors. Solid conductors are used in permanent, infrequently handled or low flex applications and stranded conductors are used in flexible cable applications. Common materials include copper, tinned or silver plated copper, copper clad steel and copper clad aluminum. Plated copper is used to aid in solderability of connectors or to minimize corrosion effects. Because of a phenomena known as skin-effect,

copper clad materials may be used in higher frequency applications ( $> 50$  MHz) to improve tensile strength and reduce weight and cost. (*Skin-effect* is the result of higher frequency signals propagating along the outermost surface, or skin, of the conductor.)

The insulation, or dielectric material, is used to provide separation between the conductors. It is desirable that the material has stable electrical characteristics (dielectric constant and dissipation factor) across a broad frequency range. The most common materials used are polyethylene (PE), polypropylene (PP), fluorinated ethylene propylene (FEP), and polytetrafluoroethylene (PTFE). PE and PP are desirable in lower cost, power, and temperature range applications (PE is 85C, PP is 105C)<sup>1</sup>. FEP and PTFE are for higher power and temperature range applications (200C)<sup>1</sup>, and offer some additional environmental resistance properties. However, they are also much higher in cost. The materials may be used in their natural form (solid), or injected with air bubbles (foam or cellular) to improve the dielectric constant and electrical properties of the material and cable. Some designs also incorporate a mono-filament or disc designs sometimes referred to as air gap.

<sup>1</sup> Temperature range of the cable is often limited by the choice of jacket material.

The outer conductor is typically made from a number of smaller aluminum or copper conductors combined together. These conductors are woven together to form a braid around the dielectric core. For higher frequency applications, a second braid or aluminum foil tapes are often added to improve attenuation and shield effectiveness.

The jacket material serves as a protective covering from the environment and may also serve to add in the overall flame retardant properties of the cable. Typical materials include polyvinyl chloride (PVC), PE, FEP, and polyvinylidene fluoride (PVDF).

**Agency Requirements:** As mentioned in the overview, coax cables are typically identified or classified according to their impedance or RG-type. RG, or Radio Guide, is the manner that the military used to identify transmission lines. The RG number specified the physical construction, materials, physical, mechanical and electrical requirements of the cable. This methodology is now obsolete and the military has changed to “slash sheets” for identification. For example, RG-58C is now M17/155-00001 or M17/28-RG058. Today, the RG number has become a generic identifier, telling the user of it’s general construction and electrical properties, but not specific enough to compare attributes from one product to another. Products (and manufacturers) that are recognized as military specification (MIL-Spec) approved are published in the Qualified Parts List (QPL). These products are compliant with a specific slash sheet, and are tested in accordance with the latest revision of MIL-C-17, currently revision G. Today the majority of cable applications do not require a MIL-Spec cable.

The most common agency requirement is for the cable to comply with the National Electric Code (NFPA-70) for its specific intended use and application. This document requires specific material physical properties and flame/smoke attributes for safety. The most common agencies to list and/or recognize compliance to the NEC are Underwriters Laboratories (UL) and Intertek Testing Services (ETL). Cable manufacturers will document in their product literature and on the cable itself the appropriate listings for a specific cable. It is important that the end user confirm with the local electrical, fire, and building inspectors to ensure that the appropriate cable is selected for the intended use and application. The following table lists the common NEC listings for communication cables (Article 800 *Communications Circuits*).

Cable Listing	Location
<b>CMP</b> (NFPA-262, FT6)	Suitable for use in ducts, plenums, and other space used for environmental air.
<b>CMR</b> (UL-1666)	Suitable for use in vertical runs in a shaft.
<b>CMG</b> (UL-1685, IEEE-1202, FT4) <b>CM</b> (UL-1685)	Suitable for general-purpose communication use, with the exception of risers and plenums.
<b>CMX</b> (UL-1581 VW-1)	Suitable for use in dwellings and for use in raceway.

NFPA-70 c2002

In addition, there are other articles in the NEC for other cable applications, such as Article 725 for *Class 1, Class 2 and Class 3 Remote-Control, Signaling, and Power-Limited Circuits*.

Recognized Appliance Wiring Material or AWM is also common among coaxial cable. These are less stringent than the NEC requirements and are intended for use with internal wiring.

**Electrical Properties:** The most common electrical property referred to in coax cable is the **characteristic impedance**, or simply impedance. Impedance is the total opposition to the flow of electrical energy within the cable. It is a complex value defined by the cable’s resistance, capacitance, inductance, and conductance, and is the equivalent value of these items combined. It is the most important characteristic to discuss since it is derived from all the other electrical properties in the cable. It is not length dependent, and is expressed in Ohms. Coax cable is typically designed as 50 ohm, 75 ohm, and 93 ohm depending upon the application. A simple formula to determine the impedance of a coaxial cable is:

$$Z_o = 138 * V_p * \log_{10} \left( \frac{D}{d} \right)$$

Where:  $Z_o$  = Characteristic Impedance  
 $V_p$  = Velocity of Propagation  
 $D$  = Diameter of the Dielectric  
 $d$  = Diameter of the Conductor

Characteristic Impedance is commonly measured using a Time Domain Reflectometer (TDR), such as a Tektronix 11801C digital sampling oscilloscope with SD-24 TDR/sampling head, on a 10 ft. length of cable (2).

**Capacitance** is the ability of the cable to hold a charge. The larger the capacitance value, the longer it takes a signal to reach full amplitude within the cable. Therefore, higher capacitance is usually a bad attribute. Capacitance is length dependent and is expressed in pF/ft.

$$C = \frac{7.36 * \epsilon_r}{\log_{10} \left( \frac{D}{d} \right)}$$

Where:  $\epsilon_r$  = Dielectric Constant

Capacitance is commonly measured using a capacitance meter, such as a Hewlett-Packard 4194A Impedance/Gain-Phase Analyzer, at 1 kHz on a 10 ft. length of cable.

**Velocity of Propagation** is the speed at which a signal travels through the cable with respect to the speed of light. This value is typically represented as a percentage of the speed of light in free space. For example, solid PE is 66% while foam PE may be as high as 87%. This may be an important attribute if running several signals/cables in parallel, as it is important for all signals to arrive at (generally) the same time. This attribute may also be referred to as delay (nS/ft).

$$Vp = \frac{1}{\sqrt{\epsilon_r}}$$

$$Delay = 1.0167164 \times \sqrt{\epsilon_r}$$

Velocity is commonly measured using the resonance method on a network analyzer, such as the Hewlett-Packard 8751A, on a 10 – 15 ft. length of cable.

**Attenuation** is the inherent signal power loss within the cable. It is dependent upon the cable design and is both frequency and length dependent. It is most effected by DC resistance of the center conductor and dissipation factor of the dielectric material. Attenuation is typically expressed in db/100ft.

Attenuation is commonly measured using a network analyzer, such as the Agilent 8753ES on a 100 ft. length of cable.

**Reflection Losses** are based upon signals reflecting back to the source rather than propagating through the cable. These reflections are caused by impedance mismatches or variations typically as a result of minute physical changes in the cable. Randomly spaced throughout the cable, these mismatches will cause minimal loss, but when spaced periodically, that is at the same repeat distance, they add up together causing a large loss corresponding to that period wavelength (frequency). This loss can be minimized by quality cable manufacturing techniques and proper installation practices. This reflective loss

is typically expressed as **Structural Return Loss (SRL)** or **Return Loss (RL)** in dB for 75 ohm cables and as **Voltage Standing Wave Ratio (VSWR)** for 50 ohm cables. The difference between these values is that SRL is a measurement of impedance variation within the cable with respect to the actual cable characteristic impedance, while RL and VSWR measure variation from a fixed source impedance. This can be an important difference if the application can not compensate for cable impedance mismatch.

Return Loss is commonly measured using a network analyzer, such as the Agilent 8753ES (with option 010), on a 150 ft. length of cable.

**Power Handling** capability is dependent on the thermal dissipation and maximum voltage withstand properties of the cable design. The power rating is based upon the permissible rise in temperature above ambient, and is mostly dependent upon the temperature properties of the dielectric material. The values typically assume a low RL or VSWR value and 20C ambient temperature in air. Burying cables, or other installation variances, will alter this capability. Manufacturers typically publish this data for transmission lines, and may have it available by special request for other cables.

**Physical Properties:** The mechanical and physical properties may be critical in selecting the appropriate cable for the application.

**Physical Dimensions** are critical to assure that an industry standard connector is available. Other odd-size dimensions will require use of a custom termination. Diameter of the center conductor, core, and jacket are the critical values.

**Temperature Rating**, which may be listed as operational or storage, provides the limitations on temperature extremes that the cable material can handle. This safe range, based upon the thermal properties of the dielectric and jacket materials, assures that the product will not fracture, melt, or otherwise deform resulting in electrical or mechanical failures.

**Bend Radius and Flex Radius** are the minimum values for these attributes. Adherence to these guidelines will minimize the degradation of the cable due to cold flow and other stress/material properties in the application. Bend radius is for

permanent install and flex radius is for flexing. Flex radius should not be misunderstood to mean that the cable is designed for continuous flexing.

**Pulling Tension** is the maximum load bearing weight for the cable. It is typically a safe value well below the break strength of the cable. Staying below this maximum assures that the conductor will not be stretched resulting in electrical performance problems in the cable.

**Applications:** One of the broadest uses of coaxial cable is for **video distribution**. From CATV signals around the neighborhood to precision digital signals in a post-production studio, these signals are routed on 75 ohm coaxial cable. Broadband CATV (or MATV) signals typically use a series 59 (RG-59) or series 6 (RG-6) type coaxial cable, or drop cable. These cables use copper covered steel conductors and aluminum foil/braid combination shields (outer conductors). They are designed for use above 50 MHz, with high strength, low weight and low cost the primary factors. These cables are all typically designed to a SCTE standard and are a commodity-type item. Electrical performance is good and clearly defined in the industry standards. Cables used in outdoor environments typically utilize a polyethylene jacket material. The distribution trunk cable is series 11 (RG-11) type or larger – typically “hard line” cable utilizing a corrugated copper outer conductor. These cables are designed for minimum attenuation and good power handling capability.

Another type of 75 ohm video cable is standard video cable. These cables are based upon standard RG-type designs, utilizing copper covered steel, copper, or tinned copper conductors and bare or tinned copper braid only shields. This cable is used primarily for CCTV, security, surveillance, and other “non-critical” video applications – video for consumption that will not be manipulated, saved, or used for other purposes. These cables are not typically associated with an industry standard, so there is much variation and differentiation among available designs. Typical cables specify nominal electrical values only.

The high end of video cables is precision video cable. These cables are loosely based upon the standard RG-type designs. They have solid bare copper conductors, foam dielectric, combination

foil and 95% tinned copper braid shields. They are designed for maximum bandwidth, minimum return loss, and minimum attenuation loss. The cables have very tight requirements on all electrical attributes and are used for both analog and digital video in broadcast, post-production, and other critical video applications.

There are also many specialty types of video cables, such as S-VHS, RGB, DBS, and Triax to name a few.

Cables used for two-way communication, **RF and microwave transmission**, data transmission and instrumentation/control are typically 50 ohm coaxial cables. These cables are based upon MIL-Spec designs and are most often referred to by their RG type number. The cables fall into a few categories: Transmission and computer cables that are based upon RG type designs, but not per the current MIL-Spec; MIL-C-17 QPL cables that are in compliance with the current MIL-Spec; and low-loss cables based loosely upon RG type designs. The RG type cables are the most used products since the majority of cable applications do not require QPL cables. Furthermore, most manufacturers have a limited availability of QPL cables for this reason. The major differences between the cables are typically the type of PVC jacket material used and less stringent electrical and physical requirements. For **wireless and antenna applications**, the low-loss cables are gaining popularity because of their size, weight, cost, and performance advantages over the traditional designs. These cables typically utilize a foamed dielectric material and combination foil/braid shields.

Other impedance cables are used for data transmission and **instrumentation/control**. These are typically 93 ohm or 125 ohm and are not as common as they once were. As with the transmission and computer cables, the majority of cables used are RG type cables with minimal use of QPL product.

Specialty coaxial cables **include low-noise and musical interconnects** cables. These are specially designed to minimize piezoelectric and triboelectric noise in cables and are not for RF use. The cables may be loosely based upon RG type designs, but utilize semi-conductive material layers within the cable.

## **Conclusion:**

Hopefully this chapter has given you a brief overview of coaxial cable and a better insight to the relevant design properties. When choosing a cable for your application, work backwards from the end-need requirements. What is the specific application? Do you know what impedance is required? What is the frequency of interest? What is the loss budget (how much cable attenuation loss is allowed)? How long is the cable run length? Indoor or outdoor? Are there agency requirements (UL, NEC, AWM, MIL-Spec, etc.)? What connector type will be used? These few questions should help you easily identify an appropriate coaxial cable.

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