Coaxial Cable—Still The Best Way To Make An RF Connection

The coaxial cable remains the transmission line of choice for RF, video, and microwaves to 40 GHz.

You know about coaxial cable *(Fig. 1)*. We all use it in one form or another, and it seems simple enough. But while modern cable products are better than ever, there are some real subtitles in their selection and application.

Connecting dc and low-frequency ac including audio is easy. You just run some wires from point A to point B. The biggest challenge may seem to lie in choosing the right connector *(see "Coax Connectors," p. 36)*. Your main concern, though, is resistance over the longer runs as well as high-power or high-voltage signals. Frequency doesn't usually enter into it. But try that with signals with frequencies over a few hundred kilohertz, and weird things start to happen.

At these frequencies, the inductance and capacitance of the cables begin to come into play. The serial inductance and shunt capacitance form a distributed low-pass filter. The cable begins to store energy and delay the signals applied to it, not to mention attenuate them. The cable becomes a transmission line with very specific characteristics.

A cable doesn't act like a transmission line until it is more than 0.1 λ long at the frequency of operation. For example, one wavelength at 450 MHz is:

$$\lambda = 984/f_{MHz} \text{ in feet}$$
$$\lambda = 984/450 = 2.19 \text{ ft}$$
$$0.1\,\lambda = 0.1(2.19) = 0.219 \text{ ft or about 2.63 in.}$$

At this frequency, a pair of conductors over 2.63 in. long will have the characteristics of a transmission line.

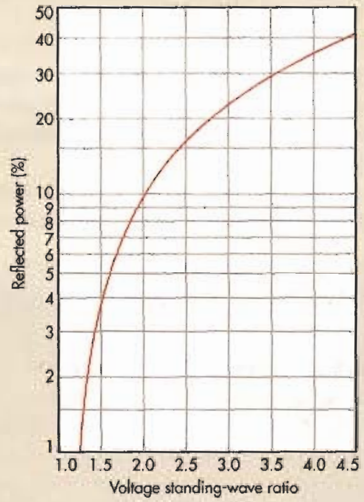
The basic characteristic of a transmission line is that the cable will act like a complex impedance (R ± jX) to a signal source unless it is terminated in its characteristic impedance (Z_O). The characteristic impedance (sometimes called surge impedance) of a transmission line is a function of the inductance (L) and capacitance (C) per foot or other unit of length or:

$$Z_O = \sqrt{(L/C)}$$

Z_O is a pure resistive value. An infinite length of the transmission line will appear to be a resistance equal to Z_O to a signal source. Terminating any other length of line with a resistive load equal to Z_O will appear to be a resistive load of Z_O to a generator.

If the transmission line isn't terminated in its characteristic impedance, the generator will see a complex impedance that is a function of its length. In addition, an improperly terminated transmission line will produce reflections. Signals not absorbed by the load are reflected back down the line toward the generator producing standing waves.

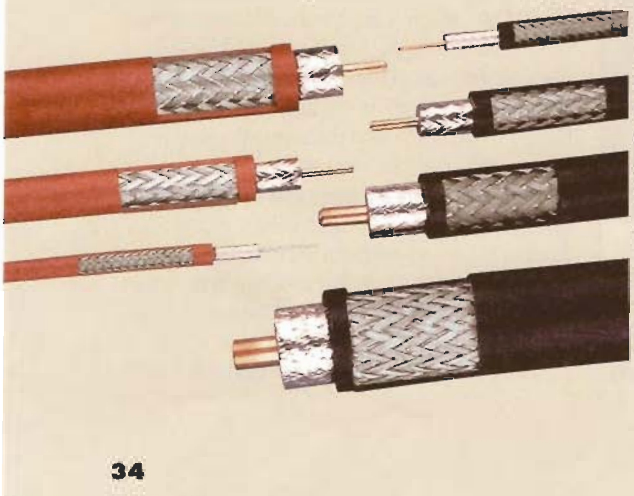
Standing waves are stationary variations of voltage and current along the line. These standing waves are the sum of the incident or transmitted signal and any reflected signal not absorbed by the load. In a matched line or one properly terminated, the voltage and current along the line is constant. Standing waves are undesirable, as they can cause signal distortion (for pulses), losses, and excessive voltages or current.



2. An increase in VSWR can lead to an increase in power reflected back to the source in a mismatched transmission line.

Coax cable is an ideal interconnection medium because it is self-shielding. The electromagnetic wave that propagates down the line stays entirely within the cable, except for some leakage where the shield isn't solid. Solid foil shields do a better job than braid. But there are coax cables with two or more shields to ensure no signal leakage.

Unlike twisted pair, coax signals do not produce nor are they subject to cross talk and other coupling problems. Coax keeps noise and stray signals out and the desired signal in, meaning you can run coax cables directly parallel to one another or with twisted pair without interference.



1. Coax cable has a solid center conductor or, in some cases, a stranded conductor. That inner conductor is surrounded by a plastic or Teflon insulating medium, which in turn is surrounded by a shield made of fine copper braid or in some cases a solid aluminum foil. The outer jacket is usually made of PVC plastic. This is Times Microwave's popular low-loss LMR coax cable.

COAX SPECIFICATIONS

The primary specification of a coax cable is its Z_O. The most common value is 50 Ω, with 75 Ω also widely used. Most wireless

4. The hard-line Celflex Lite cables from Radio Frequency Systems have a corrugated aluminum outer conductor that makes the cable bendable and very light for long runs. The cable is available in sizes from 0.5 in. to 1.25 in. and has an impedance of 50 Ω. It features low loss and high power capability. Its main application is cellular basestation installations.

runs of cable, coax is a reasonable design solution. Just watch the attenuation figures and select the lowest-loss coax you can find. Lengths of coax from a few inches to a few feet are practical at frequencies up to about 50 GHz. Generally, the larger the diameter of the cable, the lower its attenuation—but also the lower the operating frequency.

SELECTING A CABLE

There are thousands of different cable sizes and types. The most common ones are designated with the letters RG. The RG standards came out of World War II. RG means radio guide, and the U suffix often attached to the RG designation means universal. The RG standard is no longer used, and different RG numbers will probably have different specifications from manufacturer to manufacturer. Military-specification coax cable has an M17 designation. The standard is MIL-DTL-17H. The international standards with the IEC are 60096 and 61196.

A good choice is to stay with the popular and common types of cable, as they are widely available from multiple sources and cost less than some of the specialty cables *(Table 2)*. The primary application will determine the most important specifications. Other important cable specifications include operating temperature range, the outside diameter of the cable, and the weight of the cable in pounds per foot.

Also, consider the environment, such as rain, wind, and ultraviolet exposure, as well as if cable flexing is involved. Coax does not flex well. Examine the manufacturer's specifications and applications carefully.

HARD LINE

As its name implies, hard line is coax that isn't flexible like regular coax cable.

COAX CONNECTORS

Just as important as the cable itself are the connectors that terminate coax cable. They're a weak link since they also add to the signal attenuation and cause anomalies that can change the impedance slightly, causing reflections. Over the years, connectors have gotten better at minimizing attenuation and impedance mismatches.

BNC, F, N, SMA, TNC, and UHF are the most commonly used coax connectors *(see the table)*. Most of these connectors are for 50-Ω cable, except for the F connector, which is 75 Ω. Also, 75-Ω versions of the BNC, N, and TNC connectors are available.

Since attaching coax connectors to the cable is a tricky and often frustrating process, special tools have been created to simplify the problem. However, designers often select cable assemblies with pre-attached connectors *(see the figure)*.

There are hundreds of different coax connectors and many variations of each. Also, there are adapters that can convert one connector type to another, such as F to BNC or N to UHF and various male-female combinations. **ED ONLINE 21109**

Common Coax Connectors

Type of connector	Upper frequency limit	Applications
BNC	3 to 4 GHz	Test instruments, local-area networks (LANs)
F	2 to 3 GHz	Cable TV, broadcast TV
N	9 to 10 GHz	High-power RF, antenna feeds
SMA	18 GHz	Test instruments, microwave radio
TNC	9 to 10 GHz	Aviation, basestations
UHF	300 MHz	HF/VHF radio

These hand-formable cable assemblies from Electronic Assembly Manufacturing have SMA connectors, though BNC, N, TNC, and other connector typess also are available. The cables are available in 2- to 12-in. lengths and have a typical insertion loss of only 0.7 dB/ft at 20 GHz.

Table 1: Common Dielectrics And Their Velocity Factors

Cable dielectric	Velocity factor (VF)
Solid polyethylene (PE)	0.659
Foam polyethylene	0.80
Air-space polyethylene	0.88
Foam polystyrene (PS)	0.91
Solid polytetrafluorethylene (PTFE)	0.695
Solid Teflon	0.69
Air-space Teflon	0.90

and test applications use 50-Ω cable. Cable TV and video uses 75-Ω cable. Other available impedances are 93 and 125 Ω, but they aren't as common. The impedance is set by the physical nature of the cable—specifically, the inner and outer conductor dimensions, their spacing, and the dielectric constant (ε) of the insulating medium.

Voltage standing-wave ratio (VSWR) is an important factor in applying coax, but it is not a specification as such. It is usually calculated as:

$$VSWR = Z_O/Z_L \text{ or } Z_L/Z_O$$

depending on which provides a value greater than one. Z_L is the load resistance.

VSWR is actually the ratio of the maximum peak voltage to the minimum voltage along the line. It is related to the reflection coefficient (Γ), the ratio of the reflected voltage V_R to the incident voltage V_I:

$$\Gamma = V_R/V_I$$

The ideal Γ is 0. VSWR is calculated using the reflection coefficient:

$$VSWR = (1 + \Gamma)/(1 - \Gamma)$$

The ideal VSWR is 1, but many applications can tolerate mismatches with VSWR as high as 2 or 3 without excessive power loss. Figure 2 relates VSWR to power lost due to reflection.

The velocity factor (VF) is one more common parameter. It is the ratio of the propagation of the signal in the cable to the speed of light. Also, it is a function of the dielectric constant of the insulating material:

$$VF = 1/\sqrt{\varepsilon}$$

For coax, the VF is usually in the 0.6 to 0.9 range. Table 1 shows the most common dielectrics used in coax and the velocity factors. The VF affects the length of a wavelength of a cable. One wavelength is:

$$\lambda = 984/f_{MHz}$$

One wavelength of coax is:

$$\lambda = 984(VF)/f_{MHz}$$

Capacitance per foot is another common parameter. It too depends on the dielectric constant. The typical range is from about 6 to 31 pF per foot. Note that the lower the dielectric constant, the lower the capacitance per foot and the lower the decibel (dB) loss in the cable.

One especially important specification in high-power applications, the maximum voltage rating, is usually given as the RMS value of the maximum voltage rating. It ranges from 1000 to 15,000 V. Be sure to know the maximum peak value (1.414 × RMS) of the signal to be transmitted to ensure you are within the safety range.

If you know that there is a mismatch involved from cable Z_O to load, then to determine the approximate effective value of voltage involved, multiply the actual input voltage by the square root of the expected VSWR. Incidentally, some coax also carries dc. The maximum dc voltage that can be applied is about three times the ac voltage maximum.

Time delay is an inherent characteristic of any transmission line, as it takes a finite amount of time for the signal to propagate through all that inductance and capacitance. That time delay (t_R) shifts pulses and produces phase shifts in sine waves. It is a function of the dielectric constant:

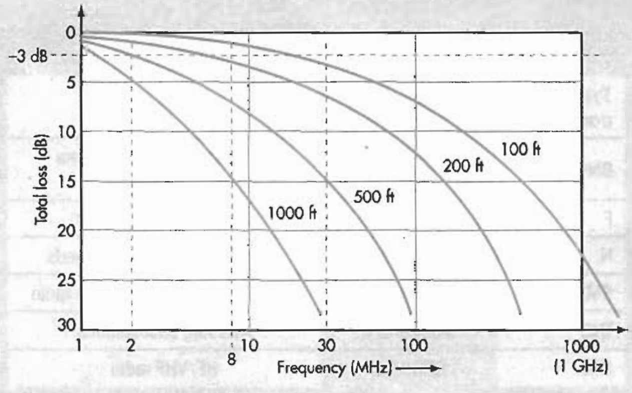
$$t_R = 1.016\sqrt{\varepsilon} \text{ ns/foot}$$

One of the most critical specifications of coax is its attenuation, which is usually stated in dB power loss per foot. Specifications are sometimes stated as dB/100 feet or as dB/100 meters. Of course, that value increases with the frequency of operation.

When high frequencies and long lengths are involved, the cable represents a major loss of power. For example, a common RG-58A/U cable has a typical attenuation of 5.3 dB per foot at 100 MHz. That is a loss of –0.53 dB/foot. If you put 100 W into this cable, you will get out only 29.5 W. That is a massive loss of 70.5 W in the cable itself. Attenuation is critical. For a given application, your job is to select the cable that will have the lowest possible loss—and keep the cable as short as possible.

A trend in wireless today is to locate the transmitter and/or receiver at the top of the antenna tower to avoid high transmission line losses. To achieve a desired output power, the designer has to produce a more expensive higher-power transmitter to compensate for cable loss. Tower-top electronics has gotten easier with smaller and lighter components, but it is still an issue in the cellular business where the need to climb towers for maintenance and repair and wind loading are still big problems.

A coax cable is a long low-pass filter whose cutoff frequency decreases with length *(Fig. 3)*. But you can use coax well up into the gigahertz region. This is where waveguide is normally used. Yet for short



3. Like all coax cables, the popular RG-58A/U 50-Ω coax cable is a long low-pass filter whose cutoff frequency decreases with length.

It's essentially a pipe within a pipe whose outer conductor can be up to several inches in diameter. Keep in mind that hard line isn't waveguide, though. It truly is coax cable, but it's designed for high power and low loss at UHF and low microwave frequencies. It is widely used for radio and TV broadcast antenna feeds and cellular basestations.

Most hard line is made with a solid copper outer shield with a solid copper inner conductor that may also be a small tube. The dielectric insulation between the two may be a foam polyethylene, air, or pressurized gas like nitrogen. The gas keeps the interior of the line dry since moisture may collect and attenuate the signal in most pipes. When air or gas is used, plastic or nylon spacers are used internally to keep the spacing between the conductors stable and consistent.

A good example of the latest type of hard line is the Cellflex series of cables made by Radio Frequency Systems *(Fig. 4)*. They're available in diameters of 0.5, 0.875, and 1.625 in. The center conductor is a copper tube, and the outer conductor is a corrugated aluminum tube. The corrugation makes the tubing bendable.

The dielectric is polyethylene foam with a VF of 0.90 and a capacitance of 22.9 pF/ft. The impedance is 50 Ω. As for specs, the 0.875-in. cable is usable up to 5 GHz. The attenuation at 1 GHz is a low 1.28 dB/100 ft. Power rating is 2.53 kW at that frequency.

Coax has been around for decades. With its continuous improvement over the years, it is still the connecting link of choice for RF and video. Fiber-optic cable may be making continuous inroads of its own, but for now, coax is still king.

Table 2: Common Coax Cables And Specifications

Cable	Z_0 (Ω)	VF	Capacitance (pF/ft)	Diameter (in.)	V_{MAX} (V)	Attenuation at 1 GHz (dB/100 ft)
RG-6 (TV)	75	0.83	16.2	0.275	350	6.5
RG-8A/U	52	0.659	29.5	0.405	5k	9.0
RG-8X	50	0.80	26	0.242	2.5k	13.5
RG-58A/U	53.5	0.66	28.5	0.195	1.9k	20
RG-59B/U	75	0.659	20.6	0.242	2.3k	11.5
RG-174A/U	50	0.695	30.8	0.100	1.5k	31
RG-214/U	50	0.659	30.8	0.425	5k	9

INDUSTRIAL AUTOMATION CABLES MEET STRINGENT REQUIREMENTS

The Industrial Automation family of high-performance cables from Alpha Wire Co. promise industry-leading quality, reliability, and the performance to meet the rigorous requirements of major communication architectures, according to the company. The product line consists of five categories.

The ControlNet components consist of a low-loss RG-6/U 75-Ω coaxial cable with a double braid/foil shielding for maximum signal integrity and run length. Available in one to four pairs, the RS-485 category cables use a braid/foil shield to reduce electrical noise sensitivity and maintain reliability and performance. Meeting UL PLTC flammability requirements and CM listed, the sunlight-resistant cables suit Class 1 Division 2 locations per NEC Article 501.

The DeviceNet cables integrate power and data into a single, two-pair cable with 15 AWG stranded conductors for power and 18 AWG for signals. Available for ODVA thick and thin trunks, the cables support data rates of 500 kbits/s at 100 m and 125 kbits/s at 500 m. Fieldbus and Profibus cables meet the requirements of virtually all Fieldbus and Profibus environments and are available with a 100-Ω impedance for Types A and B Fieldbus and a 150-Ω impedance for Fieldbus and Profibus DP.

Also on tap, industrial twinax, A UL Type TC cable, is suitable for use in trays and conduits also containing 600-V power cables. Additionally, the cable meets the requirements of Allen-Bradley data highway networks.

ALPHA WIRE CO. • www.alphawire.com ED ONLINE 21110

COAX CABLES ELIMINATE OUTER JACKET

The plenum DS-3 and DS-4 series of coax cables from Belden feature the company's Banana Peel composite cable construction, reducing installation time and labor, according to the company. They're designed for digital signal interconnect and cross-connect applications in telco central offices and data centers, as well as other large, complex installations with data/telecom plenum cable runs requiring DS-3/DS-4 signaling. The cables are available in two sizes, 26 AWG (735A plenum-rated) and 20 AWG (734A plenum-rated), and both sizes are offered in a three-count and a six-count configuration.

The Banana Peel design eliminates the outer jacket to achieve a smaller outer diameter, compared to similarly bundled cables, suiting tight or densely packed plenum spaces. It also improves the cable's bend radius, enabling the use of smaller conduits. Instead of a fluoropolymer jacket that would make the individual coaxes difficult to dress, the DS-3 and DS-4 feature PVC Flamarrest individual jackets that are much easier to strip and terminate, Belden says. And, eliminating the outer jacket cuts a whole step from the termination process, as users simply peel the individual cables off the center spline and terminates.

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