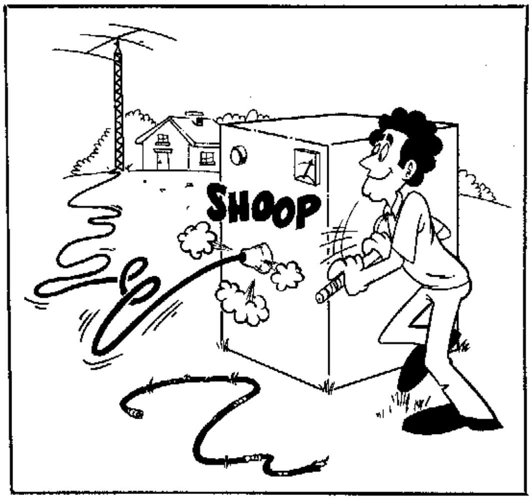
Coaxial Cables: Their Construction and Use



Most hams give little thought to the cable that connects transmitter and antenna. Here is some background information that can help us understand coaxial cable and use it more effectively.

By John Magnusson,* W0AGD

It is common for a ham to consider coaxial cable with the same reckless abandon given an extension cord. After all, isn't coax about as involved as any other shielded wire? The center conductor is insulated, and the shield goes to ground — right?

Not quite. The simple hot/ground concept should be reserved for power-supply cables and jumper cords. Coaxial cable should receive the same respect as any other two-terminal device (see Fig. 1). After all, we rely on coaxial cable to provide several characteristics, some of which must provide operational stability over the long term. Also, the selected cable must provide optimum performance over a wide frequency range.

There is an impressive list of design considerations and production factors involved in the manufacture of coaxial cable. Each one is important in the end result. Variations produce the panorama of different sizes, features and costs of the more than 1500 types of coaxial cables available in the marketplace today. Manufacturers have the technical information in catalogs and data sheets; much of it is yours for the asking.

The four characteristics most important to the amateur are

- Surge impedance
- Velocity factor
- Attenuation
- Power-handling capability.

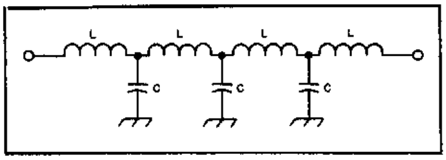


Fig. 1 — An equivalent circuit for a coaxial cable. L and C are specified, in value per unit length, by the manufacturer.

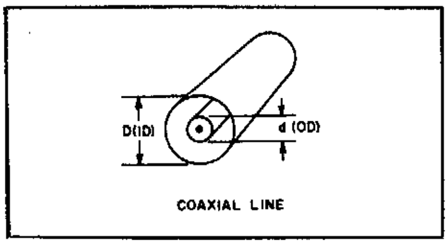


Fig. 2 — Coaxial-cable dimensions used in Eq. 1.

Impedance

The most common coaxial cable impedance used by amateurs is 50 Ω. Antennas, low-pass filters, pi networks and pi-L networks are usually designed for 50-Ω unbalanced operation. The 50-Ω characteristic impedance is a compromise between 75 Ω, which is best for low attenuation, and 30 Ω, which is best for power transmission. Thirty-ohm cables are not used for power transmission because the attenuation and capacitance values are high. Cable capacitance decreases as impedance increases. In applications that demand low capacitance (such as data transmission), cable with a characteristic impedance greater than 90 Ω is used. Coaxial cable can be manufactured in any impedance value from 35 Ω to 185 Ω. The impedance is established by the ratio of the center-conductor outside diameter to the outer-conductor inside diameter (see Fig. 2):

$$Z = \frac{138}{\sqrt{\epsilon}}\left(\log\frac{D}{d}\right) \qquad \text{Eq. 1}$$

where

Z = characteristic impedance
D = inside diameter of outer conductor
d = diameter of inner conductor
ϵ = dielectric constant of the core insulation (1.0 for air, approximately 2.3 for polyethylene)

Manufacturers control impedance by making the core first. The center conductor is run through an extruder, and the dielectric is extruded around it. If a solid copper or copper-clad aluminum center conductor is used, the tension used to pull the center conductor through the process must be monitored, as excessive tension can resize the center conductor. Speed and temperature must be monitored to ensure the correct outside diameter of the core. The outside diameter of the core establishes the inside diameter of the outer conductor. The impedance is raised if either, or both, of the following things happen:

- The diameter of the center conductor is reduced (through stretching).
- The outside diameter of the core is enlarged.

Velocity Factor

The dielectric material used in the core determines how quickly RF travels through the cable. Solid polyethylene slows the signal to 66% of the speed of light. Foam polystyrene provides a velocity factor of 91%.

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Table 1

Common Coaxial Cables and the Characteristics that Determine Their Power-Handling Capability[†]

Cable	*Center Conductor*[††]	*Dielectric*[†††]	*Max. V*
RG-8/U	7 (no. 21)	Solid	5000
8/U type	7 (no. 19)	Foam	600
RG-58/U	1 (no. 20)	Solid	1900
58/U type	19 (no. 32)	Foam	100
RG-59/U	1 (no. 22)	Solid	2300
59/U type	1 (no. 22)	Foam	200

[†] Specifications vary among manufacturers.

[††] The number outside of the parentheses is the number of strands; inside is the size (A.W.G.) of the individual strands.

[†††] Polyethylene dielectric is used in all cables shown.

This slowed propagation can be used to our advantage. If you are building phasing lines or networks in which long lengths are needed, use cable with a low velocity factor. The lines will be physically shorter, with attendant reduction of weight, bulk and cost.

Attenuation

Cable attenuation is specified by the manufacturer. It is measured in dB/100 ft and increases with operating frequency.[1] The dielectric and conductor materials determine cable attenuation. Foam dielectric and tin- or silver-plated conductors are used to reduce attenuation. Size is also a factor: the loss in a ¼-inch-diameter coaxial cable is greater than the loss in a ½-inch coaxial cable (all else being equal). The size and construction of each cable is chosen to provide optimum operation.

Over a length of time, the center conductor and braid naturally corrode if unplated. This increases attenuation. "Bargain" coax that is corroded is no bargain.

Power-Handling Capability

The amount of power that a particular cable can safely carry is determined by its voltage and current limitations. Working voltages are published by the cable manufacturer, and it is a simple matter to calculate the peak voltage on the feed line of the installation. The allowable current determination is more complex. Duty cycle, environment (temperature and air flow) and insulation material each play a part. Generally, cable power rating decreases with increases in frequency, temperature, altitude and SWR.

Consider an Amateur Radio installation with 1 kW of RF output. RG-58A/U (solid dielectric) could be used with little danger of exceeding the working voltage:

$$E_{eff} = \sqrt{PZ} \tag{Eq. 2}$$

where

E_{eff} = effective ac voltage
P = power in the line
Z = impedance of the line

Then

$$E_{pk} = E_{eff} \times 1.4142 \tag{Eq. 3}$$

From Eq. 2 and Eq. 3, the peak voltage with 1 kW fed to a 50-Ω matched line is 316 V. This voltage level is no threat to solid-dielectric cables, but it exceeds the rating of some common cables with foam dielectric (see Table 1). At an SWR of 7:1, our hypothetical kilowatt station has an E_{pk} of 1106 V. This is well below the 1900 V allowed for RG-58A/U, but it is worthy of concern. Once the working voltage is exceeded, a pin hole through the dielectric and a carbon track through the hole are formed. Subsequent arcs can occur at much lower voltage.

The amount of current in the cable can be calculated from

$$I = \sqrt{\frac{P}{Z}} \tag{Eq. 4}$$

where I = current.

When the system is matched, at 50 Ω, 4.47 A flows. The *ARRL Electronics Data Book* recommends that no. 20 A.W.G. wire (the center conductor of RG-58A/U) carry no more than 2.08 A at low frequencies. The situation is worsened at RF by skin effect.

For most amateur use, the duty cycle is so low that this substantial overload is permissible on current peaks. A small cable is capable of handling high power with a moderate SWR for CW and SSB use at HF (although larger cable is the best choice to reduce attenuation). Give thought to current limitations when choosing a cable for FM, RTTY, ATV or other high-duty-cycle applications. The cable manufacturer should be consulted in such cases.

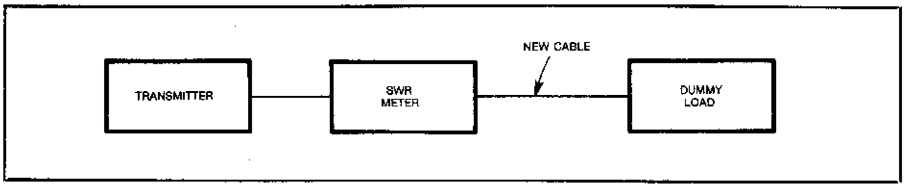

Fig. 3 — A test arrangement for checking the impedance of new cables. The SWR with the new cable should be nearly as low as that of the dummy load.

Mechanical Considerations

We have discussed the four electrical characteristics originally mentioned. Equally important are the mechanical characteristics of coaxial cable.

In some of the smaller coaxial cables with stranded center conductors, you may find the use of copper-clad steel. This adds mechanical strength needed when pulling new cable into existing cableways or conduits. Use common sense when exerting stress on the cable. A "messenger" cable should be used to help support the coax on long overhead runs. Tie the cable to the messenger at regular intervals. The messenger may be metallic or nonmetallic, as long as it has the strength to support the cable.

The installation of coaxial cable also calls for attention to the minimum bending radius of the cable, which is normally 20 times the outside diameter of the coax. A ½-inch-diameter coax cable needs a 10-inch radius as a *minimum.* If you bend the cable too tightly, "cold flow" takes place inside the coax.

Cold flow can be demonstrated with an ice cube, a dish and a copper penny. First lay the penny flat on one of the ice cube surfaces to reduce its temperature to that of the ice. Next, pick up the penny with tweezers and set the edge on one of the remaining ice cube surfaces. Hold the penny in the upright position with the tweezer, press down on it with the pencil and watch it slowly cold flow into the ice cube. After about 10 minutes, the bottom half of the penny will be submerged into the ice cube.

This demonstrates that if you bend a coaxial cable into a small radius, the center conductor may cold flow to the inside of the turn, making its way through the dielectric over a period of time. The center conductor has a certain amount of "memory" of its position when the cable was straight, and since only the low density of the dielectric resists movement of the center conductor, the center conductor always wins!

Tips

Test new cables on the ground. Always check a new cable with an ohmmeter after connectors are installed. After the dc check, connect the new cable between an SWR meter and a dummy load, and test it at RF (see Fig. 3). It is much easier to replace a defective cable before it is completely installed.

Record the electrical length (electrical length equals physical length times velocity factor), and measure the attenuation (see Fig. 4) of cables that are important in your installation. The antenna impedance appears only at half-wavelength intervals (measured from the feed point) along a mismatched line. The Smith Chart helps calculate the actual load impedance, but

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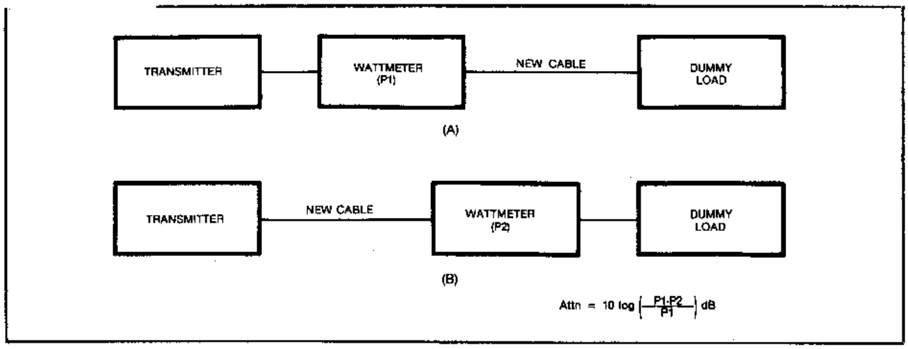
[1] m = ft × 0.3048; mm = in × 25.4; km = mi × 1.613.



$$\text{Attn} = 10 \log \left(\frac{P1 - P2}{P1} \right) \text{dB}$$

Fig. 4 — An equipment arrangement for measuring the attenuation of a new cable.

only if the electrical length of the line is known. Similarly, cable attenuation affects SWR measurements made far from the feed point (such as those made at your transmitter). You must know the cable attenuation to calculate the true SWR.

In theory, a $\lambda/2$, center-fed dipole mounted $\lambda/4$ above a perfect reflector should have a feed-point impedance of 72 Ω and be fed with a balanced line. In practice, a typical 80-meter dipole is mounted at about 0.15 λ (40 ft) over imperfect ground and fed with a low-grade coaxial cable. At 0.15 λ, the dipole impedance is close to 50 Ω. Low-grade cable allows considerable RF leakage (this is not so with high-quality, double-shielded cables), and it approximates balanced line in lengths of 100 ft or more. The antenna system described should work reasonably well, and the inconvenience of installing a balanced feed line is avoided.

Things to Come

Present technology has produced a real challenger to the coaxial cable. This is the optical fiber, or lightguide. A small optical fiber (smaller than a fishing line) can carry more information than a cable with 900 twisted pairs. In addition:

- no more RFI
- no more EMI
- no security invasion due to ingress or egress of the cable signal
- losses per mile that are less than the loss in 160 ft of coaxial cables.

While it is questionable as to when and how this new lightguide technology will become applicable to Amateur Radio, the excitement of learning about its vast applications is well worth the effort.

New Books

ELECTRONICS PRINCIPLES AND APPLICATIONS

by Kamiran S. Badrkhan and N. David Larky. Published by South-Western Publishing Co., Cincinnati, OH. First edition, 1984. Hard-bound, 7½ × 9½ inches, 628 pages. $29.93.

For the beginning electronics student, a well-illustrated, easy-to-understand textbook is most important, and much thought should be given to this selection by the instructor. As a class progresses, the book transforms into a "bible" of sorts, with the student often referencing its material.

Authors Badrkhan and Larky (WA6DHO) originally published their text with the intent that it be used in the classroom. If you are a student of electronics seeking a firm foundation of the basics, this book will prove to be a handy addition to the shelf.

The text consists of 16 chapters bursting with information on the electronics industry, components and theory. It reveals facts on ac and dc circuitry, test and measurement equipment, integrated circuits, and much more. Thirteen appendixes includes the standard but necessary schematic symbols, logarithmic tables and formulas. A glossary of terms is included, as well as a short section on soldering for the enthusiastic builder.

Anyone with the ability to solve algebraic equations can indulge in this material and benefit. Each chapter is compiled of topic sections, so the student is not overwhelmed with new material. A series of thought-provoking questions follows, each providing an opportunity for review. Topic sections within each chapter are straightforward and are kept short to eliminate confusion. A well-defined illustration, chart or symbol accompanies each new topic. Little is left to the imagination.

The book's appearance is inviting. The first chapter takes a detailed look at the history of electricity and electronics. Current job opportunities are realistically reviewed. Chapters are written in down-to-earth language, and its technical content is consistent throughout. With a copyright date of 1984, the authors were able to expose examples of basic electricity with the newest of technology. In many areas where information is introduced, the authors cite examples with which readers can identify easily. Without such a vehicle, the lesson might be misunderstood or not comprehended at all.

The Amateur Radio hobbyist who likes DXing or ragchewing may not be attracted to this type of technical literature. The operator who likes to build his or her equipment and does not work in the electronics field should take the time to browse through its pages, however. With information presented on laboratory procedures and equipment, and sections dedicated to each electronic component, it can be used as a reference guide at the work bench. And the authors take care to point out safety notes and precautionary measures to take when working around various materials to ensure the reader's well being.

Badrkhan and Larky seem to have been able to combine the basics of electronics and design techniques to produce a refreshing new book on an old subject. Instructors using this text with appropriate notes and teaching aids should enjoy a successful course. (The book's preface mentions the use of accompanying teaching aids. I have not seen these and thus cannot comment on them.) — *Maureen Thompson, KA1DYZ*

Next Month in QST

If you weren't the first on your block (or the last) to shoot a signal up to W5LFL in the Space Shuttle last year, you won't want to miss out when the next ham/astronaut orbits the earth. A December *QST* article describes a helical antenna designed expressly for Space Shuttle communications. Check it out!

The First Steps in Radio installment deals with that often-underestimated foe of all Amateur Radio operators — electrical hazards.

Elsewhere in the issue, you'll find an update of the VHF/UHF Century Club standings, and a clear, concise introduction to the latest reincarnation of our old friend, the FCC Form 610.