The author is chairman of the wire and cable engineering group of the Electronic Industries Association and serves on similar committees in NEMA and USASI. Mr. Holland joined Amphenol in 1961. Prior to that he was vice-president, engineering for Cable Designs, Inc, chief engineer for Hi-Temp Wires, Inc., and a standards engineer for Sperry Gyroscope Co. in New York. He is a graduate of Pratt Institute and a veteran of the Coast Guard

New Directions in Cable Standardization

By JOHN W. HOLLAND/Vice-President, Engineering
Amphenol Cable Division, Bunker-Ramo Corp

Two groups are coordinating their efforts to derive cable criteria.

FOR THE FIRST time communications cable standardization is now moving rapidly in two directions. Parallel efforts are under way by the U.S.A. Standards Institute (USASI) in the military coaxial cable area, and by the National Electrical Manufacturers Association (NEMA) in commercial communications cables, including coax, microphone, multi-conductor, and hook-up wire. The ultimate result will be an easier job of specification and selection for both commercial and military cable users.

Until recently, no formal commercial cable standards existed, and the only military standardization effort centered around just one old spec. (ELECTRONICS WORLD, June 1968, p. 22)

USASI Committee Goal: New Spec

Last March a meeting was held at the Defense Electronics Supply Center to study the possible revision of MIL-C-17D, which covers the popular "RG" types of coax cable. To handle the job, an industry-government standards subcommittee—USASI C-83.3—was organized.

The new unit's principal purpose will be to re-write MIL-C-17D into basically a design performance type spec, similar to MIL-C-39012, the new coaxial connector specification which was prepared by USASI Committee C-83.2 under the chairmanship of Tore N. Anderson, vice-president, engineering, of the *Amphenol RF Division*.

The committee will establish performance levels for certain groups of cable types and thoroughly investigate new methods of r.f. measurement. Future cable buyers using the re-written spec will have a far better idea of how the cable they select will perform. The planned new spec will include complete information on v.s.w.r. and shielding effectiveness of standard cables. It will also recommend compatible connectors for each cable type and size covered. This effort will be closely coordinated with the C-83.2 connector committee.

Our new coax cable spec is long overdue. MIL-C-17D is one of the oldest Mil-Specs in existence and, although it's been amended from time to time, a complete overhaul has not been done.

As chairman of the C-83.3 committee, I have divided up our tasks into three groups and appointed group leaders: Morton Pomerantz (U.S. Army Electronics Command) will have charge of spec format, selection of cables to be included and recommendation of each type's performance requirements; Dr. Bruno Weinschel (*Weinschel Engineering*) will head a group investigating r.f. measuring procedures and new techniques. David Peterson (*Times Wire & Cable*) will take charge of establishing environmental conditioning, mechanical testing and non-r.f. electrical measurements. Ronald A. Kunihiro of DESC is the committee secretary.

NEMA Task Group

Just last Spring NEMA formed a new section that will, as its charter states, be concerned with "wire, cables, and cords, whose primary use is on devices which produce, transmit, receive, detect, distribute, control, record or modify electrical impulses principally conveying information rather than power."

In short, the new Electronic Wire and Cable Section's main concern is communications cabling and wire. All cabling and wire included in this new section's scope are rated up to 150° C. Cabling and wire designed for higher temperature applications are presently covered by NEMA's High Temperature Wire Section.

As now organized, the section, chairmanned by Fred O. Weirich of *Belden Manufacturing*, has two subcommittees: a statistical group headed by Airy Mossiman of *Anaconda* and a technical group headed by myself. Our tech subcommittee's main task will be to develop standards for communications cables that will be useful to both commercial and military equipment designers.

Coordinated Committees

The cable industry's two new committees will not be working on divergent paths. Just the opposite is our plan of action. Since both the USASI C-83.3 committee and NEMA's new section have many common members, the groups will be fully aware of each other's progress and will assist each other technically.

Military and commercial cables users will definitely derive untold benefits from this bi-directional standardization effort. ▲

The author joined Amphenol in late 1965. He formerly served as vice-president, engineering of Airtron Inc. He is a graduate of Cooper Union, he has served as a consultant to the DOD Advisory Group on Electronic Parts, as a delegate to the International Electrotechnical Commission for Waveguide and Flange Standardization, and is chairman of the USA Standards Institute C83.2 working group on r.f. connector standardization.

Coaxial Connectors

By TORE N. ANDERSON/ Vice-President, Engineering, Amphenol RF Division, Bunker-Ramo Corp.

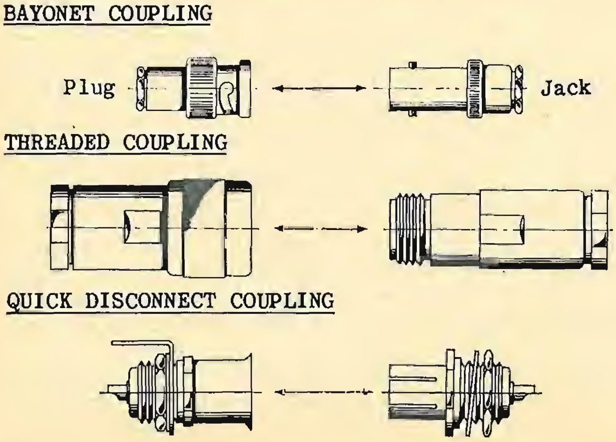
Proper selection of coaxial connnectors is as important as the cable on which they are to be used. Sometimes engineers overlook application for convenience. The result is system degradation caused by using adapters with high v.s.w.r.

PROPER coaxial connector selection is second only to accurate cable specification in insuring optimum performance of a radio-frequency transmission system. The right connector maintains a constant impedance throughout the unit, regardless of the fact that a drastic transition from solid-dielectric coaxial line to air-dielectric line (in the connector) has taken place. And it can withstand the r.f. power levels employed without significantly affecting this delicate balance, measured in terms of standing wave ratio (s.w.r.).

The first step in selecting the right r.f. connector for a given application is to narrow down the choice to a specific coaxial "series." Interestingly, however, this is frequently overlooked by the user intent on staying with a familiar-type connector for the sake of convenience. The result is often severe system degradation caused by the use of adapters and high v.s.w.r. Incidentally, several manufacturers have been known to make this same mistake. Some have used inexpensive phono-type connectors for r.f. applications exceeding 200 watts. Accidental damage to the fitting and dielectric occurs easily and tends to culminate in a blown final transmitter tube or power transistor due to shorted output.

When classifying connectors into their respective series, there are three main defining characteristics. The first is by the size of cable for which they are designed, that is, they can be classified as small, medium, or large. Cables whose dimensions, for example, exceed ¼-in diameter are generally well suited to connectors of the UHF and type N style; below ¼ in, BNC and TNC are popular. For tiny miniature cables, the subminiature connector types such as the *Amphenol* 27 series (MIL-C-22557) or new SMA microwave subminiatures should be used. See Table 1.

Fig. 1. Mating characteristics of three connector types.



The second criterion of classification is the method of coupling or mating. See Fig. 1. This, in turn, can be broken down into three sub-categories. The first method of coupling is the bayonet-coupling method. The jacks and receptacles have two or three circular protrusions on the exterior of the body which are referred to as bayonet ears. The plugs have internal slanted slots on the internal portion of the coupling nut. The next method of coupling is by the use of threads. The jacks and receptacles have the external body threaded and the plugs have the internal thread on the coupling nut. The last comes with numerous "aliases," such as push-on, plug-in, and quick disconnect. But the principle is always the same; simply push to mate, pull to unmate. The connectors are held together during mating by a press fit, retaining springs, or, in some cases, by spring-loaded ball bearings. Each of the three basic methods has advantages and disadvantages. Some are apparent, like the ease of connecting a push-on coupling type over a threaded coupling type; some are not so apparent, like the noise generated in the circuit by the two-ear bayonet-locking type when subjected to vibration.

The third criterion when classifying connectors is electrical or application, such as high voltage, close impedance matching, and d.c. pulse circuits, to name a few.

Classification by Series

"UHF" Series. Now that we have covered the basic parts and the rules of classification, the series themselves fall right into line. Of course, the first one we come to is the exception that proves the rule. The UHF series was the first real coax connector. It is designed for use with small diameter cables (0.185 in) to large diameter cables (0.630 in), and also cables having single and twin center conductors. The insulation materials of the UHF are the mica-filled Bakelite, Rexolite, polystyrene, and Teflon.

The connector is not designed for impedance matching but it can be used at frequencies up to 200 MHz and peak voltages of 500 V. The twin-contact UHF connectors are manufactured in accordance with the applicable portions of the MIL-C-3655A specification.

"LC" Series. The largest cable connector in common usage is the LC series. It is designed for cables of the 0.870-in diameter range. It has screw-thread coupling and is designed especially for the transmission of large amounts of r.f. energy. The LC's are made to match 50-ohm impedance cables and can withstand a peak voltage of 5000 V. The receptacle has a dielectric material of either Teflon or polystyrene. The plug, however, has the unique feature of using the cable dielectric and core as its insulator and contact. This series is covered by MIL-C-3650.

"LT" Series. One of the other large series of connectors is the LT series. This series differs from the LC series in cable size, being 0.730-in diameter cable. The LT cable series is generally aluminum in order to reduce its weight. The LT Mil-Spec is MIL-C-26637.

"LN" Series. The LN series is the next large connector group. The LN is used with only three cables: the RG-14/U, RG-74/U, and RG-94/U. It has a threaded coupling connector. Peak voltage for the LN is 1000 V. There is no Mil-Spec for this series.

"N" Series. The N series is by far the most popular of the medium-size connectors. The average cable diameter for the N connector is 0.400 in, but due to its popularity, the diameter ranges from around 0.200 in to 0.900 in for special applications. Some threaded N connectors are designed to match 50-ohm cables and others to match 70-ohm cables. Type N is covered by MIL-C-39012.

"C" Series. The C connectors are used with the same cables as the N. The C connector is a bayonet-locking connector which has been electrically improved to afford better matches for 50-ohm cables. It works well at frequencies up to 10,000 MHz. Teflon is used exclusively as the insulation material; so is the improved cable-clamping mechanism. The C can be used with peak voltages of 1000 V. Original connectors were made in accordance with MIL-C-3989, new units are made to MIL-C-39012.

"HN" Series. For high-voltage use with medium-size cables, there are the HN connectors which can withstand maximum voltage of 5000 V peak. The HN is a screw-threaded coupling type with insulators of either polystyrene or Teflon. This is a 50-ohm constant-impedance connector, giving low v.s.w.r. values up to the 10,000 MHz limit. The specification of HN connectors is MIL-C-3643.

"BNC" Series. The BNC connector is the most popular connector for small-size cables, having an average outer diameter of 0.250-in. The BNC is a bayonet-coupling type. The newer units incorporate improved clamping and use Teflon as the predominant insulation material. They are also constant 50-ohm impedance connectors with low v.s.w.r. values throughout the frequency range. Due to the smaller size, they are good only up to 500 V peak. The old BNC specification is MIL-C-3608, the new designs are covered by MIL-C-39012 specification.

"TNC" Series. Since the two-ear bayonet-locking device tends to rock during vibration, setting up r.f. noise in the circuit, manufacturers developed the TNC connector which is a threaded-coupling BNC connector.

"MHV" Series. The high-voltage (5000 V peak) version of the small-size connector is the MHV series. The

Table 1. Useful electrical and mechanical specifications for a number of popular coax connector types.

TYPE	COUPLING	MATCHED IMPD. OHMS	TERMINATION: Solder	TERMINATION: Crimp Cable Braid, Solder Ctr. Contact	TERMINATION: 100% Crimp	MIL SPEC: Mechanical	MIL SPEC: Electrical	Max. VSWR to 1	VOLTAGE: Peak	VOLTAGE: Hi Potential 60V RMS	Weather-proof Availability	Maximum Freq.	Typical RG Cables
SUBMINIATURE RF CONNECTORS—FOR CABLE UP TO .150 O.D.													
SUBMinax 27	Threaded, Push-on	50, 70	No	Yes	No	No	No	1.2	500	1500	No	4Gc	174, A21-597
SUBMinax 27 Quick-Crimp	Threaded, Push-on	50, 70	No	Yes	No	Yes	Yes	1.2	500	1500	No	4Gc	161, 174, 187, 188
SUBMinax 27 Field Serviceable	Threaded, Push-on	50	Yes	No	No	No	No	1.2	500	1500	No	4Gc	196
SUBMinax 5116	Threaded, Push-on	50, 75, 95	No	Yes	No	No	No	1.2	500	1500	Yes	4Gc	174, 180, 187, 188, 195 196, 316
MINIATURE RF CONNECTORS—NORMALLY USED WITH CABLE UP TO .350 O.D.													
BN	Threaded	No	Yes	No	No	Yes	No	—	250	—	Yes	200Mc	55, 58, 59
BNC	Bayonet	50	Yes	No	No	Yes	No	—	500	1500	Yes	10Gc	55, 58, 59, 62
Quick Crimp BNC	Bayonet	50	No	Yes	Yes	No	No	1.25	500	1500	Yes	10Gc	55, 58, 59, 62
Mil Crimp BNC	Bayonet	50	No	Yes	Yes	Yes	Yes	1.25	500	1500	Yes	10Gc	55, 58, 59, 62
Original BNC Quick Crimp	Bayonet	No	No	Yes	No	No	No	—	500	—	Yes	—	55, 58, 59, 62
MB	Bayonet	No	Yes	No	No	No	No	—	500	—	No	500Mc	55, 58, 59, 178, 188
MC	Threaded	50, 75	Yes	No	No	No	No	—	500	—	No	500Mc	11, 58, 59
MHV	Bayonet	No	Yes	Yes	No	Yes	No	—	5,000	—	Yes	50Mc	54, 55, 58, 59, 62, 71
PLUG-IN	Plug-in	No	Yes	No	No	Yes	No	—	500	—	No	200Mc	58, 59, 62
SM	Threaded	No	Yes	Yes	No	Yes	No	—	500	—	No	200Mc	58, 59, 174, 187, 188
TNC	Threaded	50	Yes	No	No	No	No	—	500	1500	Yes	10Gc	55, 58, 59, 62, 180, 195
Quick Crimp TNC	Threaded	50	No	Yes	Yes	No	No	1.25	500	1500	Yes	10Gc	55, 58, 59, 62, 180, 195
Mil Crimp TNC	Threaded	50	No	Yes	Yes	Yes	Yes	1.25	500	1500	Yes	10Gc	55, 58, 59, 62, 180, 195
Original TNC Quick Crimp	Threaded	50	No	Yes	No	No	No	—	500	—	—	10Gc	55, 58, 59, 62, 180, 195
MEDIUM SIZE RF CONNECTORS—NORMALLY USED WITH CABLE UP TO .600 O.D.													
C	Bayonet	50, 70	Yes	No	No	Yes	No	—	1.5-4Kv	—	Yes	2Gc-10Gc	8, 9, 10, 11, 58, 59
HN	Threaded	50	Yes	No	No	Yes	No	—	1,500	5000	All	10Gc	8, 9, 10, 11, 17
N	Threaded	50, 70	Yes	No	No	Yes	No	—	500	1500	Yes	10Gc	8, 9, 10, 11, 58, 59, 62
TRIAX	Threaded	50	Yes	No	No	No	No	—	1.9-5Kv	—	Yes	10Gc	Triax
TWIN	Threaded	78, 95	Yes	No	No	Yes	No	—	100-500v	—	Yes	100-500Mc	22
	Bayonet	78, 95	Yes	No	No	Yes	No	—	100-500v	—	Yes	100-500Mc	108
UHF	Threaded	No	Yes	Yes	No	Yes	No	—	500	—	Yes	200-500Mc	8, 9, 10, 11
LARGE RF CONNECTORS													
LC	Threaded	50	Yes	No	No	Yes	No	—	5-10Kv	—	All	1Gc	17, 18
LN	Threaded	50	Yes	No	No	Yes	No	—	1,000	—	All	10Gc	14
LT	Threaded	50	Yes	No	No	Yes	No	—	5,000	—	All	1Gc	117, 118
PULSE	Threaded	48	Yes	No	No	Yes	No	—	5-15Kv	—	All	Pulse or DC	25, 26, 27, 28

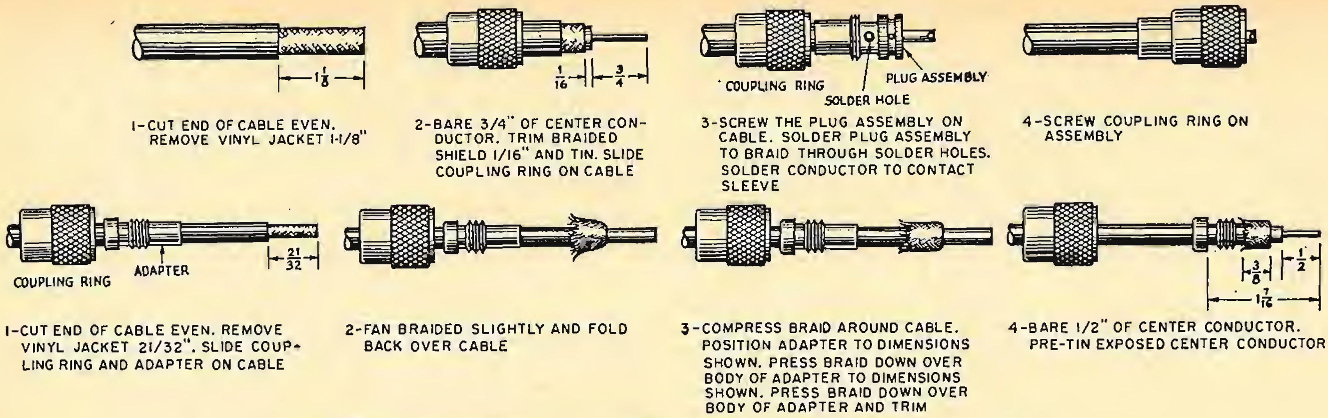


Fig. 2. The assembly method covering the 83-1SP plug and adapter. See text for details.

MHV uses bayonet-type coupling and the cable-clamping method for the same cables as the BNC connectors.

"BN" and "MC" Series. The BN and MC series are also for use with small-size cables. These screw-threaded couplings are low-cost items designed for low-power r.f. applications.

"Subminax 27" and "5116" Series, "SM" and "MB" Series. There is another group of connectors for the subminiature size cables with 0.100-in diameters. These are the constant-impedance, 50-ohm and 75-ohm 27 series: 50-ohm, 75-ohm, and 93-ohm matched 5116 series; and the non-constant impedance SM and MB series. They are push-on, screw-on, and bayonet-coupling, respectively.

"Twinax" Series. This is a special application series for twin-conductor coax. They match the 95-ohm impedance of RG-22/U.

"Triax" Series. Triax connectors electrically connect the Triax cable's two braids separately when the threaded coupling connection is made.

"Pulse" Series. Pulse connectors are rubber or ceramic insulated connectors rated to handle a 15,000-V pulse at sea level or a 5000-V one at 50,000 feet with no corona effect.

Application Requirements

Considerable misunderstanding exists in the field concerning the impedance match of connectors and cables. Most UG-type connectors, for example, are designed for an impedance match with 50-ohm cables. In the case of type N connectors there is a group with smaller center contacts to provide a 70-ohm impedance. These are old designs, covered by military drawings, which do not include newer design features such as reactive cancellation characteristics. In the new miniature connectors there are 75- and 93-ohm versions, but in many cases they have not been completely checked with regard to v.s.w.r. Most applications for higher impedance cables are at relatively low frequencies such as encountered in video and pulse circuitry. For such low-frequency applications, the electrical length of the connector is a small fraction of a wavelength and appears as a small shunt capacitance in the circuit. Generally speaking, where the electrical length of the connector does not exceed 1/50 wavelength, a mismatch between cable and connector has negligible effect. With a mated BNC plug and jack this would correspond to a frequency of 140 MHz.

In many cases, connectors that are mechanically designed for 75- and 93-ohm cables require some form of shouldered contact because the cable conductor is too small to position the contact properly. This tends to make the impedance lower than the 50-ohm nominal. The BNC connectors for use with RG-9/U and RG-62/U are examples of this construction. To increase the impedance of a connector from 50-ohm nominal requires a smaller center contact or a larger outer conductor. In most cases, it is not feasible to reduce the diameter of the center contact without introducing fabrication and assembly problems. To increase the outer conductor means an increase in the shell size and basically a completely new connector design. Whenever the application requires the use of higher impedance cables, and there is no standard matched-impedance connector available, the possible use of a 50-ohm connector should be carefully considered. Demanding a 75- or 93-ohm connector may result in an expensive item which offers little improvement in performance. Additional problems are created when it is necessary to mate these special impedance connectors with standard test equipment. The latter generally has 50-ohm connectors and very few inter-impedance adapters are available.

Understand Assembly Techniques

Assuming a connector is properly designed and manufactured to the required tolerances, the most important contributions to high v.s.w.r. are those variables associated with the assembly of the connector to the cable. See Fig. 2. The importance of this operation cannot be overemphasized. Any air gap between the cable core and the connector insulator introduces an impedance discontinuity that can greatly increase the s.w.r. of the assembly. Similar effects are present when the connector contact is not butted against a square cut of the cable dielectric. For best results, special fixtures and tools should be used to accurately cut the cable dielectric and position the contact. This procedure is recommended whenever a precision assembly is required.

Check Frequency, Power Needs

Next to impedance matching, the electrical characteristic of most importance is voltage rating. In general, r.f. connectors are a compromise type of design wherein one desirable characteristic is sacrificed to some extent in order to obtain other characteristics. This is especially true with regard to impedance matching and high-voltage characteristics. The two are not compatible. To obtain a high-voltage rating, especially at the junction of the cable core and connector insulator. requires a long overlap of the cable core. This presents an inductive discontinuity. It can be compensated to some extent by an adjacent section of low-impedance line which generally takes the form of an oversize center contact. These two sections comprise a line which is an appreciable portion of a wavelength at the higher frequencies and always limits the connector to usage at something less than the 10-GHz range of the standard connector. The HN series and high-voltage C connectors are examples of this construction. For a 1.5 maximum s.w.r. these connectors can be used up to 4 GHz.

Attenuation in an r.f. transmission line is a paramount design consideration. In practice, the loss in connecting

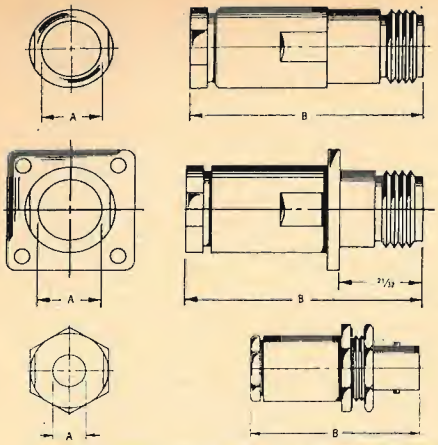


Fig. 3. Jacks tie cables to each other or to panels. Dimension A is the cable o.d.; Dimension B is jack length.

cables is large in comparison with that of the connectors. Therefore, in most cases, the latter can be disregarded. A type N connector, for example, has a dissipative loss of approximately 0.03 dB at 10 GHz, but the reflective loss in a system with various combinations of cable and connectors can be much higher. Consequently, a careful selection of well-designed, properly assembled connectors is the only available solution to this problem.

There is some small r.f. leakage from coaxial connectors. The slotted outer contacts are a contributing factor although leakage through the slots is reduced by the shielding of the coupling mechanism. Threaded-coupling types of connectors are better in this respect than the bayonet-lock type. When properly tightened, they form a low-resistance contact which effectively suppresses any leakage from the slots. Even with the bayonet-lock connectors, the leakage is small provided the cable support is such that the spring loading of the bayonet coupling mechanism permits a full bottoming of the outer contact. All of the recently designed connectors use positive metal-to-metal clamping of the braid wires to insure a consistent low-resistance connection at this point.

Coax-Connector Construction

As in the construction of a cable, let's start in the center and work out. There are two types of center contacts (male and female) which are terminated in the center conductor of the cable. The male contact, sometimes referred to as the male pin, almost always has a solder pocket in one end and is tapered at the other. The female or socket contact may have a variety of terminations such as a solder, flattened and pierced, or turret, but the front end is always hollow, slotted, and set. The male contact is made from ½-in hard brass for ease in machining and is plated with gold or silver. The trend seems to be toward gold plating because it doesn't tarnish and because of the increase in solderability. The female contacts are either brass or beryllium copper; the majority being beryllium copper because of its good spring action even after many insertions and withdrawals. Again, the platings are gold or silver, with gold becoming more popular. Both male and female may be what we call captivated or a captive contact. This is done by adding a shoulder of some type on the contact and then physically holding it in the connector. It is usually held stationary by placing it between two insulators which are, in turn, held stationary by a clamp nut or staking operation.

As in the cable, we come next to the dielectric or, as it is referred to in the connector, the insulator. The insulator varies in configuration depending upon the connector style and type. The materials also vary with the applications. The major insulation materials are polystyrene, Rexolite, polyfluoron (tradenamed Kel-F), polytetrafluoroethylene (Teflon), glass, and mica-filled Bakelite.

Next, is the outer contact. It is this portion of the connector that is electrically connected to the outer shield of the cable and serves the same purpose, that is, to carry a signal, to act as a shield, or as a grounding member of the circuit. In the case of jacks and receptacles, the body of the connector is the outer contact. The plug may have an outer contact and a coupling nut or just a coupling nut which acts as the outer contact. The term, "outer contact" is used only when referring to the tined portion of the body and is generally made out of silver-plated beryllium copper, again because of its good spring action and good electrical characteristics.

Still working outward, the coupling nut is encountered. This nut is that portion of the connector that mechanically joins two connectors. In the case of bayonet coupling, it is sometimes referred to as the bayonet sleeve. The coupling nut material is ½-hard brass with either a gold or silver plating. Most of the UG items are silver plated.

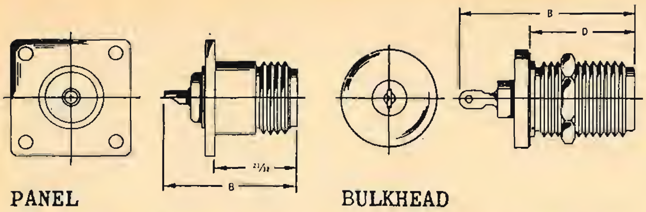
Connector bodies, last on our inside-looking-out list, are also silver-plated or gold-plated brass. Their configuration depends on the type of connector.

Cable-Retention Methods

Now let's take a quick look at the back of the connectors and the methods of attaching the cable to the connectors themselves. There are three basic methods of doing this: (1) soldering, (2) clamping, and (3) crimping. In UHF series, the cable braid is soldered to the connector. The second method of attachment is by clamping and is by far the most popular. In order to accomplish this, it is necessary to use additional piece parts. The first of these is the braid clamp and has two basic forms: one a tapered clamp or old style, the other an improved braid clamp. Both are silver-plated brass material. The second piece part is the sealing gasket. Originally the gasket was a flat rubber gasket. The improved type is a V-grooved gasket or chevron seal. Next comes flat washer, either of brass or phosphorous bronze with silver plate. The last part is the clamp nut. The inside diameter of the clamp nut is equal to the outside diameter of the cable and the o.d. is threaded to screw into the body of the connector. It is this part that holds the cable into the connector. The old-style clamping parts accomplished the sealing and clamping by compressing the flat gasket between the clamping nut and the braid clamp. This gave a fairly adequate seal but the cable retention, being dependent upon the rubber member, was rather weak. The last form of cable retention is by the use of a crimp. In this type, the braid clamp, gasket, washer, and clamp nut are replaced by a ferrule clamp nut assembly which is an extension of the body. The cable dielectric and center conductor are put inside the ferrule and the cable braid, and compressed by means of a crimping tool. The inner ferrule assembly is of silver- or gold-plated brass but the outer ferrule must be a softer alloy because it must be deformed. We can use the crimp in this application because it is outside of the electrically critical area of the connector. The biggest advantage to the crimping assembly method is that it is easier. The cable stripping dimensions are not as critical and there is no braid combing and no torque tightening problem to interfere with satisfactory cable retention. Its main disadvantage is the need for special tools.

Basic Coax Connector Terms

Plugs. The term "plug" defines the mating characteristics and can be broadly stated as that unit, when mated, which encompasses or fits over its mate. The two main types are the straight plug and the right-angle plug.



PANEL BULKHEAD

Fig. 4. Typical receptacle configuration. Dimension B is receptacle length; Dimension D projects through panel.

The right-angle can be of two types. The first is where the body of the unit is made from a block of brass with the circular mating units and cable-clamping portions brazed or threaded into it. This form is termed "cubic construction." The second is made by brazing the two circular portions directly together. This is usually referred to as mitred construction.

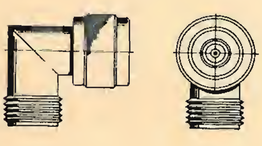
Jacks. There are two principles that define a jack. First, a jack is the mating unit to the plug and all mating features fit inside the plug during mating. Also, it must have a means for securing it to the end of a cable. There are three types of jacks. See Fig. 3. The first is only secured to the end of a cable and is referred to as a cable jack; the second is secured to the cable but is mounted to a panel by means of a square flange, this is called a panel jack; the last unit is mounted to the panel by a shoulder and hex nut and is called a bulkhead jack.

Receptacles. The receptacle has the same mating characteristics as the jack but has no cable-clamping parts. See Fig. 4. The receptacle is open-wired with the center conductor soldered on to the unit and the cable braid sometimes soldered to a grounding lug nut.

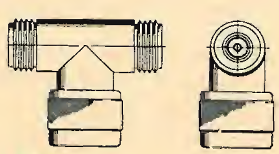
Adapters. An adapter takes two or more incompatible items and joins them together. The names applied to the adapters depend on their functions. See Fig. 5. The straight adapter joins two like units of the same series. These are also called feedthrough adapters when mounted to a panel. The angle adapter usually has a plug, or male end, and a receptacle, or female end, and is used where an angle connection is needed and an angle plug cannot be used. The "T" adapter joins three units together and can be any combination of ends, such as three-receptacle ends, two-receptacle ends, and one plug or possibly one cable-clamp end, and so on. There are also between-series adapters which give us a transition from one series to another. A note of caution should be interjected here. When referring to adapters of all types, it is necessary to be explicit as to the ends of the adapter. Some people describe an adapter by designating the unit with which it is to mate, such as an adapter for two plugs. This is not an adapter with two male or plug ends, but just the opposite; an adapter with two female or receptacle ends. The other method of describing an adapter is to discuss its own construction. The use of both methods is recommended when describing adapters. Also, when calling out a between-series adapter, it is necessary to indicate the specific series involved, such as an adapter with a BNC female end and a series N male end.

STRAIGHT

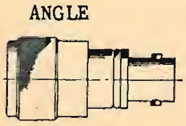
BULKHEAD



ANGLE



TEE



BETWEEN SERIES

Fig. 5. Adapters are used to tie connectors together and feed signals through panels. They can be male or female.

Cable terminations. Cable terminations are used when a complete cable connector is not required. Basically, it is a means of clamping the cable braid and jack while allowing the core to pass through. Cable terminations can be supplied with various methods of mounting from square-flange mounting to strap mountings.

Resistor terminations. This is an electrical termination rather than mechanical. Generally, it takes the form of plugs with built-in resistors that close and load the circuit when mated.

Caps: Shorting and non-shorting. This same principle is used in shorting caps. The shorting cap is nothing more than a unit having the mating features of a plug or a receptacle, except that it shorts out the center contact to the cap body.

Hoods. Since receptacles are open-wired, covering the open end by means of a hood reduces noise pickup. The hood is either attached to the flange or screwed onto the threaded portion of the bulkhead connector.

Pressurized connectors. Another general term that requires clarification is pressurized connectors. There are two methods of pressurizing connectors. The most effective means being the use of a glass bead which is soldered into the connector body itself. The other method of pressurizing is by means of a rubber seal gasket compressed between two insulators. This is not a hermetically sealed connector and should not be referred to as such. Its sealing effectiveness varies greatly and, in general, should be used only where low pressure differentials exists.

A Look at Mil-Spec Connectors

Since the majority of r.f. connectors find their way into military applications, let's briefly review the military terminology associated with r.f. connectors.

The UG portion of the number has been assigned the meaning "Connector,R.F.". The "/U" indicates that it is for general usage and officially defined as "used in two or more general installation classes such as airborne, shipboard, or ground." The number assigned to the connector is the identifying number and is assigned on a first-come, first-served basis. There is no correlation between this number and the type or series of the connector.

Provisions are made in the military nomenclature to reflect changes. This is the function of the letter inserted after the number and before the /U. The higher the letter, the later the revision. On some connectors, use revisions are as high as "E: indicating a fifth revision of the original design. A revision number is assigned when the detail parts and subassemblies therein are no longer interchangeable, but the component itself is interchangeable physically, electrically, and mechanically. If the change is of such a nature that the connector is not interchangeable with its forerunners, it will be assigned a new nomenclature.

There are two other identification symbols used in connection with r.f. lines. These are CW and MX. The MX denotes a miscellaneous category and covers such things as caps, hoods, and armor clamps. The CW designates a cover and is used with caps exclusively.

It can be seen, then, that proper selection of coaxial connectors depends upon several factors. For a quick recap, the following should be evaluated on a step-by-step basis:

1. Determine coaxial cable—cable should be chosen on the basis of impedance, temperature, attenuation or power capacity. 2. Determine possible connector series. 3. Constant or non-constant impedance. 4. Coupling. 5. Cost and availability. 6. Shell style. 7. Solder or crimp terminations. ▲

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Martin Mirsky received his BEE degree from Pratt Institute in 1957 and attended Ohio Sate University Graduate School. In 1961 he joined Filtron and is presently associate director of the Interference Laboratory. Prior to that he was employed by the Wright-Patterson Air Development Center as an RFI/EMC specialist. He has published several papers on interference.

Grounding Techniques

By SAUL BERNSTEIN, Manager, Test Division
& MARTIN MIRSKY, Associate Director, Interference Laboratory/Filtron Co.

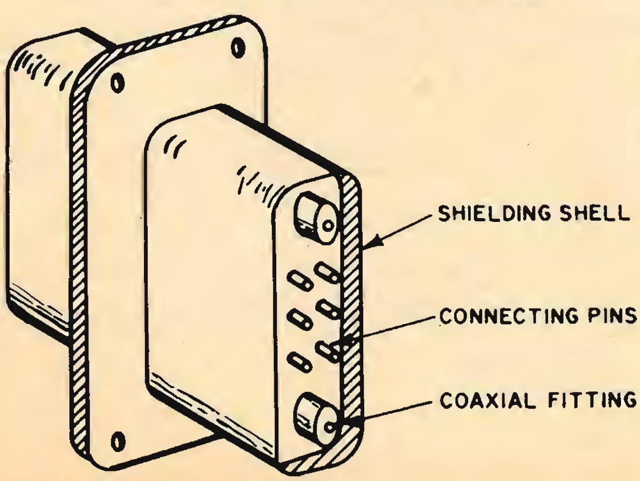
Improperly grounded shields can cause coupling and interference problems in sensitive electronic circuits. Shields can be single- or multi-point grounded.

THE problem of electrical compatibility in a complex electrical or electronics system is, in many cases, dependent on the treatment of the shielding and the grounding of the wire shields. Injudicious application of a grounded shield to a wire may cause coupling problems that otherwise would not exist. Grounding of the shields may be accomplished as single-point or multi-point grounding. Factors that influence the selection of single-point or multi-point grounding include the interference signal frequencies involved, the length of the transmission line, and the relative sensitivity of the circuit to high- or low-impedance fields.

The two grounding methods are more completely defined as follows:

Single-point shield grounding. For multi-lead systems, each shield may be grounded at a different physical point as long as individual shields are insulated from each other. Single-point grounding is more effective than multi-point shield grounding only for short shield lengths. Single-point grounding is ineffective in reducing magnetic or electrostatic coupling when conductor length-to-wavelength (L/λ) ratios are greater than 0.15; where the wavelength is that of the highest frequency to be used (or the highest frequency interference to be expected) on the wire or on the system.

Fig. 1. Connector with pins enclosed by shielding shell.



Multi-point shield grounding. For L/λ ratios greater than 0.15, multi-point grounding at intervals of 0.15λ is recommended, for the shield can act as an antenna that is relatively efficient at L/4λ when one end is grounded. When grounding the shield at intervals of 0.15 is impractical, shields should be grounded at each end. Multi-point shield grounding is effective in reducing all types of electrostatic coupling, but is subject to failure if large ground currents exist. In general, multi-point shield grounding solves most problems, but in audio circuits single-point grounding may be more effective because of a ground-current problem.

General Considerations

Proper cable installation is essential if interference difficulties are to be avoided. Assuming proper grounding techniques have been employed, the following guidelines for good signal cable practice should be observed:

1. Shields should not be used for signal returns.

2. All signal circuits, including signal ground returns, should be individually shielded and have insulating sleeves or coverings over the shields. Balanced signal circuits should use twisted pairs or a balanced coaxial line with a common shield. Where multi-conductor twisted-pair cables that have individual shields as well as a common shield are used, all shields should be insulated from one another within the cable.

3. Coaxial cables should, in all cases, be terminated in their characteristic impedance.

4. On shielded cables in harnesses, where a common shield ground must be utilized, a clamp or shielded and grounded backshell should be used to ground all shields to the connector body. This should be done in addition to connecting the shields to ground through one or more connector pins.

5. Coaxial cables carrying high-level energy should not be bundled with unshielded cables or with shielded cables carrying low-level signals. Although the characteristic impedance of the cable or signal circuit will normally be quite low, the shield-circuit impedance may become appreciable if the shield becomes open-ended or electrically long. This reduces shield effectiveness.

6. Shields should be grounded on both sides of a connector

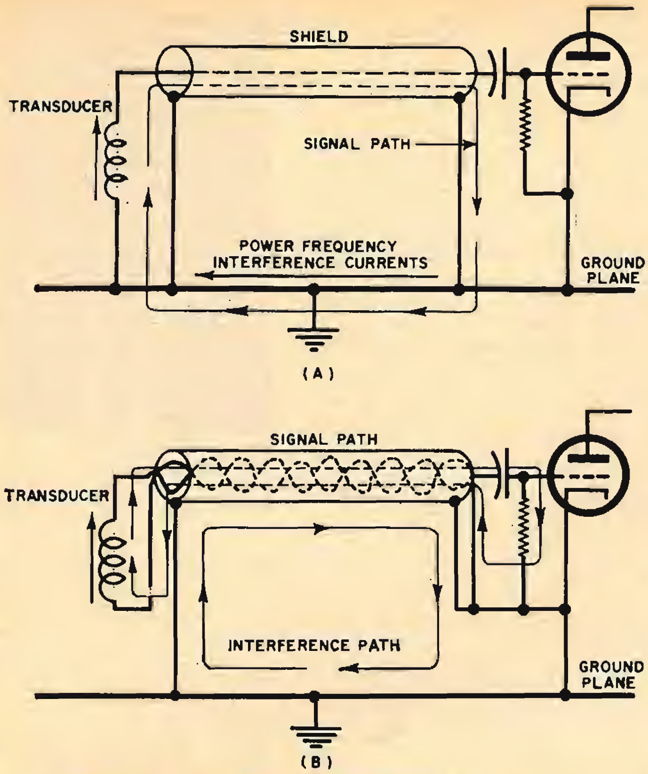


Fig. 2 (A) Multipoint shield grounds couple noise into signal circuits; twisted pair (B) reduces interference.

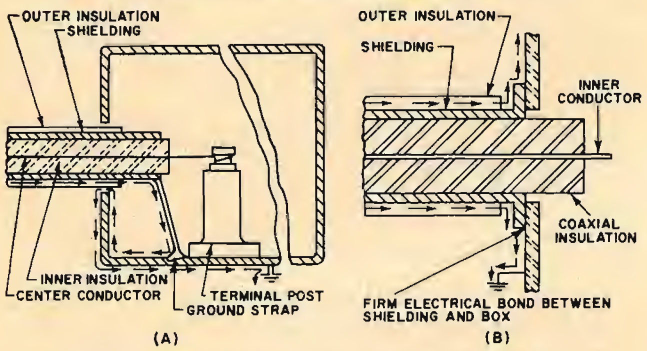


Fig. 3. (A) Shows the incorrect method of introducing shielded cable into junction box, (B) is the right way.

to avoid discontinuity; if not possible, the shield should be carried across the connector through a connector pin.

7. Grounding a number of conductor shields by means of a single wire to a connector ground pin should be avoided, particularly if the shield-to-connector or connector-to-ground lead length exceeds one inch, or where different circuits that may interact are involved. Such a ground lead is a common-impedance element across which interference voltages can be developed and transferred from one circuit to another.

Connectors

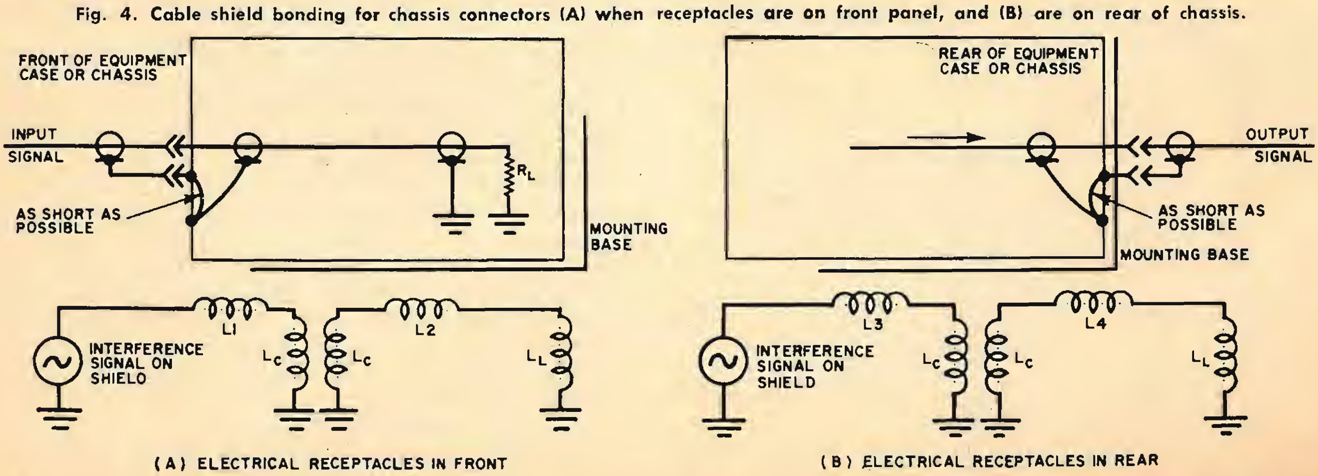
Great care must be taken at connectors if impedance characteristics and shielding integrity are to be maintained. A shielding shell should be used to shield the individual pins of a connector. A well-designed connector has a shielding shell enclosing its connecting points (Fig. 1). The shells of multi-pin connectors should be connected to the shield. Coaxial lines should be terminated in shielded pins. Pigtail connections for coaxial lines are undesirable since they permit r.f. leakage.

Cable Shield Grounding

Each shield circuit should be carried individually; each should be electrically continuous and grounded at both ends. In the case of long cable shield runs, bonding of shields at intermediate terminals or locations will reduce impedance of the shields to ground, rendering the shielded circuits less susceptible to radiated or induced interference. Individual shields should not be electrically joined together so that one shield carries the r.f. currents of another. To obtain minimum r.f. shielding from shielded wires or coaxial lines, it is necessary to bond them effectively to the ground plane. For a low-impedance r.f. connection, the shortest length of connecting strap or jumper that is mechanically practical should be used. If coaxial cables are used to transmit r.f. signals, they should be grounded at both the sending and receiving ends. Normal coaxial connectors are adequate for this purpose; pigtail connections should be avoided. In applications where twisted-pair cables are used, the shield should be grounded at each end and the circuit return path should be floating (single-point grounding). Bonding and grounding techniques employed should comply with standard good installation practice.

Both multi-point and single-point ground systems offer singular design features. For electronic and electrical systems distributed over a large area, multi-point shield grounding for interference control is superior. The multi-point approach allows short ground connections, provides a low-impedance ground-return circuit, and improves the effectiveness of filter installations. While multiple-ground circuits are recommended for r.f. applications, there are some circumstances, primarily in low-frequency, low-level work with audio or servo amplifiers, in which single-point grounding is necessary. When a shielded cable in a sensitive circuit is grounded at both ends for the return circuit, power-frequency currents in the ground plane can induce audio-frequency interference (Fig. 2A). Therefore, single-point grounding may be the best approach where large a.c. currents flowing in the ground plane may couple into very sensitive low-frequency circuits. To provide extra protection, a shielded twisted pair should be used (Fig. 2B).

Fig. 4. Cable shield bonding for chassis connectors (A) when receptacles are on front panel, and (B) are on rear of chassis.



The shield should be grounded at both ends; the signal return lead only at one end. Because of multiple grounding of the shield, magnetic fields may be coupled into the shield by conduction or induction. The twisted leads reduce magnetic susceptibility because of field cancellation.

Reducing Interference

Serious interference problems arise when shielded wires or coaxial cables are not properly terminated at the connector. It is important that the connector be properly grounded. The direct bond for this ground can be achieved by maintaining clean metal-to-metal contact between the connector and equipment housing. In those cases where a large number of individual shields from shielded wires must be connected to ground, it is recommended that the halo or shielded backshell technique be used. The exposed unshielded leads should be as short as possible to reduce electrical coupling between conductors. Interference is caused when a shielded cable is run into a completely sealed box, but is grounded internally. The correct way to install a shielded r.f. cable is to run the shield well inside the connector and bond it around the connector shell. The arrows in Fig. 3A show the path that any signal or interference that is picked up on the outer surface of the shielding must follow to return to ground. The currents around the loop generate a field in the enclosed box, as do coupling loops used with resonant cavities. Fig. 3B shows the correct method of introducing shielded cables into a box where shielding must be maintained. Interference currents may be carried when a shielded r.f. cable entering an enclosure has its shield stripped back to form a grounding pigtail. Such pigtails should therefore be avoided. If it is absolutely necessary to use a pigtail it should be kept as short as possible and soldered to provide a ground without breaking the shield. The pigtail should also maintain continuity of the shield (through a pin in the connector) to a continuation of the shield inside the enclosure. The cable r.f. shield is a part of the complete shielding enclosure. Care should be taken to insure there are no openings through which airborne noise can enter.

Electric plugs and receptacles are usually mounted on the front and/or rear of the equipment chassis or on the mounting base. If electrical receptacles are on the front of the case, the plugs should be separate units. Shield grounds should be made in accordance with Fig. 4A. If electric plugs and receptacles are placed at the rear of the case one unit should at least be securely attached to the case or chassis; the other separate or securely attached to the mounting base. Shield grounds should be made in accordance with Fig. 4B. Two poor methods of grounding cable shields are shown in Fig. 5. These methods are not recommended because their use permits interfering signals to enter the equipment. In cases where a common shield-ground must be employed, such as on multi-shielded cables or harnesses having a large number of individually shielded circuits, a clamp, bus, or shielded backshell should be used to ground all shields to the connector body; this in addition to grounding them through one or more of the connector pins. The common ground should be avoided when the shield-to-connector or connector-to-ground lead length exceeds one inch, or when current circuits that may interact are involved. To prevent discontinuity of the shield because of possible disconnect at intermediate connectors, shields should be grounded to the structure on both sides of the connector. If this isn't possible, the ground should be carried across the connector or through a conductor pin.

Cable Shield Bonding

Shields should be terminated no further than 0.25 inch from the ends of the lines they are shielding. Bonding halos, shielded backshells, or interlacing straps should be used to terminate the shields and to minimize the impedance of the shield termination (Fig. 6). Shields should be connected to the ground plane by 1.5 inches or less of 0.25- or 0.5-inch wide tin-plated copper strap. The halo technique is acceptable only when a few wires are involved. The interlacing strap or shielded backshell method should be used for a common shield ground in multi-shielded cables and in harnesses that have a large number of individual shields. The interlacing strap should be at least 0.25-inch wide by 0.012-inch thick and be bonded securely to the connector. This is shown in (Fig. 7).

Coaxial fittings should be kept tight at all times not only to provide a good impedance match but to eliminate loose connections that may result in rectification of interference energy at the fittings. Again, the resulting d.c. voltage may interfere with circuit operation by imposing an undesired bias signal at the circuit's input; or, in the case of power measurements, cause an erroneous wattmeter reading. For these same reasons, shielding or bonding clamps that may be part of the fittings should also be kept tight. Soldered fittings are recommended, particularly at terminations of shielding and braid. ▲

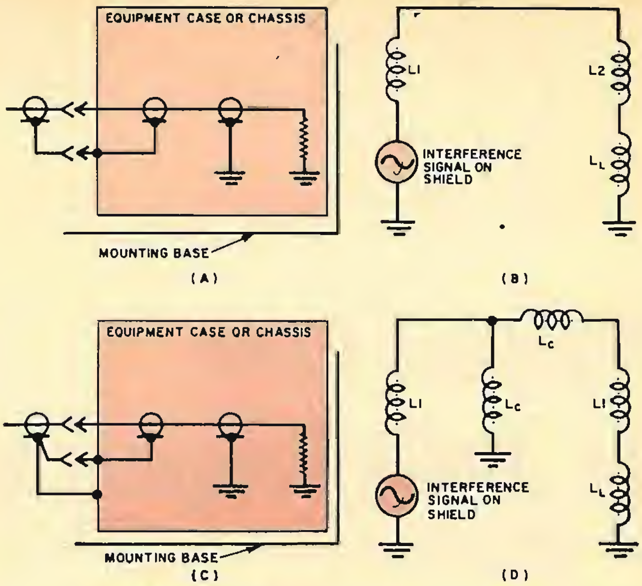
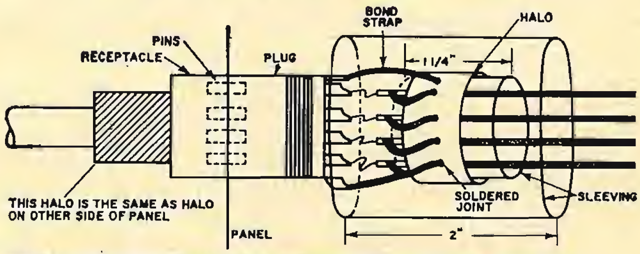


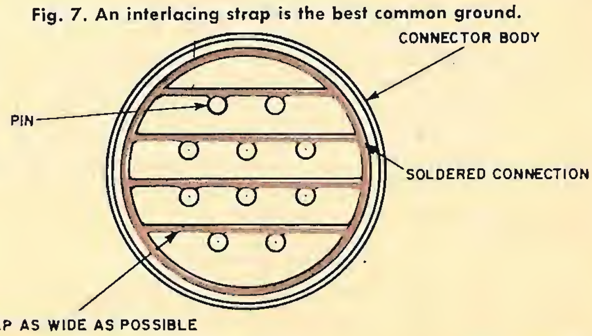
Fig. 5. Poor bonds permit noise to enter equipment.



NOTES: 1. BOND STRAP MAY BE CONNECTED AS SHOWN OR WITH 1/4" BOND STRAP TIED TO STRUCTURE OR CONNECTED BY MEANS OF EARED WASHER
2. HALO IS 1/4" TO 1/2" WIDE

Fig. 6. When bonding halos are used to terminate shields in a harness, they minimize the termination's impedance.

Fig. 7. An interlacing strap is the best common ground.



The author has held his present position for the past 11 years. Prior to that he was engaged in the design of power transformers for electronic applications. He has a BSEE from Illinois Institute of Technology.

Shielded Cable at Audio Frequencies

By ROBERT E. SHARP/Product Development Engr., Belden Corp.

"Audio" frequencies range from d.c. to 100 kHz. Shielding cables which carry these signals presents engineers with some very special problems.

WHEN it comes to choosing a properly shielded cable for an audio-frequency application, many engineers are baffled. "Audio" may mean an electrical signal whose frequency is too low to be distinguishable, but one that nevertheless conveys information; or it may mean a signal which contains frequencies up to 100 kilohertz, or higher. For purposes of this discussion, we will define "audio" as d.c. to 100 kHz.

In audio circuits, as in radio-frequency circuits, the primary reason for shielding a cable is to keep external noise or electrical energy from disturbing the signal within the cable. The type of shield needed, and indeed, whether a a shield is needed at all, depends on the nature of the signal and on the electrical and physical environment in which the cable will be used.

Fig. 1 shows the six most popular types of flexible shields. They are: braided wire, spirally wrapped wire, plastic-supported metallic foil, self-supporting metal foil, conductive textiles, and conductive plastic or rubber-type sheaths. Of course, some cable types have combinations of these basic shield configurations.

Shield quality is described by one or both of two terms; percent shield coverage—which is the percentage of the surface of the shielded element physically covered by the shielding material, and shield effectiveness—which indicates how well the shield is doing its job.

Shield effectiveness is the ratio of signal leakage with the shield in place to signal leakage if no shield is present, and is usually expressed in decibels. In the case of cross-talk measurements on a multi-pair cable, isolation between the pairs is given in terms of the ratio of the voltage picked up on one pair to the voltage which is applied to another pair, and is also expressed in decibels. Some isolation between the pairs may be the result of uniform twisting of each pair and, of course, isolation can be improved by shielding each wire-pair individually.

Normally, the higher the percent coverage, the more effective the shield. However, a shield made of high-resistance material such as carbonized yarn (used to give 100% coverage) may not be as effective as a copper-wire shield having only 85% coverage.

Braided Shields

For quite some time braided-wire shields were considered the industry standard and, although they have been replaced by more efficient foil shields in many applications, they are still best for some uses. For most audio applications these shields are made of tinned copper wire for high conductivity, ease of soldering, and good flexibility. Braided-wire shields are recommended in other applications where the cable will be subjected to a great amount of flexing.

Sometimes a compromise must be made between shield coverage and flexibility. It's easy to see that the more complete the coverage, the stiffer the cable. For example, most microphone cables are not near sources of severe interference, so exceptionally good shielding is not required and shield coverage as low as 70% is frequently used with good results. In addition, braided-wire shields are frequently used on cables for strain-gage instrumentation, especially where the part under test is in motion and the cable must be extremely flexible.

In practice, the maximum wire-braid coverage is approximately 98%. This is because openings are required to pass shield strands over and under one another during the braiding operation.

Spirally Wrapped Wire Shields

Braided-wire shields are expensive to manufacture and assemble in a finished product. For that reason, spirally wrapped wire shields, frequently called *served shields,* are used. They are less expensive because the manufacturing process is simpler, and because they use less copper—approximately one-half the copper of an equivalent length of braided shield. Theoretically, a spirally wrapped shield can cover a cable completely because no holes are required as in braiding. In practice, however, coverage is kept below 100% to keep the wire strands from piling up.

Spirally wrapped shields are easy to terminate. The user merely unwinds a few wraps of the shield, twists it into a pigtail, and makes his connection either by soldering or clamping to a terminal.

Spirally wrapped shields are found in many home-entertainment systems such as tape recorder mikes, electronic guitars, and high-fidelity sound equipment. Fig. 2 shows a spirally wrapped shielded cable used with stereo sets. The two insulated wires which have spirally wrapped shields covered by a plastic jacket, resemble the familiar "zip cord." When it is necessary to split the cable for the two channels, the web between the wires is cut and the

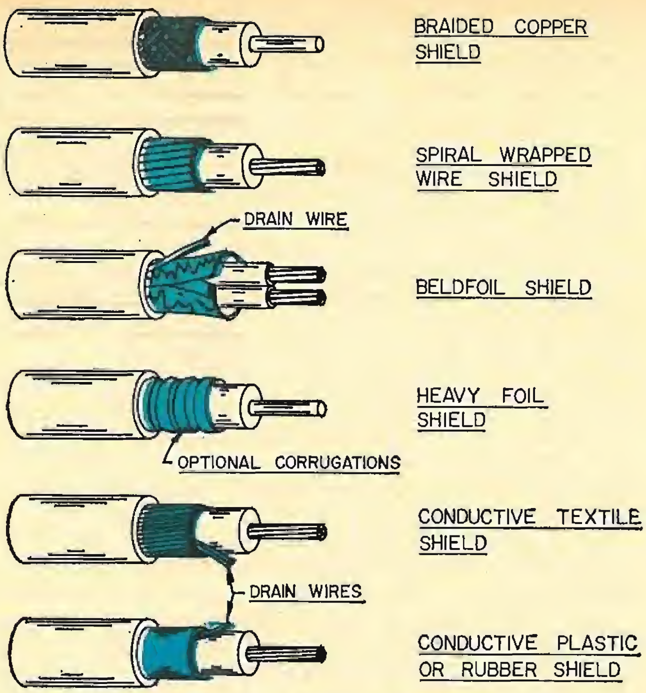


Fig. 1. Six popular types of flexible audio cable shields.

user then has two individually shielded and jacketed cables.

Inductance is the major disadvantage of spirally wrapped shields. Sometimes when a microphone cable is connected to a transmitter, the inductance causes it to resonate at the transmitted frequency—creating interference. Normally, spirally wrapped wire shield is satisfactory for audio use, but when it is necessary to overcome the inductive effect of the spiral, some cables use an uninsulated wire running lengthwise under the shield to short the turns of the shield coil.

Plastic-Supported Metallic-Foil Shields

While most wire shields are adequate for cables which carry audio signals that are to be interpreted by the human ear and brain, better shielding is needed for cables that carry information between machines. For example, digital data (in the form of pulses) can be erroneously interpreted if some noise pulses get through the cable shield. Then, too, the demand for more cables in less space has made shielding more difficult. This is true even when cables carry only speech or music. Why? Because the closer together you have two cables, the more coupling you will have between them.

Clearly better shielding had to be developed. A thin aluminum foil tape wrapped around a cable makes a good shield; but most foils which are strong enough to withstand the manufacturing processes are so thick that they make the cable too stiff.

A few years ago the introduction by *Du Pont* of Mylar plastic film made possible the development of a shield consisting of Mylar laminated to thin aluminum foil by means of a suitable adhesive and wrapped around the cable. An uninsulated wire, called a "drain wire", is in contact with the aluminum foil for the entire length of the cable and is used for making connections to the shield.

From the basic concept, plastic-reinforced aluminum foil shields have been developed into many forms for specific applications, so that such shields can be much more than just a Mylar-backed aluminum tape wrapped around a cable. The excellent insulating properties of Mylar are used to provide a "bonus insulation" between the shield of a cable having a single shield and the conductors.

In cables having several shields, such as a 27-pair cable in which each pair is individually shielded, it is frequently important to keep the shields insulated from each other except at the grounded end to avoid "ground loops" which reduce the effectiveness of the shield. Here, the shield is used with the Mylar outward to provide insulation between the shields.

The inductive effect of a spirally applied foil tape can be a problem, just as it is with a spirally wrapped wire shield. To overcome this, it is necessary to "short-circuit" the turns of the spiral in some manner resulting in the electrical equivalent of a continuous metal tube.

Belden has a patent which pertains to folding back a

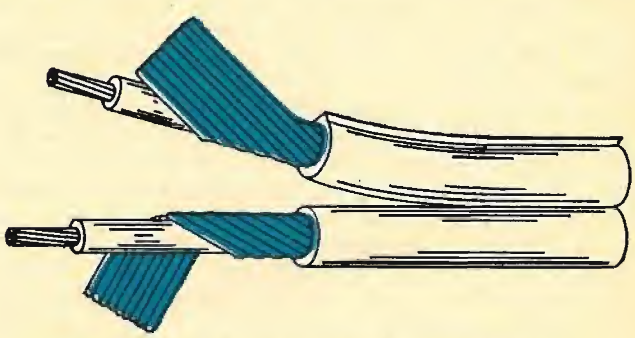
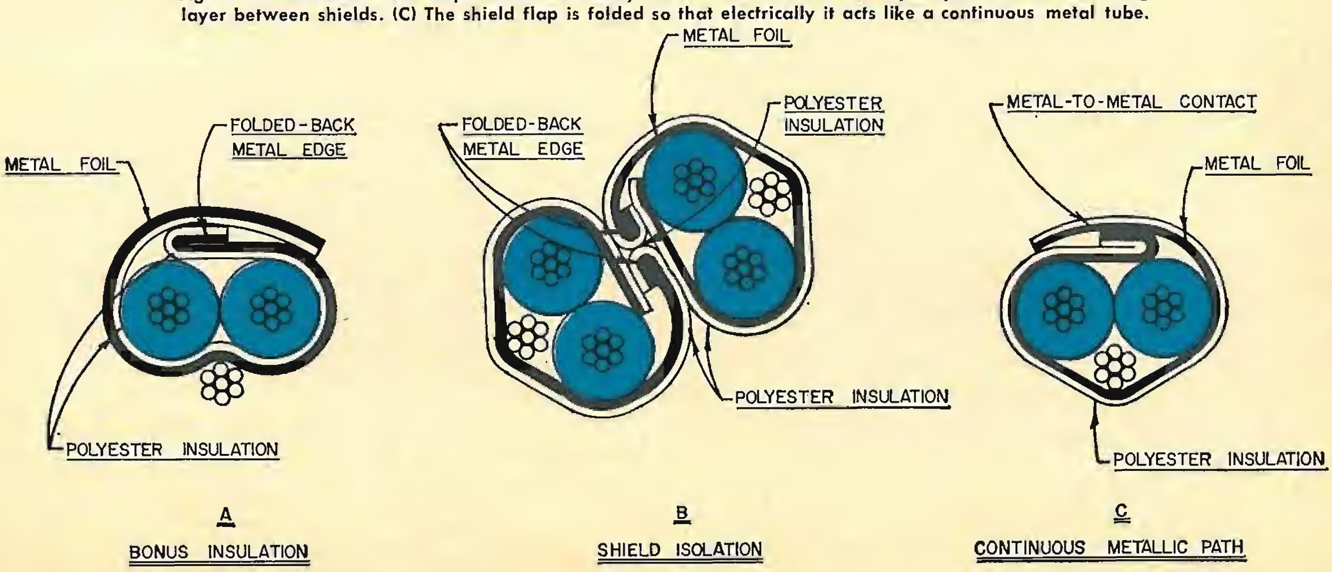


Fig. 2. Stereo cable with separately wrapped shields.

Fig. 3. (A) Patented fold keeps shield foil away from the conductors. (B) Mylar provides an insulating layer between shields. (C) The shield flap is folded so that electrically it acts like a continuous metal tube.



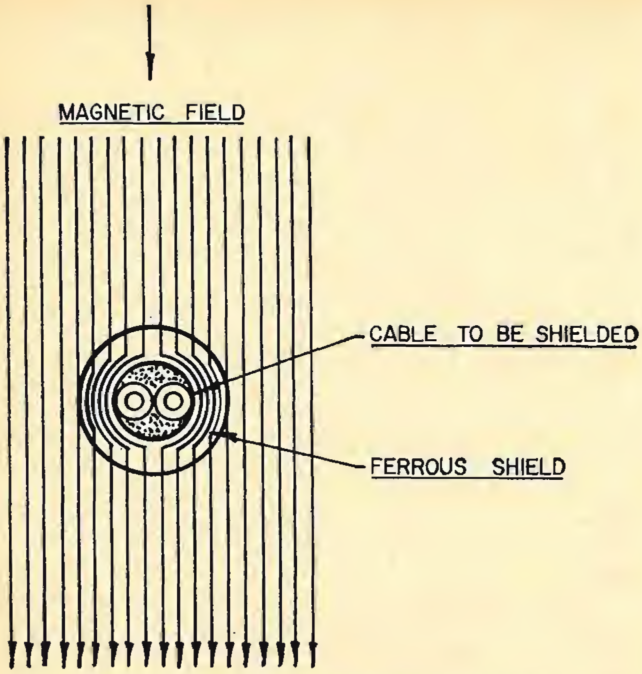


Fig. 4. Ferrous materials repel external lines of flux.

narrow edge of the plastic-supported foil tape used in its Beldfoil shielding. The folded edge is used to tuck the exposed edge of foil in such a manner that it is prevented from touching a conductor or another shield. Thus it enhances the "bonus insulation" and improves the reliability of shield isolation (depending on the type of cable). Folding one edge of the tape in the other direction permits metal-to-metal contact, effectively eliminating the added inductance of the helically applied shield. The various folds are shown in Fig. 3. The foil-to-foil fold is shown separately for clarity, but is actually used together with the other folds.

Plastic-supported foil-shielded cables are being specified instead of braid-shielded cables in nearly all new radio and TV studio installations because they give better shielding, take up less space, are easier to terminate, and are lower in cost than the old-style braided shields.

In addition, plastic-supported foil-shielded cables are being used in all sorts of applications where the best in electrostatic shielding is required. They are used in intensive care equipment in hospitals; with huge parabolic antennas used to track space probes; and with data collection instrumentation, especially at underground nuclear test sites.

It was at first felt that plastic-supported foil shields should not be used where they would be subject to flexing. However, exhaustive laboratory tests by the *Belden Co.*, backed by experience in the field, have shown that foil shields will withstand continuous flexing as long as the cable is not bent sharply, and sharp bends will reduce the life of any cable.

It was found that after many thousands of bending cycles there will be some hairline cracks in the aluminum. However, the Mylar remains undamaged and the cracks in the foil are bridged by the drain wire, so the effectiveness of the shield remains better than that of a braided-wire shield.

(Editor's Note: Most of the major cable companies have developed and manufacture Mylar-backed aluminum-foil shielded coaxial and multiconductor cables. Apparently the big difference between the Belden *cable and those of the other manufacturers is the method of wrap, and the fold on which* Belden *has a patent. The other companies use a short spiral wrap where* Belden *uses a long wrap in which the spirally wrapped shield turns slowly around the cable insulation. According to some cable makers, the short wrap is equally effective as the long wrap; however, users should test each cable type to see which best meets their needs.)*

Self-Supporting Metallic-Foil Shields

For mechanical strength it is necessary to use a relatively thick foil in unsupported metallic-foil shielded cables. Because of this, unsupported foil tapes are rarely used when individual cable elements must be shielded. However, they are frequently used as an over-all shield under the final outer jacket. While they have excellent shielding properties, they are also used to give the interior of a cable a certain degree of mechanical protection.

Heavy foil shields are usually made of copper or aluminum, and may be wrapped spirally or laid parallel to the axis of the cable. In general, spirally wrapped shields are more flexible, although the necessity for overlapping the tapes may cause some roughness in appearance. Heavy tapes applied parallel to the axis of the cable tend to collapse when the cable is bent. Two methods have been devised to overcome this problem. One method is to corrugate the tape so that it will bend easily at each corrugation. This results in many small bends rather than one large, single bend which could collapse the shield. The other method is to use a foil tape which is coated with a material which melts and bonds to the plastic jacket. This causes the jacket to support the foil, and thus helps to prevent its collapse.

Conductive Textile Shields

Textiles may be made conductive by impregnating them with carbon. When used as shields, conductive textiles are spirally wrapped around the cables to obtain 100% shield coverage. Usually a metallic drain wire running the full length of the cable is used as a shield termination, however, conductive textiles may be used in concert with a braided-wire shield and, in this case, the termination is made to the wire braid.

Conductive textiles are effective against 60-Hz hum and low-frequency noise caused by mechanical impact. However, effectiveness decreases significantly as frequency increases, therefore they are not used in high-frequency applications, especially when many cables are bundled together.

Plastics and rubber-like materials may also be made conductive by the addition of carbon or similar metals. When conductive plastics are used as shields, they are extruded over the cable and a drain wire is used for the termination. These shields are usually effective against low-frequency noise and 60-Hz hum but tend to be less effective at high frequencies. Effectiveness also decreases with the age of the material and also varies from one production lot to the next.

Table 1. Summary of audio cable shield characteristics.

	Copper Braid	Copper Serve	Foil/ Plastic	Heavy Foil	Conductive Textile	Conductive Extrusion
Shield Effectiveness	Good	Good	Excel.	Excel.	Fair	Fair
Limpness	Good	Good	Fair	Poor	Excel.	Good
Fatigue Life	Good	Fair	Good	Poor	Excel.	Good
Relative Cost	High	Med.	Low	High	Med.	Med.
Tensile Strength	Good	Fair	Poor	Good	Poor	Poor
Termination Methods	Pigtail, crimp ring	Pigtail	Drain wire	Direct connection	Drain wire	Drain wire

Is it Just a Shield?

We have discussed the basic shield types without regard to what is underneath them. Sometimes we find that a shield is more than a "shield" and this has a bearing on the type of cable chosen and how it's used.

In the ideal case, a shield has no function beyond intercepting undesired energy and carrying it to ground. However, we frequently encounter a system in which the shield is a signal return path. A typical example is the mike cable on a tape recorder. Here the shield has two jobs, carrying the signal and protecting it from interference, but since the shielding is not too critical, it does both jobs satisfactorily. However, consider a long run of shielded single-conductor microphone cable between two metal chassis, and assume the connectors ground the shield to both chassis. Neither chassis is directly grounded but each has different capacitance to ground through its power supply. The result is dissimilar voltages at the two shield ends. This causes current in the shield and hum in the input.

Of course, the problem can be eliminated by installing a low-impedance bonding wire between the two chassis, and insulating the connectors from the chassis. A better way is to use a balanced input and output and a twisted-pair cable. Then the shield can be grounded at only one point and no current will flow through it to introduce interference.

Shields are sometimes used as one side of a push-to-talk circuit or buzzer system. In this case, the user must be sure the shield can carry the current. In the case of Beldfoil shields the drain wire is rarely more than 2 AWG sizes smaller than the conductors in the cable and is usually adequate for use as an auxiliary conductor, although the user should satisfy himself that voltage drops will not be excessive.

Magnetic Shielding

So far, we have concentrated on electrostatic shielding, or the prevention of capacitive coupling. One other way in which interference occurs is by magnetic coupling, or "transformer action." Whenever a wire crosses a varying magnetic field a voltage will be induced in the wire.

Reduction of magnetic interference may be accomplished in several ways:

1. Route the cable away from the source of interference. 2. Use a balanced twisted-pair so that equal voltages of opposite polarity are induced in the conductors. 3. Use a magnetic shield. The first two methods, proper cable routing and a balanced pair, should be used whenever possible because an effective, flexible magnetic shield is extremely difficult to achieve. The object of a magnetic shield is to divert the magnetic field by providing a low-reluctance path which bypasses the magnetic flux around the cable (See Fig. 4.)

The best magnetic shield for cables is an ordinary soft-iron water pipe, but it can hardly be called flexible. Flexible cables may achieve some degree of magnet shielding by wrapping soft iron tape or high-permeability alloy tape around them.

Cable manufacturers constantly strive to develop more effective shields for the newer, more critical applications. New materials, new combinations of materials, and new methods of applying them are under evaluation, and vast amounts of test data is on file. Engineers with unusual cable applications may find this information helpful. Test data can be obtained by writing to the cable manufacturer direct. ▲

A NEW TYPE OF SHIELD

THE best way to shield a wire is to surround it with a continuous metal tube. In effect, this is what the Plaxial Cable group of United-Carr did when they developed what they claim is the first fully shielded, flexible coaxial cable. Tradenamed Plaxial Cable, the coaxial line is made by plating a ductile copper onto flexible Teflon or polyethylene dielectric.

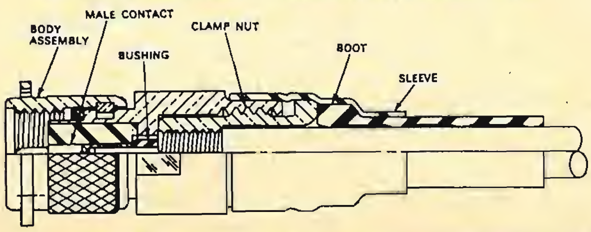
Actually, the desire to miniaturize as much electronic equipment as possible has made large, rigid coax line obsolete. Therefore, the tendency is to replace rigid lines with miniature semi-rigid cables or with conventional single- or double-braided shielded cable. Both of these conductor types have serious shortcomings, however.

Plaxial cable offers a third choice. It is flexible like braided cable, but without the losses, and it is fully shielded like semi-rigid cable but there is no need for the accurate cutting and bending that limits semi-rigid cable use.

Plaxial cable is flexible because a continuous helical groove is scored in the polystyrene or Teflon dielectric to permit the outer copper sheath to flex without cracking or degrading the cable's v.s.w.r. or other characteristics. Bends as small as 1/8" radius can be made with the standard 50-ohm cable, which is 0.145-inch o.d.

As engineers know, semi-rigid cable does provide complete shielding of high-frequency signals but it must be accurately cut to length and bent to fit, so it is difficult to install in the field; it is heavy; and it is subject to damage by vibration. The fitting problem generates engineering drawings for every piece of harness yet the major variations aren't electrical but physical.

Fig. 1. In straight or right-angle connectors, Plaxial cable makes contact by screwing into connector body.



Braided cables cannot be used at the higher radio frequencies—above 6 GHz—because of high signal loss through the braid. And when the braid is flexed, the attenuation varies widely, indicating unstable shielding effectiveness. A flexed braid is also a noise source.

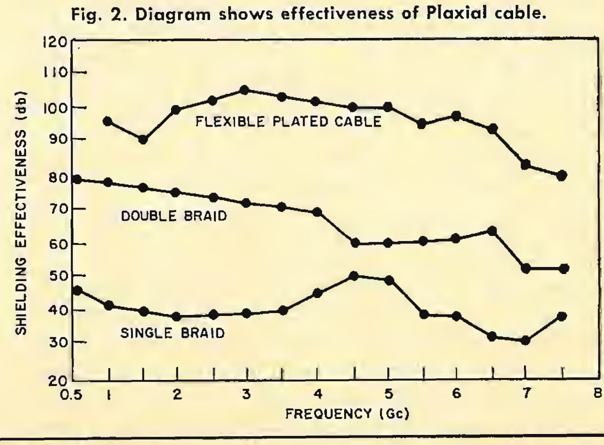
The Plaxial cable design provides a unique advantage for right-angle connectors. Rather than the lossy pin-to-pin contact used in conventional connectors, the Plaxial connector has no more degradation or v.s.w.r. than the straight connector. The cable itself makes the right-angle turn and thus avoids the additional signal loss.

Because this cable's construction is unlike any other, special connectors are required. At this time, Plaxial cable connectors are made only by United-Carr. They also make adapters which will mate with other type connectors made by Cinch and other companies.

In special situations where the Plaxial cable's shield must be externally grounded, a special conductive epoxy should be used to bond a drain wire to the corrugated copper shield since heating can deform the cable and change its characteristics.

Plaxial cable harnesses are being used on the Apollo spacecraft, the Sparrow missile system, and on Army combat helicopters.

Fig. 2. Diagram shows effectiveness of Plaxial cable.



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Connectors For Audio-Frequency Applications

By JOHN H. GOVE, Product Specialist
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Most engineers choose the right connectors but put them together improperly. This article shows the correct method of assembling audio cable connectors.

TO SAY that the most serious problems in audio-frequency termination are the direct result of improper connector selection would be a mistake. Most users appear well schooled in what connector should be employed for a given application—thanks in part to a substantial degree of connector standardization on commercial audio equipment. Perhaps because of significantly simplified connector selection, however, some users often make hasty cable installations without regard to line attenuation, impedance characteristics, cable length, etc. Worse, actual wire and shield termination is far from consistent and often incredibly crude. Frequently the result is the right audio connector badly terminated to the wrong shielded cable.

For these reasons an over-all evaluation of the basic compositions of both shielded and coaxial cables can be important. Shielded audio lines typically contain one or more inner conductors covered by an outer conductive shielding. Coax, on the other hand, consists of two conductors having a single, common axis. Radio-frequency cable line inner conductors are covered with a low-loss dielectric material; the typical interwoven metal braiding tightly wound over the dielectric forms the outer (or second) conductor.

Outer conductors of both r.f. and audio cable types come in many forms. They can be composed of a conductive plastic jacket, a metallic tube, a spirally wound metallized film, or, more commonly, a braid of finely interwoven metal wires. In addition to serving as a return conductor or ground, the outer conductor may "float" and is, therefore, often referred to as the cable shield.

Although application (a.f. or r.f.) clearly dictates which cable to choose, theoretically, at least, all coaxial lines can be referred to as shielded types. The reverse is not true. Coaxial feedlines, for example, exhibit a uniform cross-section at any point along their length. In addition, accurate calculation and measurement of such constants as capacitance per foot, nominal impedance, and attenuation at a specific operating frequency—critical to transmission of r.f. signals—is impossible with conventional shielded audio cables.

Electrical Rating

Microphone connectors, as well as phone or phono plugs and jacks, are generally capable of carrying considerably more power than most applications require. As an example: a typical six-contact microphone connector exhibits the following rating: (1) voltage, 600 V r.m.s. (sea level); (2) current, 3 amperes; and (3) voltage breakdown, 2000 V r.m.s. (sea level). In a typical actual application, though, the applied voltage is below one millivolt and the current flow below 0.1 milliampere. Operational frequency is 10,000 Hz.

Electrical ratings of audio-type connectors are usually based on sea level, room temperature, and non-environmental conditions. Where more critical conditions prevail, standard connectors should be replaced with special environmental-type connectors.

In certain low-impedance circuit networks, connector power ratings of less than one microwatt may be required. It is here that gold plating over highly finished screw-machine, male and female contacts can frequently be recommended. The low ohmic resistance of gold-plated contacts enhances reliability of the circuit and, indirectly, the entire system.

Most audio and microphone connectors are manufactured with metal contacts for soldering wire leads as opposed to crimp (or other mechanical termination) frequently encountered in r.f. applications. Instead of simplifying the process, however, solder techniques appear to vary considerably from one user to the next. It is rare indeed even to find professional service technicians following any "standard" assembly procedure. In spite of this, however, there are several recommended methods which have been developed within the audio connector industry to insure against broken connections, shorts, and a.c. hum inducement. And it's interesting that they have proven themselves admirably in a wide variety of demanding environments over the years.

Single-conductor microphone connectors, for example, use eyelet-type contacts which butt together during mating. The recommended termination procedure is shown in Fig. 1. Note particularly the cutback dimensions, critical when assembly is complete and solder operations are ready to begin. Care should be exercised to prevent accidental nicking or cutting of the braid. Also, excess solder should be avoided; this one tendency among assemblers is easily the key to most termination problems. Heat, too, should be minimized to prevent deformation of the cable core. Once the solder operation is complete, the leads should be trimmed and smoothed into button shapes.

Terminating Multi-Contact Connectors

Shielded audio lines containing more than one connector—such as in push-to-talk microphone installations, some remote p.a. systems, etc.—become somewhat more difficult to terminate. Basically, these should be approached with an eye to the type of individual connector contact employed.

The step-by-step technique illustrated in Fig. 2, for example, demonstrates the recommended method for terminating to connectors of three or more contacts which employ screw-machine contacts with solder-cup tails. Note that when the wire is inserted to its full depth, the conductor should be exposed to the length shown, bringing the insulation to—but not into—the solder cup. All conductors and pigtailed leads should, of course, be pretinned before they are soldered to the contacts; this permits easy entrance to the solder cup and tends to eliminate the possibility of loose strands.

With screw-machine, solder-cup contacts it is essential that both braids and conductor leads be of equal length. Too long a lead will result in buckling and (if assembly is subject to flexing) can cause insulation abrasion resulting in an eventual short circuit. A lead that is too short, or one without adequate slack can be difficult to solder and will have a tendency to tear from the contact as the assembly is flexed.

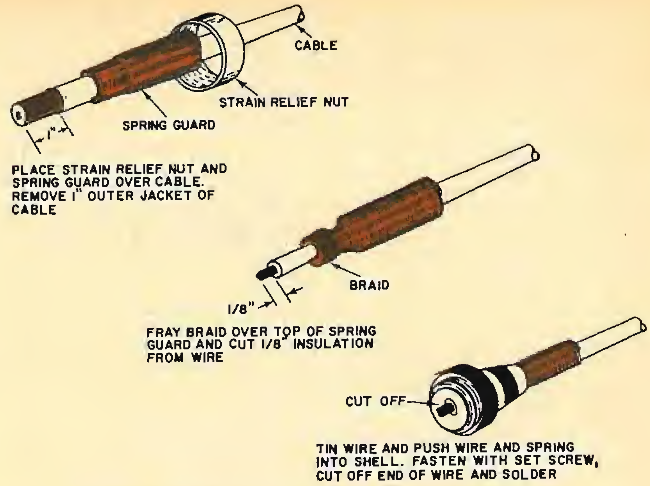


Fig. 1. Assembly procedure for microphone connector.

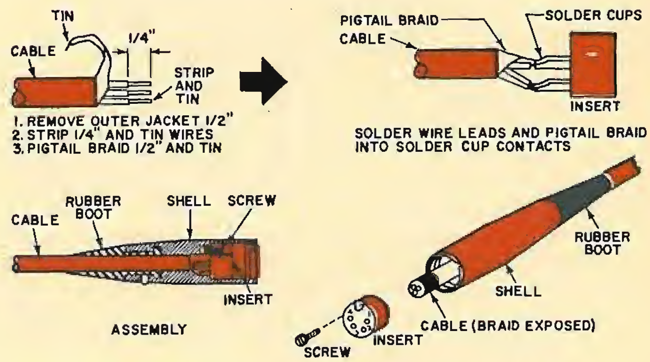
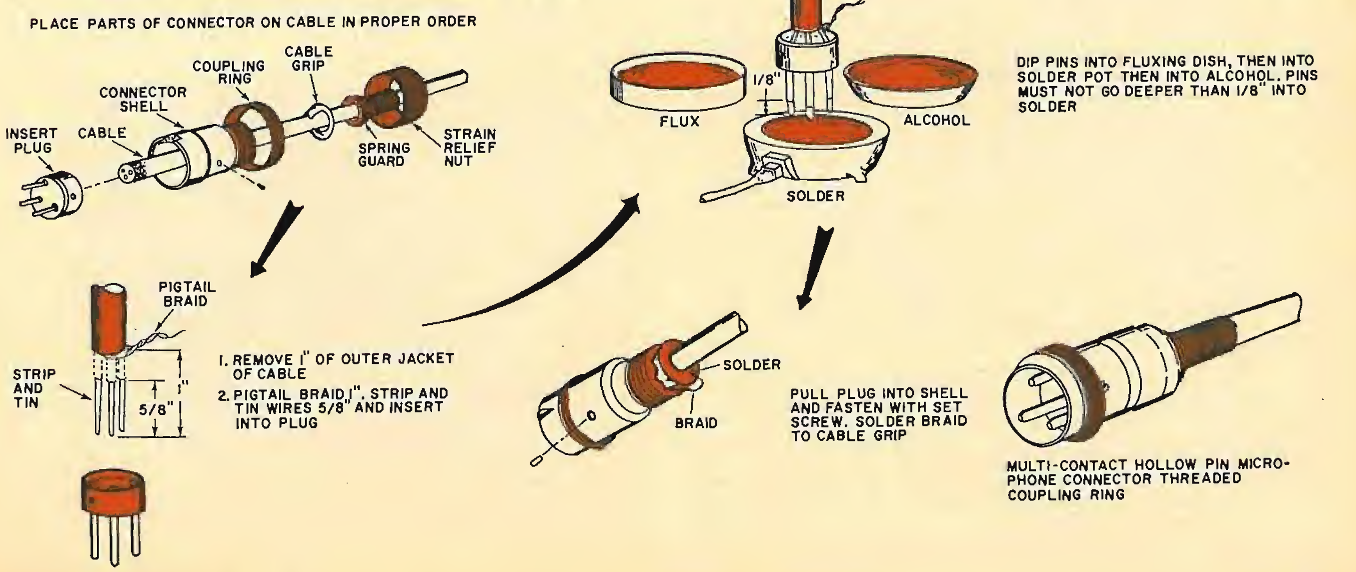


Fig. 2. When assembling multi-contact connectors, the insulation should butt the pins, and the conductors and pigtails be pretinned before placing in the solder cups.

Terminating Hollow-Pin Mike Connectors

Users of the hollow-pin and female sheet-metal-type contact microphone connectors often experience difficulty both in soldering leads and in making a suitable braid ground connection. Use of proper termination techniques, however, can overcome these problems. Before attempting connector assembly work, it is essential to select the most satisfactory materials to do the job. What follows is a description of required materials plus recommended solder-

Fig. 3. Step-by-step method for terminating to a multi-contact hollow-pin transceiver microphone connector.



ing techniques that have been based upon proven results.

For all termination work of this kind, coil and bar solder (for solder pot) should be of 60/40 consistency, indicating 60% tin and 40% lead composition. This formula provides easy flow and strong solder bond. Since the male connector pins have little or no plating on their interior surfaces, it is necessary to use a flux other than rosin and alcohol to get the cleaning action required prior to soldering. A non-corrosive flux offering good wetting action is most often preferred. (We use that supplied by *London Chemical Co.*, Melrose Park, Illinois.) In some cases it is advisable to clean pin interiors with a solution of Copperbrite; this not only cleans but also acts to produce a mild etching on the pin interior, significantly improving solder adhesion. Fluxes are also available in a water soluble formula for easier clean up after assembly.

Refer to Fig. 3. In preparing the conductors for pin plugs, all leads should be stripped back ⅝ inch. This is necessary because adequate space must be provided to allow for escape of air from the pin top. In addition, the bare wire should be pretinned prior to inserting into the pins. Following the sequence shown in Fig. 3, the next operation is that of placing the insert plug's mating face down and inserting the wires. Now actual soldering begins. When using a dish to contain the flux, a felt pad or sponge should be placed on the bottom of the dish to both hold the flux and prevent excessive deposits. With the conductor wires in position, the pins should just touch the saturated pad; only the ends should be fluxed.

After fluxing, pins and leads should be immersed in a solder pot preset for operation at 550°F. The pins should be dipped no more than ⅛" into the molten solder, held for a few seconds and then quickly transferred to a dish of alcohol. Alcohol provides a cooling action and also acts to remove flux residue from the pins.

After pigtailing, the braid may be grounded to the cable grip or terminated to a hollow-pin contact.

How Braiding is Connected

There are a number of recommended methods for terminating a cable shield, some of which have been mentioned earlier in the article. Unfortunately, braid connections seem to cause the most problems. For this reason, what follows are several additional techniques that can be safely employed.

One of the most common methods for terminating shields is to comb the interwoven braid wire and then twist to form a pigtail. The pigtail, which can also be a "drain wire" from a foil-wound shield, is then soldered or crimped to the contact. If this method is employed, the shield should be grounded at one circuit end to prevent an objectionable ground-loop effect. A slight variation would be to solder the pigtailed braid directly to the connector's cable-grip or shell.

Another method frequently employed is to comb the interwoven braid wire, wrap with a bare wire and solder to the shell or spring guard. A fourth technique is where the interwoven braid wire is combed over an auxiliary shell part, a ferrule is pushed over the braid, and the result crimped.

The last method involves the outside metal covering of a metal-jacketed cable (or the outside jacket of a conductive plastic-covered cable). Here, the covering can be mechanically terminated by means of a cable grip.

Power/Shielded-Contact Connectors

In certain applications, both power and signal circuits are combined in a single cable or cable assembly. The cable carrying this combination usually has several insulated power conductors and one more coaxial cable in its bundle. This cable is then terminated to a combination power and shielded contact connector. A typical example of this would be a rack-and-panel connector with 25 power contacts and two coaxial-type shielded contacts.

With this configuration a slightly modified termination procedure should be employed. First, the individual insulated conductors should be stripped and crimped to the connector contacts.

Next, the coaxial cables should be properly stripped and crimped to the center conductor; the braid should be combed and crimped to the shield. At this point all contacts can be inserted into the connector dielectric material. This entire procedure is repeated for the mating connector. (It is important to note that contact termination can be either by crimp or solder, depending upon connector type used.)

With both connector halves securely mated, power contacts are capable of carrying the rated current and voltage values specified The signals carried in the coaxial lines now have an uninterrupted shield, eliminating the possibility of electrical noise or crosstalk pick-up being induced through the connector. This shield, in most cases, is grounded at one end of its length while the other end is left floating. ▲

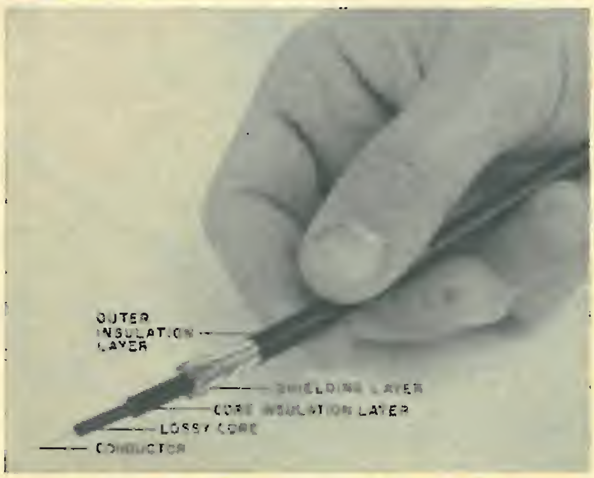
FLEXIBLE FILTERS

IN increasing numbers of aircraft, space vehicles, and commercial applications, extremely tight limitations on space and weight make it virtually impossible to package electromagnetic interference suppression filters into all vital circuits. The "LossyLine" flexible filter was developed by Lundy Electronics & Systems, Inc. as one solution to the space and weight problem.

Typically, flexible filters can be made in several configurations to meet various attenuation and power requirements. For example, in the single-conductor configuration, a low-"Q" r.f. dissipative, flexible, lossy magnetic medium (a high permeability ferrite compound containing alloys of copper, silver, and iron to increase conduction at high and low frequencies) is placed around the conductor. Therefore, all magnetic lines of force pass through the lossy material. In conventional filters, the conductor is wound around the medium.

Some LossyLine filters have helical conductors. In this configuration, a coil of wire is embedded in a cylindrical mold of lossy magnetic material which is isolated and shielded. This form of construction provides higher attenuation per unit length as compared to the single-conductor configuration. In both designs, the shields around the lossy material protect the filter from external interference.

According to the manufacturer, a 1-inch piece of LossyLine has about 100-dB attenuation at 5 GHz. The filter is usable from 10 MHz to 100 GHz; v.s.w.r. is about 1.3-1.4.



CHARACTERISTICS of RG/U TRANSMISSION CABLES

Type	Inner Conductor	Die. Material	Nominal Diameter of Dielectric	No. & Type of Shielding Material	Protective Covering	Nom. O.D. (inches)	Nom. Imp. (ohms)	Nom. Cap. (μμF/ft)	Nom. ATT. per 100 ft MHz	dB	Max. Oper. Volts (r.m.s.)
5A	16AWG, A-4	B-1	0.181	C-2	D-1	0.328	50	28.5	400	5.25	3000
58C	19/0.0071, A-2	B-1	0.116	C-5	D-2	0.195	50	28.5	400	12.60	1900
94A	19/0.0254, A-1	B-4	0.370	C-4	D-4	0.500	50	27.0	400	3.8	7000
115A	7/28 AWG, A-4	B-4	0.255	C-2	D-4	0.415	50	29.5	400	5.2	4000
141A	0.039 in. A-4, A-5	B-3	0.116	C-1	D-4	0.190	50	28.5	400	9.0	1900
142B	0.039 in. A-4, A-5	B-3	0.116	C-2	FEP	0.195	50	28.5	400	9.0	1900
143A	0.059 in. A-4, A-5	B-3	0.185	C-2	D-4	0.325	50	28.5	400	6.0	3000
178B	7/0.004, A-4, A-5	B-3	0.034	C-1	brown FEP	0.075	50	29.0	400	29.0	1000
188 A/U	7/0.004, A-4, A-5	B-3	0.060	C-1	white TFE	0.110	50	29.0	400	20.0	1200
196 A/U	7/0.004, A-4, A-5	B-3	0.034	C-1	TFE	0.080	50	29.0	400	29.0	1000
212	0.0556 in. A-4	B-1	0.185	C-2	D-2	0.332	50	—	—		3000
213	7/0.0296 in. A-1	B-1	0.285	C-3	D-2	0.405	50	30.8	400	4.5	5000
214	7/0.0296 in. A-4	B-1	0.285	C-2	D-2	0.425	50	30.8	400	4.5	5000
215	7/0.0296 in. A-1	B-1	0.285	C-3	armored, D-2	0.475	50	—	—		5000
217	0.106 in. A-1	B-1	0.370	C-4	D-2	0.545	50	—	—		7000
218	0.195 in. A-1	B-1	0.680	C-5	D-2	0.870	50	—	—		11,000
223	0.035 in. A-4	B-1	0.116	C-2	D-2	0.216	50	—	—		1900
225	7/0.0312 in. A-4	B-3	0.285	C-2	D-4	0.430	50	—	—		5000
226	19/0.0254 in A-4	B-4	0.370	C-4	D-4	0.500	50	—	—		7000
280/U	.1144 in. A-1	B-4	0.327	C-2	D-2	0.480	50	27.5	400	3.5	4000
281/U	19/.0378, A-4	B-4	0.500	C-2	D-4	0.750	50	29.0	4000	12.5	4000
9A	7/0.0285, A-1	B-1	0.280	C-2	D-1	0.420	51	30.0	1000	8.6	4000
147	0.250, A-1	B-3	—	C-3	armored PVC	1.937	52	29.5	'3000	7.7	4000
58	20 AWG, A-1	B-1	0.178	C-3	D-2	0.195	53.5	28.5	400	9.5	1900
54 A/U	7/0.152, A-1	B-1	0.178	C-3	polyethylene	0.245	58	26.5	400	6.7	2500
59	22 AWG, A-3	B-1	0.146	C-3	PVC	0.242	73	21.0	400	8.3	2300
124	22 AWG, A-2, A-5	B-4	0.135	C-5	D-4	0.240	73	20.7	—		2300
11A	7/0.0159, A-2	B-1	0.285	C-3	PVC	0.405	75	20.5	400	4.35	5000
12/A	7/0.0159 in. A-2	B-1	0.285	C-3	black PVC	0.475	75	20.5	3000	16.0	5000
59B	0.0230 in. A-5	B-1	0.146	C-3	D-2	0.242	75	21.0	400		2300
65/A	0.1045 in. A-1	B-1	0.680	C-3	D-2	1.000	75	21.5	400	2.8	10,000
140	0.025 in. A-4, A-5	B-3	0.146	C-1	D-4	0.233	75	21.0	400	8.0	2300
179B	7/0.004, A-4, A-5	B-3	0.063	C-2	brown FEP	0.105	75	—	400	21.0	1200
187 A/U	7/0.004, A-4, A-5	B-3	0.060	C-1	TFE	0.110	75	—	400	21.0	1200
216	7/0.0159 in. A-2	B-1	0.285	C-4	D-2	0.425	75	—	—		5000
302	0.025 in. A-4, A-5	B-3	0.146	C-1	D-4	0.233	75	21.0	400	8.0	2300
108	2-Conductor 7/28, A-2	B-1	0.079 over each conductor	C-5	D-1	0.235	78	24.5	—		1000
62	22 AWG, A-3	B-2	0.146	C-3	PVC	0.242	93	13.5	400	6.3	750
62B	24 AWG, A-3	B-2	0.146	C-3	D-2	0.242	93	14.5	400	6.3	750
71B	0.0253 in. A-5	B-2	0.146	C-6	black PVC	0.250	93	14.5	400	6.3	750
210	0.0253 in. A-4, A-5	TFE	0.146	C-1	D-4	0.242	93	14.5	—		750
22B	2-Conductor 7/0.0285 in. A-1	B-1	0.285	C-6	black PVC	0.420	95	16.0	400	10.5	1000
111/A	2-Conductor 7/0.0152 in. A-1	B-1	0.285	C-6	armored, D-4	0.490	95	16.0	400	10.5	1,000
133	21 AWG, A-1	B-1	—	C-3	black PVC	0.405	95	16.2	—		4000
180B	7/0.004, A-4, A-5	B-3	0.102	C-1	brown FEP	0.145	95	15.0	400	17.0	1500
195 A/U	7/0.004, A-4, A-5 (Annealed)	B-3	0.102	C-1 ind. inner common outer	TFE	0.155	95	—	400	17.0	1500
24A	2-Conductor 7/0.0285 in. A-1	2 cores B-1	0.380	C-2 ind. inner common outer	armored PVC	[illegible]	125	12.0	300	3.5	3000
63B	0.0250 in. A-5	B-2	0.285	C-3	D-2	0.405	125	10.0	400	5.5	1000
114/U	33 AWG, A-3	B-2	0.285	C-3	black PVC	0.405	185	6.5	—		1000
114A/U	.007, A-3	B-2	0.285	C-3	D-2	0.405	185	6.8	—		1000

A-1 copper; A-2 tinned copper; A-3 copperweld; A-4 silver-covered copper; A-5 copper-covered steel. B-1 solid polyethylene; B-2 air space polyethylene; B-3 solid tetrafluorethylene; B-4 taped tetrafluorethylene. C-1 silver-covered copper, single braid; C-2 silver-covered copper, double braid; C-3 copper, single braid; C-4 copper, double braid; C-5 tinned-copper, singlebraid; C-6 tinned-copper, double braid. D-1 grey non-contaminating polyvinylchloride; D-2 black non-contaminating polyvinylchloride; D-3 armored polyvinylchloride; D-4 lacquer impregnated fiberglass.

Characteristics & Parameters of Coaxial Transmission Lines

By ALLEN M. KUSHNER* / Manager, Engineering Services, Times Wire and Cable Co.

Coaxial cables are in every sense microwave components. They have an impedance characteristic, power capability, and a distortion requirement.

A COAXIAL transmission line is not just a piece of hardware; in reality it is a microwave component. It's not merely a cable which links two black boxes but a device with an impedance characteristic, a power-handling capability, an attenuation or distortion requirement, a time-delay characteristic, and a specific ability to provide electromagnetic shielding. In addition, coaxial cable must demonstrate these properties over wide frequency and temperature ranges without significant degradation due to exposure to moisture, corrosive environments, and mechanical abuse. Coax is not always the most efficient means of power transfer; but it is easy to handle and is effective over wide bandwidths. A valuable feature of coax is that the outer conductor also acts as a shield.

To achieve maximum efficiency from coaxial cable transmission lines, the engineer must concern himself with: impedance—matching cables to the system or systems to assure maximum energy transfer; energy—loss or gain by radiation or pickup; insertion losses; and time delays. Mechanical considerations enter into his deliberations since tension and frequent flexing cause insertion losses, voltage standing-wave-ratios (v.s.w.r.), and time delays to vary. Temperature and pressure in high altitude and underseas applications also affect insertion loss and power-handling capability; while exposure to moisture and chemicals influence cable life.

Dielectrics

The dielectric is normally a polyolefin, polytetrafluoroethylene, air, or some other substance. While air has excellent electrical characteristics, it is adversely affected by moisture and it does not provide the necessary support to maintain the center conductor in place with respect to the outer conductor. For a cable to have stable electrical characteristics, both factors must be kept constant. Solid dielectrics are not affected by moisture, they are easily bent without changing conductor spacing, and they are not affected by changes in ambient pressure. Offsetting these advantages, however, is the fact that solid dielectrics have the highest electrical losses (Fig. 1). Foamed-plastic dielectric is an effort at compromise between the solid-dielectric approach and the air-spaced cable. In foam-plastic dielectrics, a great many small, individual air spaces are obtained by releasing gas in the molten plastic during the extrusion process. But foamed dielectrics can absorb moisture and cause an increase in attenuation. This can be prevented by encasing the cable in a seamless aluminum tube. By doing so, a 20% or greater reduction in attenuation is achieved over ordinary solid-dielectric cables. It is apparent that we can reduce the attenuation even further by removing as much solid-dielectric material as possible, leaving only the amount needed to support and protect the center conductor. Cables housed in a seamless tubular aluminum sheath with the center conductor supported by minimum solid dielectric have the lowest possible losses for a given cable size. These sheathed cables are classified as semi-flexible since they may be easily bent for installation but not flexed in use.

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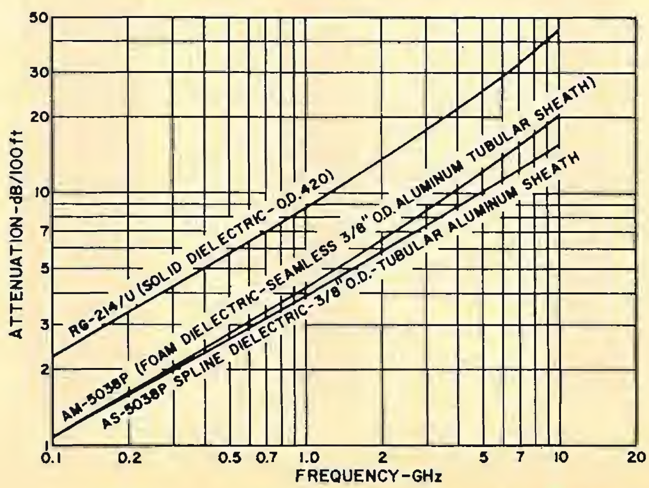
Electrical Length

Usually electrical length is not a crucial dimension but there are applications where the length of a coaxial cable is critically related to other elements and to the system as a whole. Phased array antennas, for example, are functionally dependent on the electrical lengths of their various electrical members.

Time-delay and electrical length are closely related and for many applications the engineer must know the mechanical length of the cable and the velocity of propagation of an electromagnetic wave through the cable (Fig. 2). Velocity is a function of the dielectric material. For example, solid polyethylene dielectric propagates at 66% of the velocity of light, solid Teflon 69.4%, and foamed dielectrics at 81%. Air-spaced cables vary somewhat with velocities of propagation from production run to production run. In solid-dielectric cables, variances of ±1% are usual; foamed dielectrics ±2%, and air-spaced cables ±2%.

Electrical length also changes with cable flexing and frequency. The variation from a normal linear response can be ±1° in short cable lengths, but significantly higher where electrical-length spikes (variations at specific frequencies) occur in long cable runs.

Fig. 1. Cable losses due to dielectric configurations.



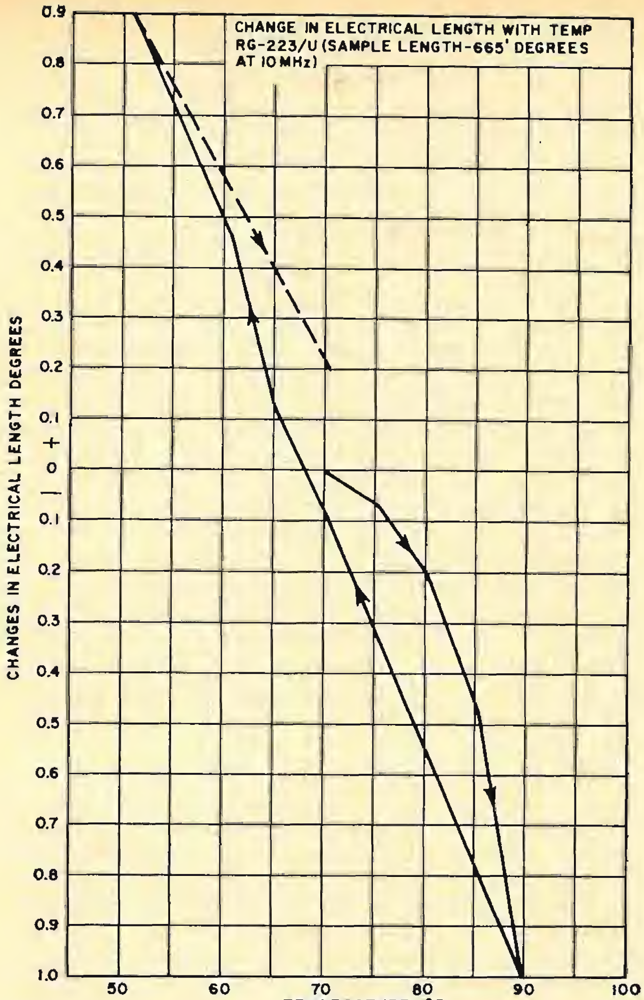


Fig. 2. In coax cables, electrical length changes with temperature. Some cable lengths will vary as much as 1°.

Shielding

Energy pickup and leakage relate to the quality of the cable's shielding. It is important that engineers know how much energy is lost through radiation and how much is picked up from outside sources (interference). The specific application will, of course, spell out tolerances. For example, consider two 20-foot lengths of single-shielded coax cable side by side. A one-volt input to one cable will result in approximately 10^{-4} volt induced in the second cable. This represents an over-all attenuation from cable to cable of 80 dB. This is only an approximation since much depends on the type of installation and surrounding conditions. But it is certainly a correct order of magnitude. In many systems, this much pickup is considered intolerable. Sensitive systems, therefore, use a second shield, triaxial cable, or a semi-flexible cable (aluminum sheath).

Double-shielded cable generally adds about 15 dB more isolation; and triaxial cable about 15 dB more than the double shielded. Cables encased in seamless aluminum sheath are at least 80 dB better than the single-shielded flexible variety. The seamless metal sheath effectively stops energy from escaping or being picked up, except at the connector interface (Fig. 3).

Cables must also match the impedances of the "black boxes" they connect. Compatible characteristic impedances mean efficient transfer of power, no overheating, and no voltage breakdown. Characteristic impedance is a function of conductor size, dielectric material, and form (solid, foam, air); and uniformity of dimensions and velocity of propagation. A 0.1% impedance variation every 3 inches may cause a serious total input impedance variation. Further, these impedance variations occur at discrete frequencies and have bandwidths of approximately 1% (Figs. 4 and 5).

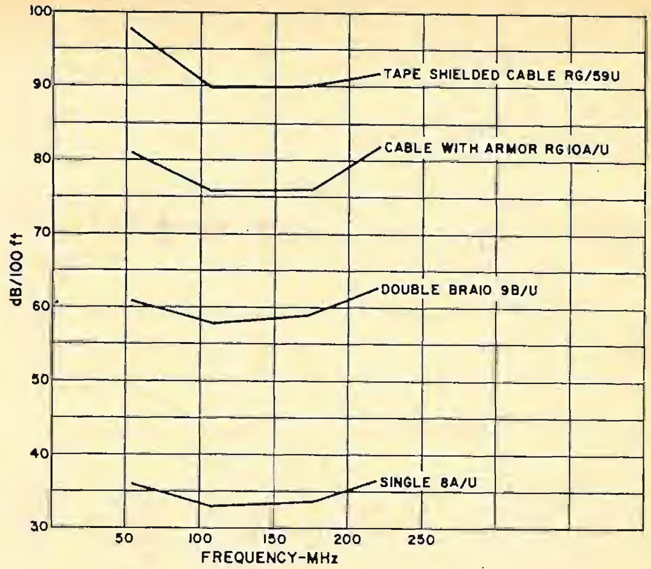


Fig. 3 Relative shielding efficiences for various cables.

The Mechanical Environment

The mechanical environment in which a cable must work is also important in its selection by the designer. A cable chosen solely for electrical characteristics may be highly unsuited for its intended environment; and one picked for environment may have poor electrical characteristics. As it is with most engineering solutions, the result must be a judicious compromise between function and cost. For example, when a flexible cable with a solid conductor is attached to a shock-mounted piece of equipment or otherwise exposed to frequent motion. A stranded center conductor could be substituted. Characteristically, the stranded conductor will have a much longer flex-life than the solid, but the stranded conductor will have a 20% higher attenuation characteristic. The stranded conductor, however, is obviously the only practical approach and represents good engineering compromise.

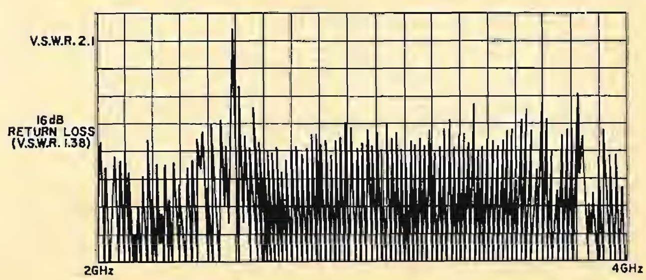
Tension

Past installation practices generally account for cable design characteristics such as tensile strength. Cables of less than ⅛-inch diameter will usually break at about 100 pounds. Sometimes coaxial cables are used to support a component, in which case a strength member, such as a reinforced center conductor, a rated metallic, Dacron, or fiberglass member, is added. Usually, the limitation in cables over ⅛-inch diameter is the method of cable termination.

Moisture and Temperature

Moisture affects the attenuation stability of cables. In

Fig. 4. Variation of v.s.w.r. with frequency. Narrow v.s.w.r. spike (2.1) was caused by bending the cable.



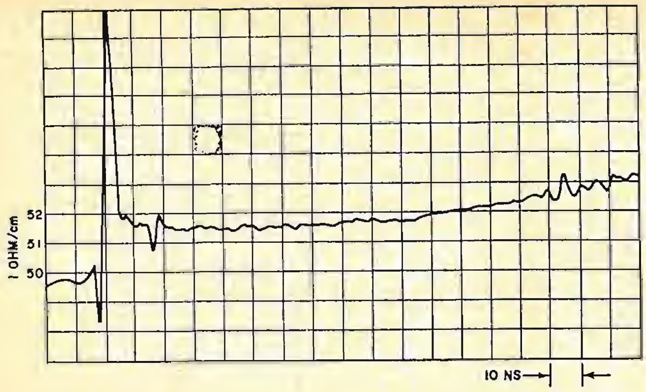


Fig. 5. Impedance changes along the length of a cable.

a 1000-foot cable run it is reasonable to expect one or more pinholes which admit water vapor. Even if there were no pinholes, water vapor might enter the cable through the connector and condense. In the ground, borers or worms may attack the cable jacketing and thus permit water to be admitted. If the dielectric is foam, water vapor will cause an attenuation increase; and if it is solid, the water will eventually corrode the braid or short the connector. Underwater, the problem is even more severe because pressure can push the water through the entire cable length.

Cables sheathed with seamless aluminum are less affected. Sheathed cables that use an air dielectric and a spline construction to protect the center conductor may be pressurized to prevent moisture entry. As long as the cable pressure is higher than the ambient pressure, the conductors will be immune to moisture and corrosion. New techniques developed for flexible and semi-flexible cables permit flooding the outer conductor with a corrosion prevention compound which does not affect the loss-characteristics of the cable. Since flexible cable jackets are not absolutely impervious to ambient moisture, corrosive vapors may also penetrate them and cause an increase in electrical losses with time. Flooding the outer conductor with a moisture-proofing compound is a good solution to this problem. Even aluminum-sheathed cables buried in the earth or otherwise subjected to corrosive ambients must be protected. Standard practice has been to extrude polyethylene jackets onto the aluminum sheaths. In a new manufacturing technique, an additional corrosion preventative layer is added between the sheath and the polyethylene jacket.

Elevated ambient temperatures may cause a permanent change in loss-characteristics by oxidizing the outer conductor. Therefore, attenuation in cables using bare copper and tinned copper conductors increase appreciably at frequencies above 1 GHz. Silver cladding of conductors brings attenuations down to acceptable levels (Fig. 6).

Impedance and Mechanical Environment

Even when the environment does not affect the cable proper, it may affect the cable-to-connector junction. The cable must at all times remain in intimate contact with the connector interface. Tension, flexure, temperature variations—all tend to destroy the contact. Temperature variations often cause some motion or shrinkage of the dielectric. Any such internal motions cause the cable-connector impedance and losses to vary. Sometimes, this kind of situation can go to extremes. A slight motion can, in certain cases, cause a v.s.w.r. of 3.0 and an increase in attenuation of 6 dB. These effects are most pronounced at the higher frequencies where a few thousandths of an inch of motion can mean significant alterations of cable characteristics and therefore significant changes in system performance.

Cable Terminations

All cables must be terminated in some manner. But the manner of termination becomes extremely important and relevant to system operation at frequencies about 1 GHz. Above this frequency, connectors of some kind are employed. But all the factors previously outlined or mentioned as leading to effective, efficient, and economic cable operation may be lost by use of an improper connector or by an improper termination procedure.

Center conductors are normally soldered and sometimes, depending on application, crimped. The UG V-type of braid clamp is usually a part of the outer conductor; or it may be crimped or restrained between the two surfaces of a friction clamp. When using the UG-type clamp, care must be taken to form the outer braid over the clamping ring and to torque the back nut up snugly. With crimp-type devices, the crimp ring location is critical to both the attenuation and v.s.w.r. stabilities of the cable. Center conductor soldering is not really desirable because low temperature dielectrics (such as polyethylene) can overheat and alter the relationship between inner and outer conductor at the connector interface. The cable must seat perfectly in the connector to achieve the designed electrical characteristics. If seating is off by as little as 20 to 30 thousandths, v.s.w.r. at high frequencies may increase. Also, above 1 GHz, cold-solder joints wreak havoc with cable parameters.

There is increasing recognition of the importance and critical character of the interconnecting cable and its termination. The sophistication of the "black boxes" of today is too high to be sacrificed by an inadequate means of energy transfer. There is a trend, therefore, to purchase cable assemblies which have been fully tested for insertion loss and v.s.w.r. over the usable frequency range. Cable manufacturers have developed semi-automated techniques that replace the normal soldering processes as well as the UG-type of clamp and hand tools used in crimping operations. Many types of connectors are now being assembled to cables in a true precision machining process and, in most cases, each and every complete assembly is evaluated by vigorous tests over its entire specified performance range.

Like so many other engineering areas, the design, manufacture, and application of coaxial cables has risen to the level of an independent technology. Nevertheless, it is still difficult to obtain enough cable design information to fully satisfy design needs. One of the best sources is MIL-Handbook-216, available to companies working on military contracts. Manufacturers catalogues are also excellent sources. Some cable fabricators issue technical memoranda from time to time which amplify specific topics of interest to cable users. ▲

Fig.6. A stability test of RG-214/U with silver-clad outer conductor and bare copper-covered RG-217/U.