

IEEE Guide on Shielding Practice for Low Voltage Cables

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of the
IEEE Power Engineering Society**

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Abstract: A concise overview of shielding options for various types of interference and recommendations on shielding practices, including suggestions on terminating and grounding methods, are provided.

Keywords: grounding methods, interference, low voltage cables, shielding practice, terminating methods

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Introduction

(This introduction is not a part of IEEE Std 1143-1994, IEEE Guide on Shielding Practice for Low Voltage Cables.)

A guide on the use of shielding on low voltage cables was proposed in Subcommittee No. 9 of the Insulated Conductors Committee due to the lack of a single source of information on this topic. For example, information on shielding of medium voltage and high voltage cables was available in several documents, but the same could not be said for low voltage cable. Subsequently, a task group was formed to develop the guide.

It quickly became evident to the task group that an extensive amount of information was available on the shielding of low voltage cable. The task group began its work by preparing a bibliography of the information by key topic. These topics eventually made their way into an outline of the guide. A first draft was prepared, and after review and comment, the draft was broken into two sections: Section I, covering shielding; and Section II, providing background information on the need for shielding. This approach was taken because an understanding of the need for shielding helps achieve the purpose of the guide—which is to provide the user with an understanding of cable shielding practices for low voltage cables.

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IEEE Guide on Shielding Practice for Low Voltage Cables

1. Overview

1.1 Scope

This function of this guide on shielding practice for low voltage cables is to inform and familiarize the reader with shielding practice. An overview of shielding practice, systems, and test methods is provided. These tests may not be standardized; however, they are included to inform the reader and provide an overview as to what has been done to characterize shielding.

This guide provides the following:

- An enumeration of sources of electrostatic and electromagnetic interference
- A review of shielding techniques to control electrostatic and electromagnetic interference for varying types of low voltage cable uses for power, control and instrumentation services, including signal and communications cable
- An overview of the functional characteristics of various types of shielding
- Criteria for defining the most favorable techniques to combat interference
- Suggested tests or techniques for measuring shielding effectiveness
- Recommendations on shielding practices, including suggestions on terminating and grounding methods

1.2 Purpose

The main purpose of this guide is to show how shielding can be used to minimize the effects of interference on low voltage cables. The secondary purpose is to familiarize the user with the topic of shielding and provide background information on the need for shielding. Alternate approaches will be given to achieve these purposes.

2. References

This guide should be used in conjunction with the following publications. When the following publications are superseded by an approved revision, the revision shall apply.

ANSI C63.4-1992, Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz.¹

ANSI/NEMA WC55-1992/ICEA S-82-552, Instrument Cables and T. C. Wire.²

ANSI/NEMA WC57-1990/ICEA S-73-532, Standard for Control Cables.

ANSI/NFPA 70-1993, National Electrical Code (NEC).³

EIA/TIA 455-181 (Feb. 1993), FOTP-181, Lightning Damage Susceptibility Test for Fiber Optic Cables with Metallic Components.⁴

IEEE Std 422-1986 (W1994), IEEE Guide for the Design and Installation of Cable Systems in Power Generating Stations.⁵

IEEE Std 518-1982 (Reaff 1990), IEEE Guide for the Installation of Electrical Equipment to Minimize Electrical Noise Inputs to Controllers from External Sources (ANSI).⁶

IEEE Std 525-1992, IEEE Guide for the Design and Installation of Cable Systems in Substations (ANSI).

IEEE Std 576-1989, IEEE Recommended Practice for Installation, Termination, and Testing of Insulated Power Cable as Used in the Petroleum and Chemical Industry (ANSI).

IEEE Std 690-1984 (W1994), IEEE Standard for the Design and Installation of Cable Systems for Class 1E Circuits in Nuclear Power Generating Stations.⁷

IEEE Std 789-1988 (Reaff 1994), IEEE Standard Performance Requirements for Communications and Control Cables for Application in High Voltage Environments (ANSI).

IEEE Std C62.41-1991, IEEE Recommended Practice for Surge Voltages in Low-Voltage AC Power Circuits (ANSI).

NEMA WC-61-1992, Transfer Impedance Testing (Modified MIL-C-85485 Test Method).⁸

3. Definitions

3.1 absorbing clamp: A portable testing device that is effective at detecting electromagnetic radiation. The absorbing clamp has a great capacity for electromagnetic compatibility cable measurements in the frequency range of 30–1000 MHz, and is non-destructive to the specimen. The test fixture clamps over the sample cable and inductively detects signal leakage.

3.2 aeolian flexure: Flexure of cables caused by the wind.

3.3 bonded sheath: Cable shielding that is bonded to a plastic jacket by means of a plastic coating on the shielding.

¹ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.

²ANSI/NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

³ANSI/NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

⁴EIA/TIA publications are available from Global Engineering, 1990 M Street NW, Suite 400, Washington, DC, 20036, USA.

⁵IEEE Std 422-1986 has been withdrawn; however, copies can be obtained from the IEEE Standards Department, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁶IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

⁷IEEE Std 690-1984 has been withdrawn; however, copies can be obtained from the IEEE Standards Department.

⁸NEMA publications are available from the National Electrical Manufacturers Association, 2101 L Street NW, Washington, DC 20037, USA.

3.4 braided shield: Cable shield that consists of groups of metallic strands, one set woven in a clockwise direction and interwoven with another set in a counter-clockwise direction. Braided shields provide superior structural integrity, while maintaining good flexibility and flex life.

3.5 broadband (electrical noise, interference): Electrical noise that contains energy covering a wide frequency range. *Contrast with:* **narrowband electrical noise.**

3.6 capacitance: The ratio of a conductor's electrostatic charge to the potential difference between conductors (required to maintain that charge).

3.7 capacitive coupling: *See:* **electrical coupling.**

3.8 chop: A sudden cessation of the flow of arc current during circuit interruption.

3.9 combination effect: An electric disturbance not caused by one of the following mechanisms, but to some extent by a combination of them: normal-mode noise (transverse or differential), common-mode noise (longitudinal), and common-mode to normal-mode conversions. *See also:* **common-mode noise (and longitudinal); normal-mode (transverse or differential).**

3.10 common-mode noise (and longitudinal): The noise voltage that appears between each signal conductor to ground caused by electrostatic induction and/or electromagnetic induction.

3.11 continuous wave (CW): A sinusoidal wave that has reached a steady state value. Continuous wave noise would be noise at a single frequency (e.g., 60 Hz “hum”).

3.12 corner frequency: The frequency at which the skin depth is equal to the thickness of the shield.

3.13 Crawford cell: *See:* **transverse electromagnetic (TEM) cell**

3.14 crosstalk: An electromagnetic field in the space surrounding a cable circuit created by an electrical signal. This field induces currents and electromotive forces in other circuits located close enough to the disturbing cable circuit to be affected.

3.15 cutoff frequency: The frequency below which a waveguide fails to transmit a signal in the differential mode.

3.16 dropouts: A subset of gain hit, dropouts are a loss of data caused by a decrease in signal, usually greater than 12 dB and lasting longer than 4 ms. Dropouts interrupt the information flow between two modems. Furthermore, even when the signal returns, some modems will take additional time to recover. Experience suggests that dropouts occur less often than the other types of transients. However, each dropout causes modem errors. *See also:* **gain hit or change; phase hit or change.**

3.17 electrical coupling: Electrical charges in conductors of a disturbed circuit formed by electrical induction. Since the ratio of a conductor's electrostatic charge to the potential difference between conductors (required to maintain that charge) is the general definition of capacitance, electrical coupling is also called capacitive coupling. Its magnitude depends on the cable geometry and the cable insulation properties: dielectric constant and dissipative losses. Magnetic coupling introduces electromotive force in the disturbed circuit due to magnetic induction. This electromotive force opposes the change in the current that generated it. *Syn:* **capacitive coupling.**

3.18 electric field: The field surrounding a charged object. *See also:* **magnetic field.**

3.19 electrical noise: Unwanted voltage or current, or both, that appears in an electrical system. For given system characteristics, electrical noise may or may not impair proper functioning. The unwanted noise can have effects that range from totally undetectable to system malfunction or even damage or destruction.

3.20 electromagnetic compatibility (EMC) (of an electrical system): An electrical system's ability to perform its specified functions in the presence of electrical noise generated either internally or externally by other systems. The goal of EMC is to minimize the influence of electrical noise.

3.21 electromagnetic field: The energy field radiating from a source and containing both electric and magnetic field components. *See also:* **electric field; magnetic field.**

3.22 electromagnetic induction (EMI): *See:* **electromagnetic interference.**

3.23 electromagnetic interference (EMI): Electromagnetic energy from sources external or internal to electrical or electronic equipment that adversely affects equipment by creating undesirable responses (degraded performance or malfunctions). EMI can be divided into two classes: continuous wave (CW) and transient. *Syn:* **electromagnetic induction**. *See also:* **continuous wave (CW); electrical noise; transient electrical noise**.

3.24 electromagnetic pulse (EMP): A high-energy electromagnetic pulse initiated by a nuclear reaction (e.g., upper atmospheric detonation of a nuclear weapon).

3.25 electrostatic discharge (ESD): Electrical discharges of static electricity that build up on personnel or equipment, generated by interaction of dissimilar materials.

3.26 foil shield: A thin, self-supported, metallic tape wrapped longitudinally or spirally around the cable core, and intended to act as a shield against EMI.

3.27 gain hit or change: A sudden increase or decrease in amplitude, usually not exceeding 12 dB of the received signal. Gain hits last at least 4 ms but may continue for hours. (Example: Modems that use amplitude modulation carry the information by the level of the signal, and a gain hit may look like data to these modems.) *Contrast with:* **impulse noise**.

3.28 galvanic action: Noise currents due to the junction or thermal potentials resulting from a combination of different metals. This current can be a part of the disturbing current passing through the conductors or shield of the signal cable.

3.29 harmonic distortion: Nonlinear distortion that appears as harmonics of a single-frequency input.

3.30 hum test: Measures low-frequency shield effectiveness against electric field coupling (dc to 100 kHz).

3.31 impulse noise: A component of the received noise signal that is much greater in amplitude than the normal peaks of the message circuit noise, and that occurs as short-duration spikes or energy bursts.

3.32 induction zone (of EMI): The area where the distance to the source of electromagnetic interference is less than the wavelength of the interference. In the induction zone the circuit or system will be affected by transverse or longitudinal fields. *Contrast with:* **radiation zone (of EMI)**.

3.33 intermodulation distortion: Nonlinear distortion of multiple-frequency inputs that shows up as harmonics of the individual inputs plus the sum and difference products of the inputs and their harmonics.

3.34 magnetic coupling: *See:* **electrical coupling**.

3.35 magnetic field: The field surrounding any current-carrying conductor. *See also:* **electric field**.

3.36 narrowband electrical noise: A disturbance at a single frequency or in a narrowband of frequencies about a single frequency.

3.37 nonlinear: The amplitude of the output is not linearly proportional to the input. If a true sine wave were transmitted through a nonlinear device, its shape would be changed.

3.38 nonlinear distortion: The generation of new signal components not present in the original transmitted signal.

3.39 normal-mode (transverse or differential): The voltage that appears differentially between two signal wires and that acts on the circuit in the same manner as the desired signal.

3.40 phase hit or change: A sudden change in the received signal phase (or frequency) lasting longer than 4 ms. Since two common modulation techniques for high-speed data transmission are phase and frequency modulation, phase hits cause errors by looking like data. *See also:* **dropouts; gain hit or change**.

3.41 radiation zone (of EMI): The area where the distance to the source of electromagnetic interference is greater than the wavelength of the interference. In the radiation zone, the circuit or system will be affected by plane waves. *Contrast with:* **induction zone (of EMI)**.

3.42 surge impedance: The impedance of an electrical circuit under surge conditions (which may differ significantly from the impedance of a circuit under steady state conditions).

3.43 transient electrical noise: An electrical disturbance that occurs in a time interval separated from other interferences. Transient electrical noise may be superimposed on other transients or on continuous waves. Transient electrical noise may be of several types, such as pulse, step, or oscillatory. It may occur as a response to a network to one of these types. Sources of transient affecting low voltage circuits are impulse noise, power switching, or lightning.

3.44 transverse electromagnetic (TEM): A wave that propagates with the electric field and magnetic field vectors transverse (at right angles to) the direction of propagation. (At high frequencies waves may also propagate in transverse electric [TE] or transverse magnetic [TM] waves that bounce back and forth between guiding structures such as waveguides.)

3.45 transverse electromagnetic (TEM) cell: A rectangular transmission line segment that produces a transverse electromagnetic (TEM). Cables, cable/connector assemblies, and/or electronic devices are placed inside the cell. Alternatively, the cell can be used as a detector to measure radiation emitted by a cable or device inside the cell. *See also: absorbing clamp. Syn.: Crawford cell.*

Section I: Shielding

4. Nature of interference

4.1 Definition of sources

For the purpose of this guide, electrical noise is defined as an unwanted electrical signal that produces undesirable effects in the circuits of the system in which it occurs. As such, it may cause malfunctioning of electrical equipment.

In its simplest terms, before an electrical noise problem can exist, three basic elements are required:

- a) A source of noise
- b) A circuit sensitive to the noise
- c) A means of interaction between source and circuit

The solution to this three-element problem is obtained by controlling any one of the three elements. This means that if an installation is malfunctioning because of electrical noise, it can be made to work correctly by suppressing the noise at its source, eliminating the way the noise is getting into the system, or making the equipment insensitive to the noise. The possibility of eliminating the source or the sensitive circuit should also be considered.

4.2 Nature of interference

The source of interference may be anywhere; it may be produced within the system containing the sensitive circuit or outside of the system. It may be man-made or natural. The effect on the circuit is somewhat independent of the origin of the interference, but the protection techniques applied will depend on whether the designer controls the source or treats the source as a part of the operating environment of the circuit.

4.3 Source-circuit interaction

For a circuit to be affected by interference from a source, the electromagnetic waves produced by the source must interact with elements of the sensitive circuit. This interaction involves propagation of waves through free space or along guiding structures (such as wires, transmission lines, and cables) between the source and the system. Upon arriving at the system, coupling of the electromagnetic fields to elements of the system induces currents, voltages, and electromagnetic fields on the system. These currents, voltages, and fields must then penetrate the system to reach the internal sensitive circuit of concern.

These three aspects of interaction are particularly important to systems that have natural or deliberate shields. The shields can be used to separate the interaction problem into external and internal interaction. The propagation, coupling, and penetration apply to both the external interaction problem and to the internal interaction problem.

4.3.1 Propagation

Propagation of a space wave occurs if the source launches the wave into a medium, such as air or vacuum. Radio and radar transmissions, distant lightning, and other atmospheric noise are examples of space waves that may interfere with systems that do not wish to receive them. Guided waves propagate along conductors, such as power lines and interconnecting cables. Switching transients, 60 Hz “hum,” and lightning transients are examples of guided waves that propagate to the system along power and communication lines. (Guided waves have been called “conducted interference” and space waves have been called “radiated interference” in the literature.)

4.3.2 Coupling

Coupling is the interaction of electromagnetic fields with conductors to induce currents and voltages on the conductors. Magnetic fields parallel to a conducting surface induce a current density on the surface; electric fields perpendicular to a conducting surface induce a charge density on the surface. Time-varying electric fields induce current on the surface of a conductor or, if the electric field is produced by the voltage on another conductor, the conductors are said to be capacitively coupled. Time-varying magnetic fields induce voltages in loops. If the magnetic field is produced by the current in another conductor, the coupling is described as mutual inductance or inductive coupling. (The coupled currents and voltages have been improperly called “radiated interference” in the literature.)

4.3.3 Penetration

Penetration is the entry of the electromagnetic interference into the system of concern. It is presumed that this system is surrounded by some form of barrier or boundary that separates it from the outside. In protected systems, the barrier might be a metal case or housing with openings for air flow, light transmission, and wires for energy supply and data input and output. Interference penetration may occur on these wires from electromagnetic fields that enter through the openings and from fields that diffuse through the metal walls of the housing.

4.4 Types of interference

Interference may be characterized as transient, repetitive, or narrowband.

4.4.1 Transient interference

Transient interference is an individual electromagnetic event, such as a lightning flash, a switching transient, or an electrostatic discharge. A transient is completely characterized by its waveform (amplitude as a function of time). For many practical purposes, transients may be characterized by their peak amplitude, rate-of-rise, energy, charge transfer, or other property that affects the sensitive circuit. Transients tend to be a problem for broadband systems, such as digital electronic circuits and computer controlled systems.

4.4.2 Repetitive interference

Repetitive interference is an electromagnetic wave that is repeated periodically (or nearly periodically). Repetitive interference is characterized by its waveform. For many practical purposes, repetitive interference may be characterized by its peak amplitude, fundamental frequency, and harmonic or spectral content. Repetitive interference may degrade analog circuit performance by reducing the signal-to-noise ratio, particularly if the operating frequency coincides with a harmonic of the interference. It also degrades digital circuit performance if the amplitude is large or if the repetition frequency coincides with the digital circuit operating frequency.

4.4.3 Narrowband interference

Narrowband interference is a nearly sinusoidal wave or the sinusoidal equivalent of broadband noise in a narrow bandwidth. Narrowband interference is completely characterized by its amplitude, frequency, and bandwidth or by its power spectral density and frequency. Narrowband interference affects the signal-to-noise ratio of a radio receiver, and it may similarly affect analog circuits operating at low levels. If large enough, it may also interfere with digital circuit operation.

Broadband sources of interference, such as transients and repetitive sources, have often been characterized by their narrowband spectral density. This characterization is useful for specifying the interference environment for narrowband analog systems. For digital circuits and systems, the narrowband spectral density is less useful, because it does not define the properties of transients and repetitive interference that are most likely to affect digital circuits—namely peak value, energy or action, charge transfer, and rate-of-change.

Narrowband spectral density has also been used to characterize broadband noise produced by random processes such as thermal noise, shot noise, and atmospheric noise. These are rather weak sources that are of interest primarily to designers of sensitive communication equipment and high-gain amplifiers, for which the narrowband spectral density is appropriate.

4.5 Sources of electromagnetic interference (EMI)

When electromagnetic energy from sources external or internal to electrical or electronic equipment adversely affects that equipment by creating undesirable responses (degraded performance or malfunctions), the electromagnetic energy is defined as electromagnetic interference or induction (EMI), and the adversely affected equipment is said to be susceptible to EMI.

4.5.1 Natural sources of EMI

The natural sources of electromagnetic interference are the earth's magnetic field, discharges in the atmosphere, such as lightning, and radiation from outside the earth's atmosphere, such as solar flares.

4.5.2 Man-made sources of EMI

For the purpose of completeness, it should be noted that sometimes man-made sources can be broken into two categories defined by the distance to the source of interference.

- *Induction zone*: When the distance to the source is less than the wavelength of the interference. In the induction zone the circuit or system will be affected by transverse or longitudinal fields.
- *Radiation zone*: When the distance to the source is greater than the wavelength of the interference. In the radiation zone the circuit or system will be affected by plane waves.

4.5.2.1 Electrical equipment and wiring

- a) *Rotating machinery*: The brush and commutator action of dc motors or generators and sliding contacts from slip rings in synchronous motors and generators produce repetitive interference.
- b) *Transformers*: Corona or partial discharges (pd) can occur in the high voltage winding insulation bushings, and voltage tap terminals. The transformer's core and windings have an inherent electromagnetic field.
- c) *Switching*: Sudden changes in circuit impedance due to switching cause current and voltage transient interference.
- d) *Dimmers*: Dimmers usually produce high levels of repetitive interference. Silicon-controlled rectifiers produce an especially high level of interference.

4.5.2.2 Discharge-type lighting fixtures

Fluorescent lighting fixtures, especially the slim-line type, produce repetitive EMI. The arcing process taking place during the lamp operation produces an electromagnetic field around the lamp and in the surrounding environment. The lamp and ballast feed conducts interference back into the branch circuit and the wiring system supplying the power.

4.5.2.3 Other sources

Some electronic equipment, such as diathermy and microwave ovens, produce considerable narrowband interference. Other miscellaneous sources are ultrasonic devices, ignition systems, and broadcasting transmitters (these include radio, television and airport radar, and carrier frequency currents). Other sources are power and communication systems, industrial radios, and telephone dialing and electronic switching equipment.

4.6 Electrical noise produced by power processing and control

4.6.1 Arcs or sparks

Current chopping in electrical contacts causes discharges known as arcs or sparks. During circuit interruption, arc current will suddenly cease to flow. This step change in current is an electrical noise transient. Peak voltages of the arc are a function of the contact gap breakdown, which depends upon number and size of the contact gaps, contact material, and surrounding atmosphere. Sliding contacts in ac motors and dc motor commutators also create showering arcs and repetitive interference.

4.6.2 Solid-state switching devices

Power line voltage transients can be initiated by switching power loads. For example, closing a switch to a resistive load when the voltage is not zero allows the current to rise to the normal value as rapidly as the circuit constants will permit, thereby producing a voltage transient.

Solid-state switching devices switch faster than mechanical contacts. Because of their speed, a common use is to control power by repeated switching operations (every half-cycle is common). This results in repetitive electrical interference.

4.6.2.1 Resistive loads

Phase control for lamp dimmers or heater controls are solid-state switching devices and can be a source of electromagnetic noise.

4.6.2.2 Inductive loads

Silicone-controlled rectifier (SCR) drives are solid-state switching devices and can be a source of electromagnetic noise. The noise is produced when the current flowing in one line must suddenly stop and be established in another line.

4.6.2.3 Circuit switching

The switching on and off of multispeed motors, capacitor banks, transformers, distribution circuitry, and fluorescent lights can be sources for electromagnetic noise.

4.6.3 Faults

Faults interrupted by current limiting fuses, arcing, and restrikes on switching can create transients and electromagnetic noise.

4.6.4 Welding and power lines

Power-frequency electric and magnetic fields can result from resistance welding machines and power lines.

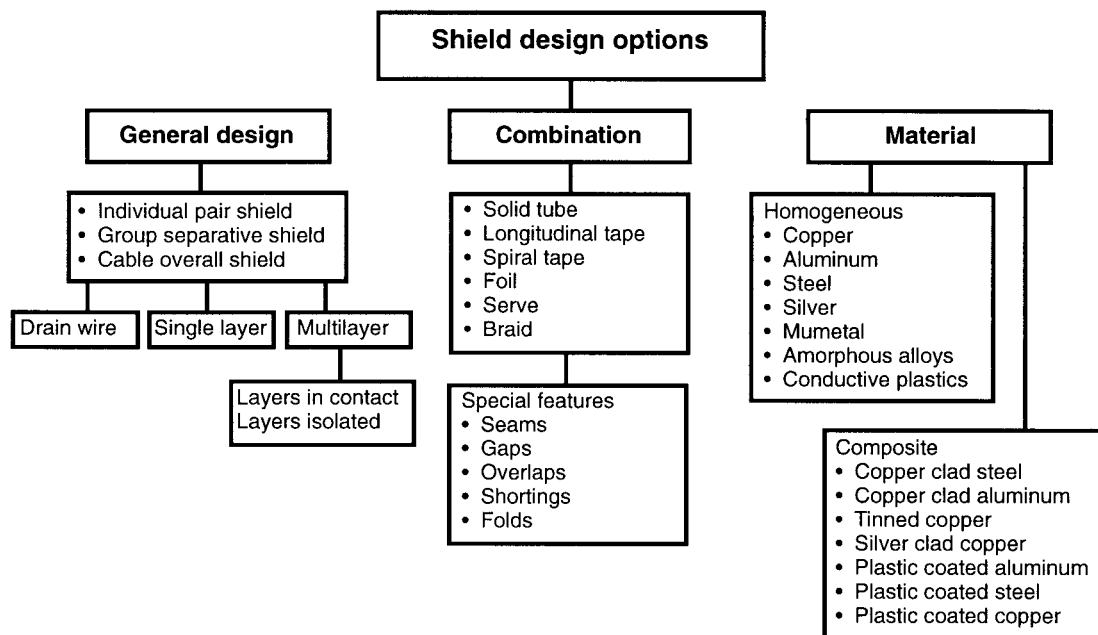
4.6.5 High voltage equipment

Corona or partial discharges occur when the electric field on the surface of an object, usually a conductor, exceeds the ionization potential of the surrounding dielectric medium (gas, liquid, solid, or combinations thereof). This causes the immediate surroundings to become ionized, producing interference. This generally occurs at cable splices, terminations, and gaps between live conductors.

5. Types of cable shielding

5.1 Introduction

Figure 1 shows the many types of shields used for cables. These differ in design and material composition and therefore have different shielding properties.



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Figure 1—Electrical cable shield design options

The cable shield is a part of an electromagnetic barrier that separates the shielded circuits from the external sources of EMI (or confines EMI effects to the shielded volume). An electromagnetic barrier is a closed surface made up of shields and other elements to exclude (or confine) electromagnetic waves propagating in space or guided along conductors. The barrier may be made up of metal or conductively coated equipment cases, interconnecting cable shields, filters or surge arresters on wires that penetrate the shield, and mesh or waveguides (below cutoff frequency) at ventilation openings. In a protected system, the barrier is everywhere sufficiently impervious to guided and space waves so that EMI sources outside the barrier do not degrade the performance of the protected system.

A perfectly conducting cylindrical shell that is closed at both ends would allow no external electromagnetic effects to affect circuits inside the shell. Since it is a closed shell, there are no apertures or conductors through which electromagnetic fields can penetrate and interact with the internal conductors. Because the cylindrical shell is a perfect conductor, no fields diffuse through the shell.

Practical cable shields are made of braided wires and tapes that have apertures through which electromagnetic fields may penetrate. Carriers in braided wire shields shuttle between the outer surface and the inner surface in the woven braid; this allows current induced at the outer surface to be carried to the inside of the shield where it can interact with the internal circuits. Spiral-wound tape shields may behave as solenoids when the turn-to-turn contact is poor. Tape shields are wrapped with an overlap that may act as one aperture. Practical shields are made from finitely conducting materials that may allow some fields to diffuse through the shield material.

Cable material characteristics and cable construction techniques affect EMI shielding effectiveness and frequency dependence. For instance, with a braided shield, the braid weave angle and optical coverage affect the amount of leakage. Tape shields allow leakage at the tape overlaps. Foil shields with interlocking slots may also exhibit leakage at very high frequencies. Apertures are also a factor in shielding effectiveness.

The coupling into the interior of a coaxial cable through an isolated aperture in the shield is shown in figure 2. Both electric and magnetic fields can couple through the aperture; thus the presence of shield apertures leads to capacitive and inductive coupling between the exterior and the interior of the cable.

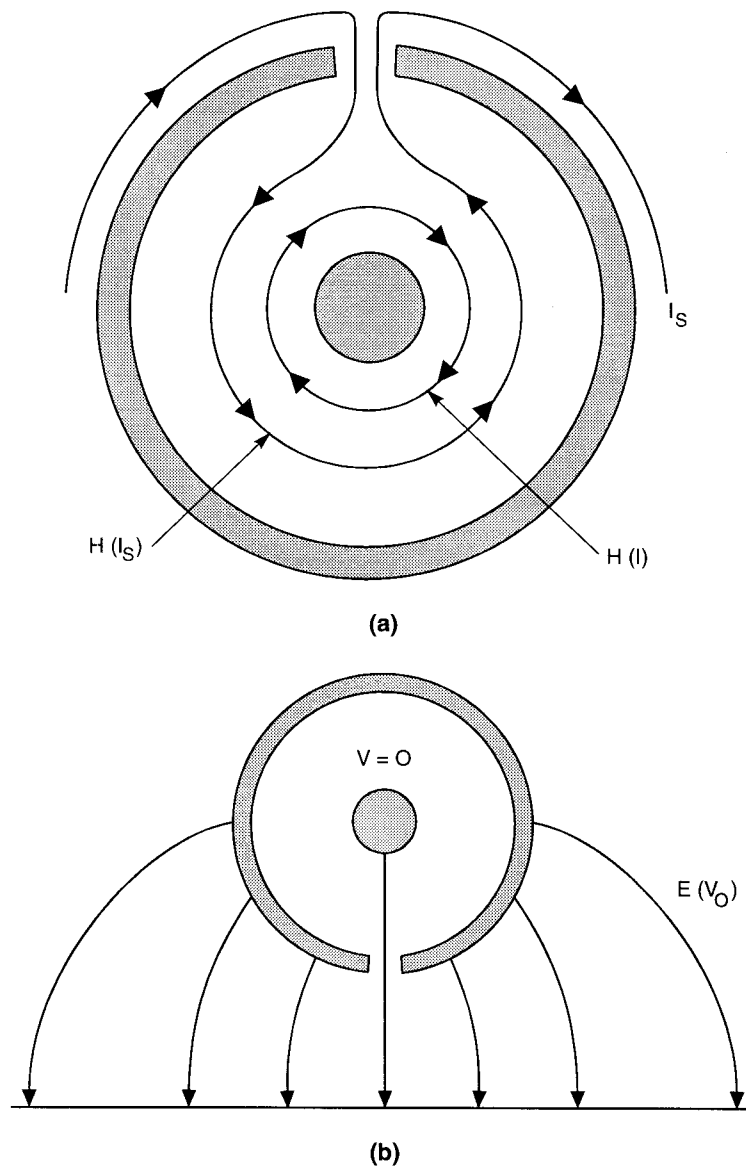


Figure 2—Electrical and magnetic field coupling through aperture in coaxial cable shield
(a) Magnetic coupling, (b) Electrical coupling

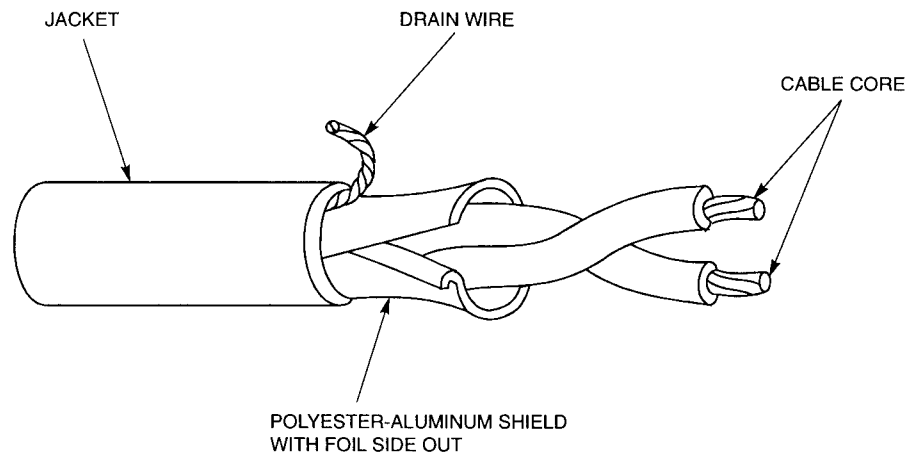
5.2 Solid tube shield

A solid wall tube shield displays the most favorable high-frequency shielding properties. Its performance is a direct function of skin effect and the diffusion transfer processes. The greater the shield conductivity, magnetic permeability, and thickness, the better the shielding properties.

Despite their excellent shielding characteristics, tubular shields have limited use where flexibility is a requirement. They are normally used in permanent installations.

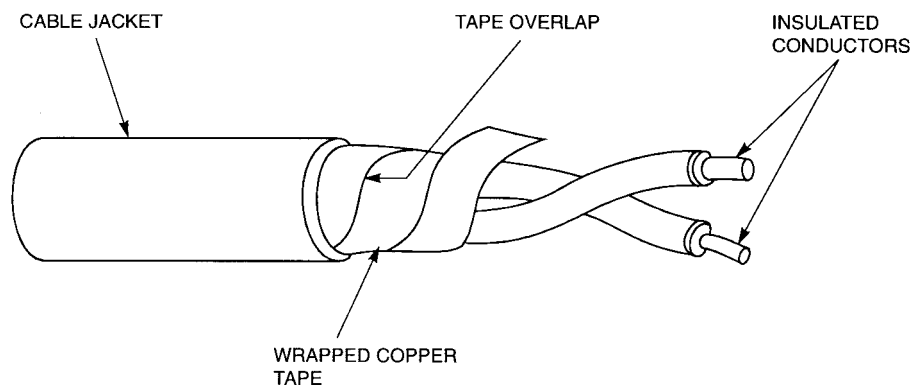
5.3 Single layer foil shield with drain wire

A foil shield is a thin, self-supported metallic tape, wrapped longitudinally (figure 3) or spirally (figure 4) around the cable core. Usually, aluminum foil is used, although some cables use copper, magnetic alloys, and conductive plastics. Occasionally, metallized film has been used.



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Figure 3—Longitudinally applied foil shield

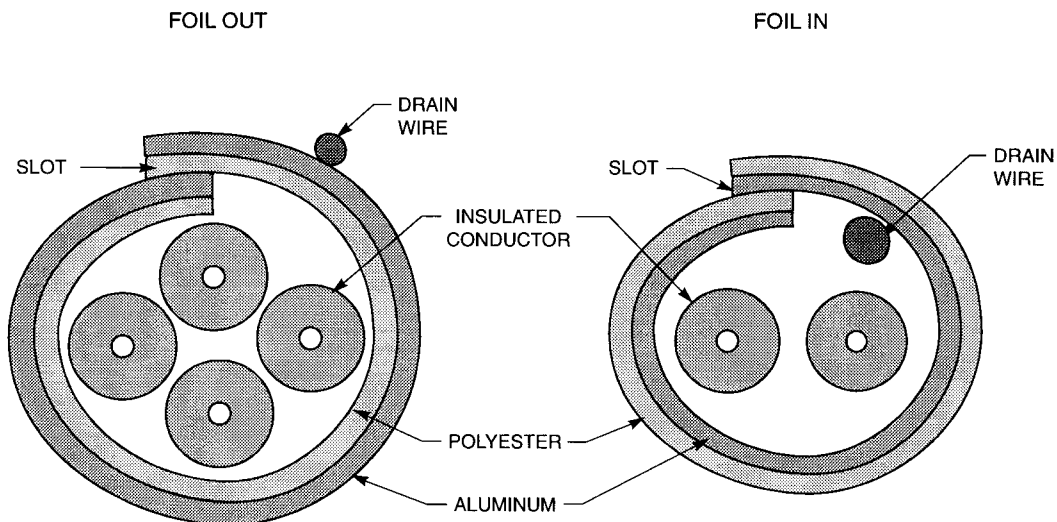


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Figure 4—Spirally applied foil shield

5.3.1 Aluminum-foil shield

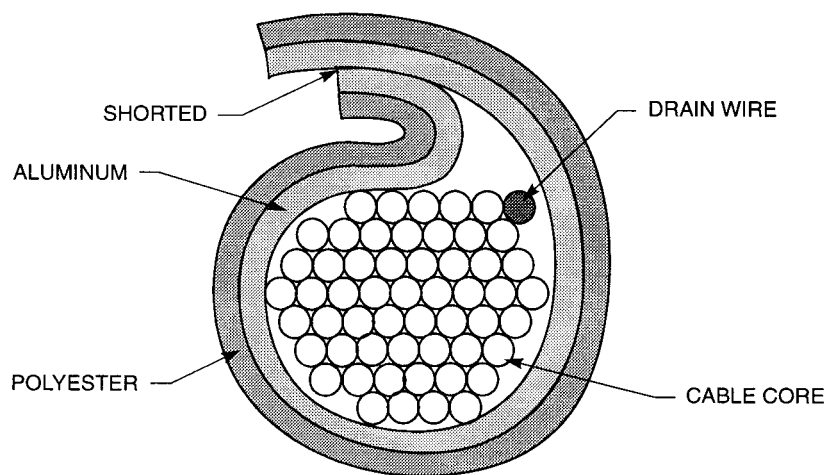
To provide the necessary mechanical strength, the foil is usually bonded to the cable insulation or laminated to a polyester tape, or both. Figure 5 shows the use of a drain wire inside or outside the shield. Since the dc resistance of the foil is large, a drain wire is used to facilitate shield termination.



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Figure 5—Slot in film-foil shield with overlap

When the plastic layer on the foil shield prevents metal-to-metal contact at the overlap, it creates a slot that allows signal leakage to occur. This slot is shown in figure 5. A special shorting-fold technique reduces the signal leakage through the slot (figure 6) [B52]. A low wrap angle also improves foil-shield high-frequency performance.



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Figure 6—Shorting-fold design for better high-frequency performance

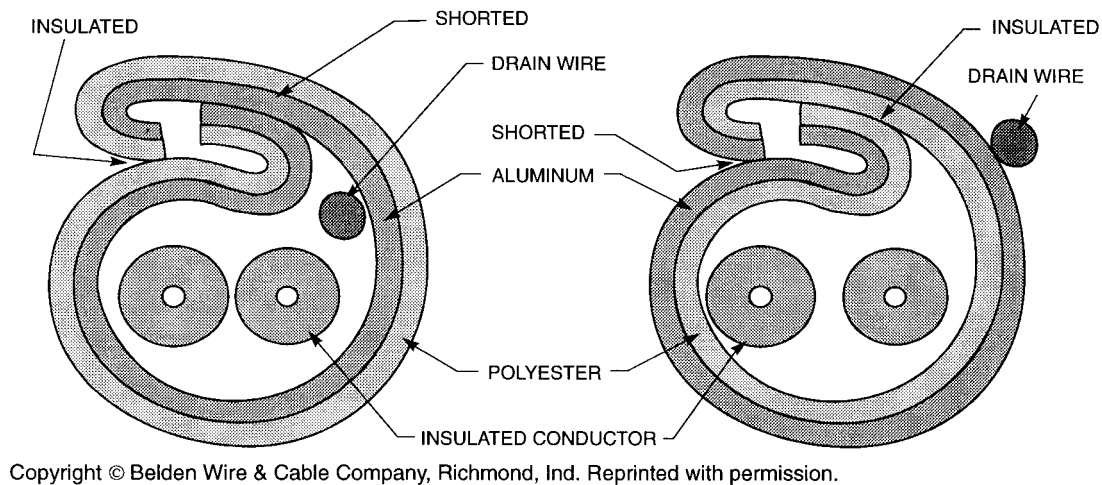
5.3.2 Metallized plastic shields

A metallized plastic film, made by vacuum depositing 2–5 μm of metal on a plastic film, can be used as a shield. Such a shield is useful where only low-frequency electric field protection is needed, and where the cable is not subject to flexing or corrosive environments.

Such a thin metal coating cannot carry much current and does not provide much protection against induced longitudinal currents. The resistance of such shields is on the order of $0.1 \Omega/\text{m}$ and its cutoff frequency is on the order of 300 MHz. Because the metal film is very thin, it has little mechanical strength, and it is easily cracked, scratched, or spalled by mechanical flexure. It is also easily damaged in a corrosive environment.

5.4 Multilayer shield with drain wire

A shorting-fold shield (figure 7) has reduced shielding at high frequencies because of contact resistance in the shorted fold, which acts as a slot at higher frequencies. Therefore, to achieve high shielding efficiency, multilayer shields are used. Very good shielding efficiency is achievable by combining, in a proper way, foil and braid layers.



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Figure 7—Additional shorting-fold designs

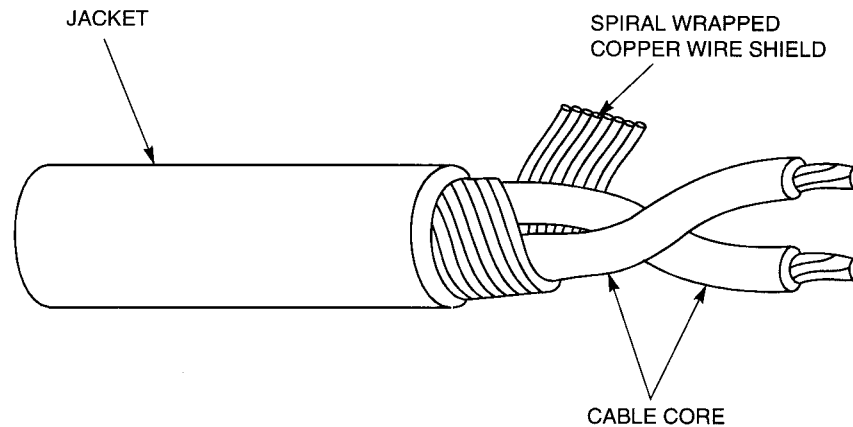
5.5 Spiral shield

Spiral shields may be helically applied to tape or wire (see figure 8). These shields provide flexibility. The spiral shields, however, produce longitudinal, solenoidal magnetic fields inside the cable, similar to the field in inductance coils. These solenoidal fields result in poor shielding characteristics at high frequencies. Therefore spiral shields find use only in the low-frequency range (audio frequency electronic cables, microphone, musical, retractile cords).

5.6 Braided wire shield

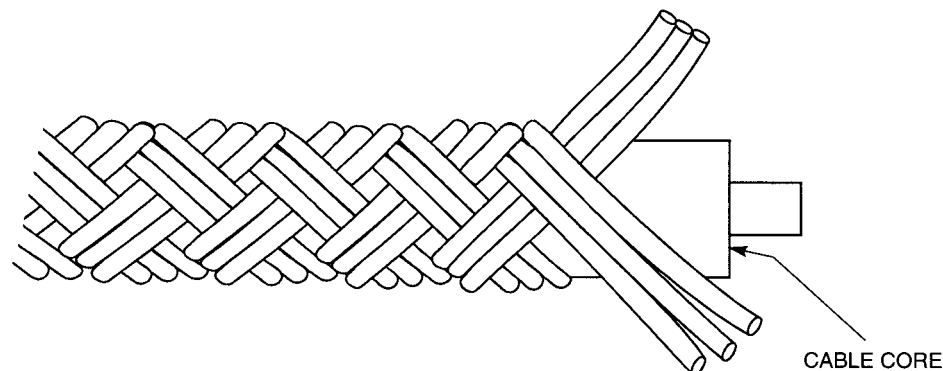
A braided shield consists of groups of coated or uncoated metallic strands, one set woven in a clockwise direction and interwoven with another set in a counter-clockwise direction (figure 9).

Braided shields provide structural integrity, while maintaining good flexibility and flex life. These shields are most useful for minimizing low-frequency interference and have lower dc resistance than foil. Braided shields are effective at audio and RF ranges. Generally, the higher the braid coverage, the more effective the shield. Typical braid coverage is between 80% and 95%. Coverage of 100% is unattainable with a braid shield. Other features to consider when choosing a braid shield are the weave angle, strand diameter, number of carriers (strand groups), and number of ends (strands).



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Figure 8—Spiral shield of wire serve



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Figure 9—Braid shield

Braided wire shields have apertures through which both electric and magnetic fields can pass. The weaving process creates small diamond-shaped apertures where the bands of shield wires cross. The developed surface of such a shield is shown in figure 10.

Braided shields are generally bulkier and heavier than other shields. Crimp or heat-shrinkable terminating devices are available for braid shields [B7].

5.7 Combination shields

Improved high-frequency performance can be achieved by combining foil and braided shields. Covering a two-layer foil shield with a braided shield can result in a shielding characteristic that begins to resemble that of the solid-wall copper tube. Since the foil provides 100% optical coverage, braid apertures may be increased. Therefore, braids with optical coverage in the 40–80% range are useful.

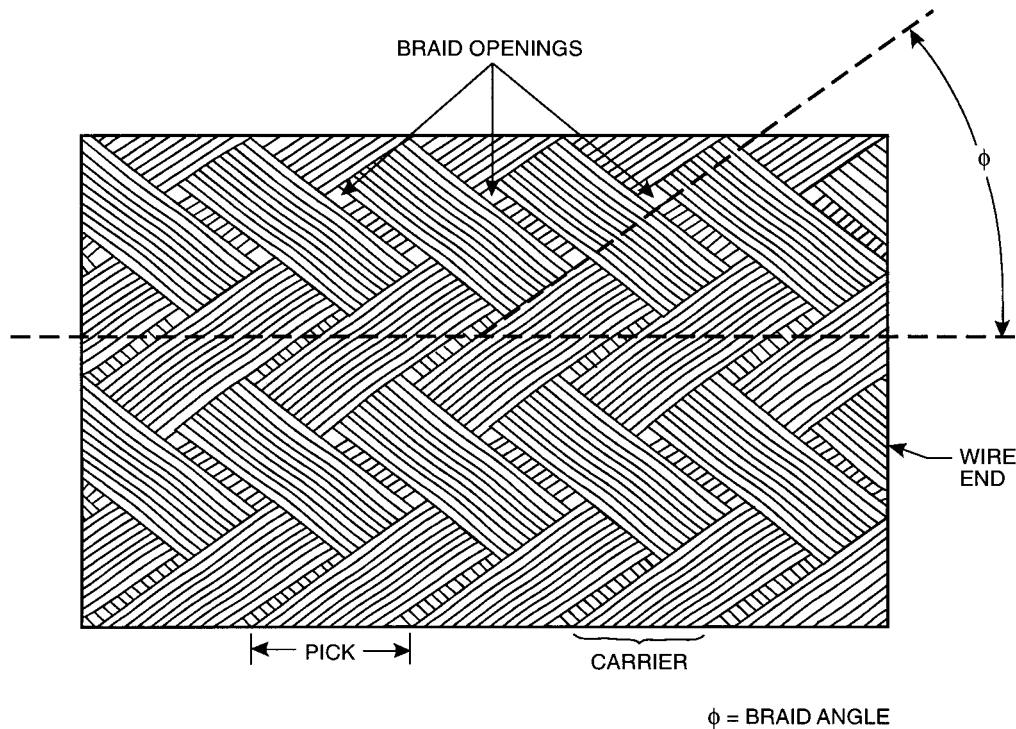


Figure 10—Developed surface of braid shield

Multiple layers of foil and braid can be used to get an even closer approximation of solid-wall copper tube characteristics. A good example of this type of approach is found in the cable used for the Ethernet local area network. Ethernet cable has a polyester-backed foil shield bonded to the inner-conductor insulation, covered by a two-foil shield sharing a common polyester backing, and a tinned-copper braided shield with 92% coverage. This shield configuration provides shielding up to 30 MHz. Three-layer shields developed for CATV coaxial cables use a bonded-foil/braid/foil-with-shorting-fold shielding format and exhibit good shielding up to 80–100 MHz [B34].

A spirally-wrapped plastic-foil tape is poor in shielding effectiveness, and effectiveness worsens with increasing frequency. This suggests poor turn-to-turn electrical contact. Longitudinally-wrapped tape is more effective. For example, a single overlapped longitudinal copper tape formed into a tube acts very much like a solid copper tube from a shielding point of view. The corner frequency at which the skin depth is equal to the thickness of the foil is about 1 MHz. A braided shield over this tape provides shielding that is more independent of frequency.

5.8 Overall shields

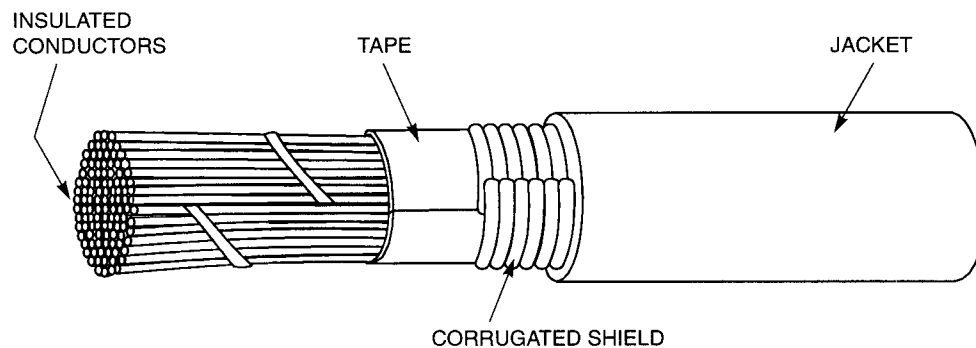
Overall shields are used primarily with multiconductor cable in the following types of applications:

- Telemetry
- Communications
- Instruments
- Supervisory
- Control
- Electronic

These shields may be of four types, as follows:

- Longitudinally-wrapped and corrugated
- Longitudinally-wrapped and smooth
- Continuously welded corrugated or smooth
- Seamless

Longitudinally-wrapped corrugated shields of plastic coated or bare aluminum, coated or bare copper, plastic coated or bare steel have been used extensively in exchange area telephone cables. In the cable manufacturing process, an in-line corrugator corrugates the tape; then the corrugated tape is formed around the cable core so that the edges overlap (see figure 11). Corrugating the tape increases the axial strength and flexibility of the cable. Such shields give 100% optical coverage. Overall shields are more effective as electrostatic shields (because of the greater shield mass) than aluminum foil-polyester laminate. Cables with longitudinally corrugated shields have greater current handling capability, but larger diameters and less flexibility than cables with only foil-polyester laminates.



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Figure 11—Corrugated tape shield

Shields of coated aluminum or coated copper utilize a plastic coating to adhesively bond the shield to the cable jacket. When the shield is bonded the jacket, the cable is said to have a “bonded sheath.” Bonded sheath cables allow the shield to be wrapped in a smooth configuration, although corrugated plastic coated metallic tapes can be used as well. Figure 12 shows the use of a smooth tape. The bonded sheath provides the cable with improved mechanical properties by combining the flexibility of the plastic jacket with the strength of the metallic tape. The bond between the jacket and shield also forms a water block at this interface. The plastic coatings provide the shield with corrosion protection [B6].

Corrugated aluminum or smooth coated aluminum shields are lighter and easy to handle for aerial installations. Corrugated coated aluminum and copper shields are flexible and provide corrosion protection to the shield for duct and direct burial applications. Bimetallic shields use metallurgical bonding to combine two layers of copper with one layer of stainless steel or low carbon steel. Bimetallic shields and coated steel armor provide protection against damage by wildlife.

Longitudinally applied overall shields serve both electrical and mechanical functions. When grounded at both ends, these shields become an electromagnetic shield. As such, they provide protection against lightning surges and low-frequency induction. They provide lower resistance, and hence are better longitudinal conductors for fault currents than corresponding spiral shields of similar thicknesses or conductivity.

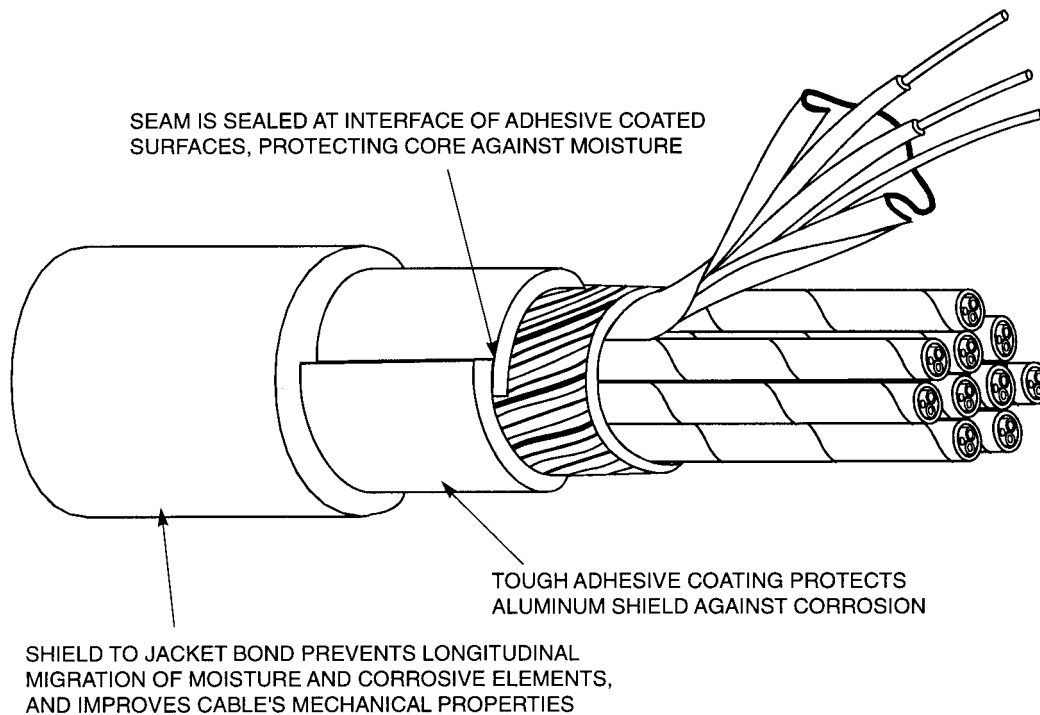


Figure 12—Bonded sheath cable

The desirability of hermetically sealed cables has grown. Considerable improvements in moisture and chemical resistance can be attributed to the use of the composite “bonded sheath,” comprised of coated 0.2 mm (8 mil) aluminum, coated 0.125 mm (5 mil) copper or 0.15 mm (6 mil) coated steel and a plastic jacket. A thin layer of a plastic coating adhering to one or both sides of a metallic strip provides the bonding. After this metallic strip is formed into a tube and overlapped, the extrusion of the final plastic jacket over the tube fuses the adjacent jacket and coating together. This provides a waterblock between the shield and jacket. The overlap is sealed with the plastic coatings and the heat of extrusion (sometimes a hot melt adhesive is inserted into the overlap to facilitate sealing). The result is a “sealed seam” or “sealed overlap.” The bond to the jacket and sealed seam provide the cable with a hermetically sealed metallic shield or armor. The cable is known as having a moisture barrier sheath. However, the seal at the overlap effectively puts an insulating layer between the surfaces of the overlap, which results in a slot. This slot can be a source of signal leakage, possibly limiting the use of the shield in cables operating at high frequencies. However, the main purpose of such shields is to provide protection against the effects of transients such as those originating in lightning or power system disruptions.

A databus cable makes excellent use of the composite shield concept and an overall bonded sheath [B6]. This design uses a 95% coverage braid of tinned copper as the electrical shield, a 70% coverage braid of tinned copper covered steel as a magnetic shield, and a coated 0.19 mm (8 mil) aluminum tape as a moisture barrier and overall shield. (The shielding performance of composite shields is discussed in 12.2.)

Corrugated welded smooth tubes, as well as seamless tubes, can provide a high degree of shielding effectiveness. In order to be fabricated, they must be considerably thicker than longitudinally folded shields. Typically they have a thickness of 0.38–1.27 mm (15–50 mils) vs. 0.19–0.20 mm (7–8 mils) for longitudinal shields.

5.9 Conductive plastics

A variety of plastics can be loaded with carbon or metallic powders. The degree of loading will influence the conductivity and many other properties of the material. Their conductivity, however, is significantly less than metals,