Flexible Metal Conduit for Critical Applications

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INTRODUCTION

High reliability flexible metal conduit is widely used to provide RF shielding and physical and environmental protection for system interconnect wiring. These conduit systems are suited for applications, such as military shipboard, missile systems, nuclear power plants, and secured installations, where flexibility is needed and the electromagnetic (EM) shielding requirements are critical. Selection of flexible conduit for these and similar applications must be based on an understanding of the properties and design considerations of the available conduit configurations.

In most applications, reliability and performance requirements demand that the conduit exhibits a number of properties in addition to RF shielding effectiveness. For example, in nuclear power plant containment areas, the conduit acts as a barrier and provides protection from wash-down solutions during a loss-of-coolant accident. The utilization of flexible metal conduit ensures interconnect cabling performance during seismic events and in explosive environments where flying objects or debris could render a system useless. Flexible conduit used in shipboard, aircraft, and vehicular military applications must provide a barrier against a variety of fluids and must provide protection against damage from ballistic fragments. Weight is usually a consideration and the shielding is expected to stand up to the radiation and thermal environments that are characteristic of EMP events. Architectural security installations, such as governmental embassies and TEMPEST-secure processing facilities, sometimes require flexible RF-tight shielding that can prevent water from reaching the internal wiring. In all of these applications, systems designers must be able to select a flexible conduit that provides the necessary EM shielding as well as the mechanical and environmental characteristics needed for full system reliability and protection.

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Electromagnetic energy transfers or couples electrical energy into nearby wiring or electrical cables by induction. Normally, the greater the physical distance from the source, the lesser the induction. Electrical shielding is used to redirect the amount of energy which normally would be coupled into such wiring. The degree of susceptibility to these outside forces determines the level of shielding necessary to sufficiently reduce the coupled energy into the system to assure reliable operation of the equipment.

Electromagnetic shielding is an essential parameter which must be addressed in the design of electronic equipment to ensure that equipment performs normally in environments of moderate-to-high levels of wideband radio frequency emissions, low frequency magnetic fields, lightning strikes, or other unscheduled transients.

METAL FLEXIBLE CONDUIT

Flexible conduit is manufactured from a thin continuous strip of corrosion-resistant magnetic metal. This metal strip is fed through a series of rollers that form it into an interlocking configuration. The conduit seam is soldered so that the resultant conduit is pressure-tight. The sealing process results in a continuous double-interlocked seam with four layers of metal on the outside diameter of the conduit, where abrasion is greatest and mechanical strength is required. This design provides a flat, smooth inner diameter which is not distorted when the conduit is flexed. The four layers of metal on the outside diameter of the conduit together with the single layer convolution wall on the inside diameter provide radial strength.

The conduit is usually covered with a braid of metallic wire. Ribbon and round wire may be combined in a double overbraid that ensures excellent flexibility, shielding, and surface abrasion resistance. The wire is woven directly onto the inner

*See Advertisement on Page 155.

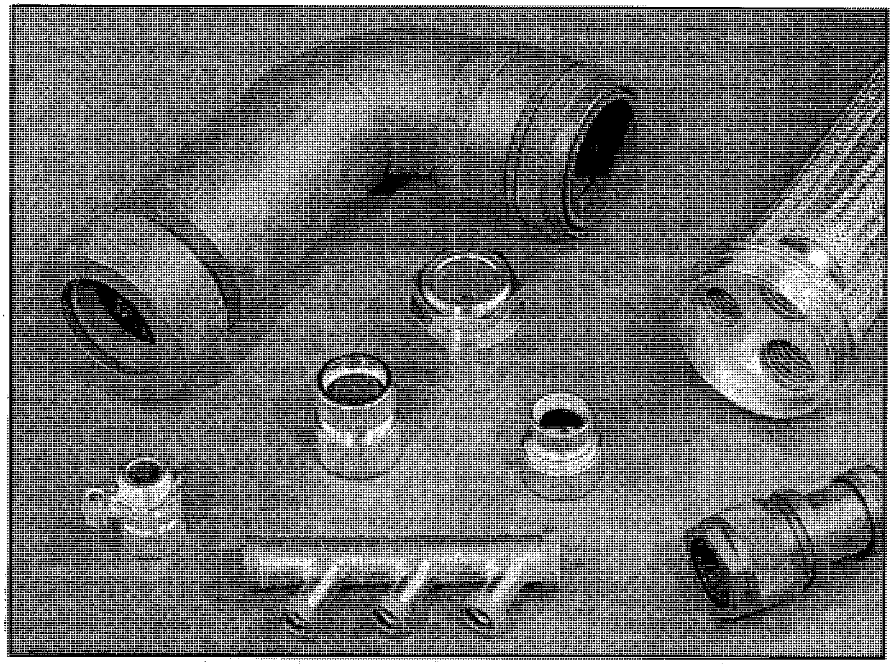

Figure 1. *Flexible Shielding Conduit and Terminations.*

core, providing a tightly wound protective surface. The close spacing of the convolutions and braid limits the extent of axial movement and increases vibration resistance. Additional protection against surface abrasions, handling damage, and fluid penetration is provided when outer jackets of synthetic materials such as neoprene are used. Several types of flexible conduit are shown in Figure 1.

Conduit of this type achieves its flexibility from the convoluted structure of the inner core. The flexure occurs over a number of grooves in the helical wound inner core. This results in excellent flexing fatigue life and increased vibration resistance. Flexibility is also increased when the inner core is mechanically compressed. This brings the convolutions together and smoothes out the inner and outer surfaces. The extra flexibility is accompanied by a gain in conduit weight per unit length.

MATERIAL SELECTION

Metallic flexible conduits can be manufactured from a number of different base metals and alloys. Use of many of these materials results in the production of conduit that conforms to military and industry specifications which control flexible conduit performance. Magnetic shielding effectiveness is dependent on two material properties, electrical conductivity and magnetic permeability. No single material exhibits optimum characteristics for both of these properties.

Stainless steel alloys are often used for both the inner core and the overbraids. They offer resistance to corrosion, high temperature exposure, and a wide range of environmental conditions. These alloys also provide strength and result in conduit with reliable mechanical properties. Stainless steel conduit is in compliance with IEEE 323 and IEEE 344 and provides a shielding range from 100 kHz to 18 GHz.

High permeability nickel-iron alloys have been shown to produce conduit with very high shielding effectiveness in low frequency magnetic environments and in the presence of EMP. Such nickel-iron conduit, which provides shielding from 10 Hz to 18 GHz, is in compliance with NAVSEA Handbooks 0967-LP-283-5010 and S9407-AB-HBK-010.

Brass alloys, usually used with bronze overbraid, cover a wide spectrum of EMI/RFI environments and often result in the lowest cost shielding. Both brass and bronze offer excellent flexing properties. Brass conduit is in compliance with MIL-C-13909, A-A 52440 and MIL-C-24758. It provides a shielding range from 100 kHz to 18 GHz.

SHIELDING EFFECTIVENESS – LOW FREQUENCY

Shielding against low frequency and static magnetic fields depends on the ability of the shielding material to conduct magnetic lines of force away from the item being shielded. Effectiveness can be tested using a standard triaxial test method. The triaxial method measures transfer impedance, which is expressed below:

$$Z_T = \frac{V_i}{I_0}\frac{1}{\Delta Z}$$

where:

Z_T = transfer impedance

I_0 = current drive over the outside of the conduit shield

V_i = voltage induced inside the conduit

ΔZ = length of conduit

Figure 2 shows the results of low frequency tests for 1-inch diameter flexible conduit manufactured from a high permeability nickel-iron alloy. Figure 3 shows testing for similar conduit made from stainless steel. The empirical results for brass flexible conduit are given in Figure 4. All tests were in accordance with MIL-C-38999 for the range 10 kHz to 1 GHz. The tests were conducted on inner core conduit without overbraid or jacketing.

SHIELDING EFFECTIVENESS – HIGH FREQUENCY

High frequency fields result in the conduit acting as a conduc-

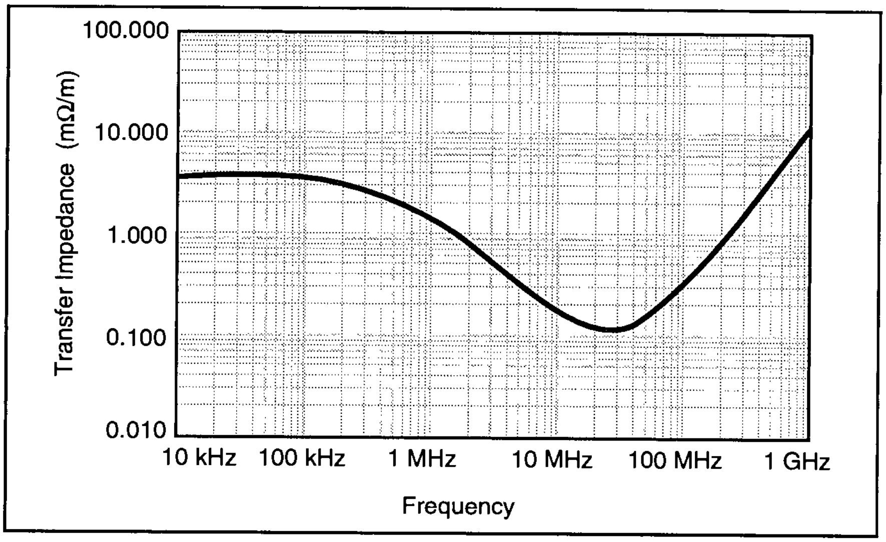

Figure 2. *Low Frequency Shielding Effectiveness of 1-inch (i.d.) Nickel-Iron Tubing.*

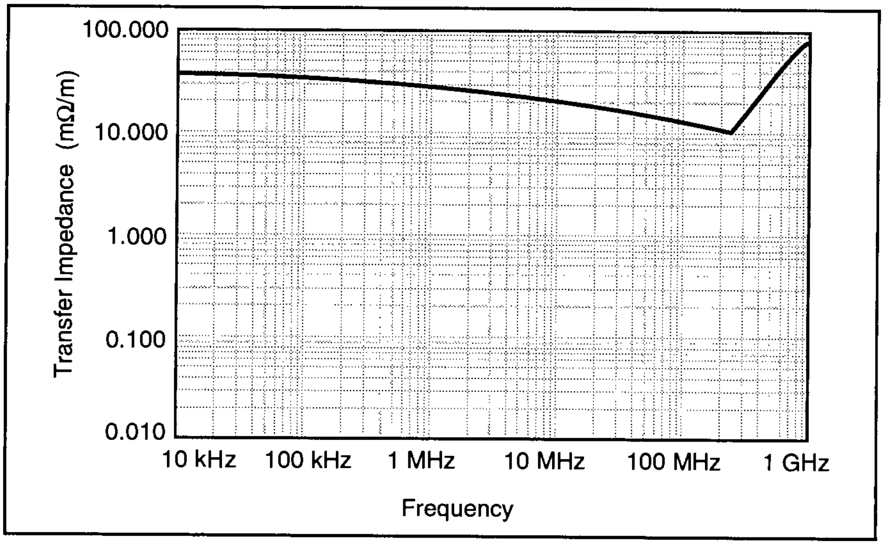

Figure 3. *Low Frequency Shielding Effectiveness of 1-inch (i.d.) Stainless Steel Tubing.*

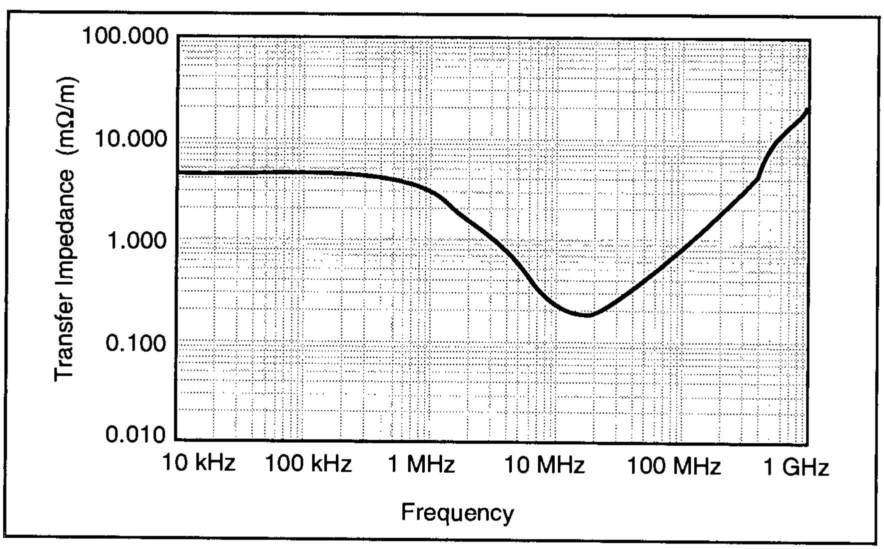

Figure 4. *Low Frequency Shielding Effectiveness of 1-inch (i.d.) Brass Tubing.*

tor to carry RF currents to system ground. These RF currents flow axially on the conduit surface, producing a circumferential H-field. The major part of high frequency shielding is accomplished by a phenomenon known as the "skin effect," which forces the RF energy to stay near the outer surface of the conduit. The material qualities which contribute to this function are conductivity and permeability, the product of which provides a measure of shielding effectiveness. High frequency fields are also attenuated by reflection at the air-to-metal interface because of impedance mismatch. Hence, the total shielding effectiveness is the sum of the reflection and skin effect attenuation.

High frequency effectiveness can be tested using the mode-stirred method. This involves placing the conduit inside a shielded test chamber which is then excited by multi-mode microwave energy. The voltage induced on a wire inside the conduit is then compared to the voltage induced on an unshielded reference wire. The difference in voltage signals is expressed as shielding effectiveness, which is measured in dB. This measurement is independent of length, since the reference and test wires are equal in length and divide out.

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Figure 5 shows the results of mode-stirred method tests for 1-inch diameter flexible conduit

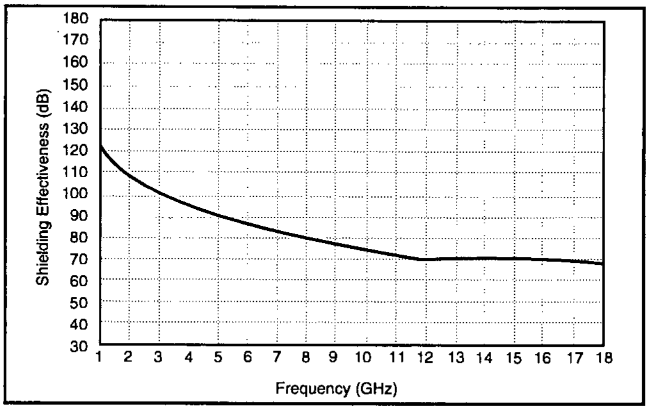

Figure 6. *High Frequency Shielding Effectiveness of 1-inch (i.d.) Stainless Steel Tubing.*

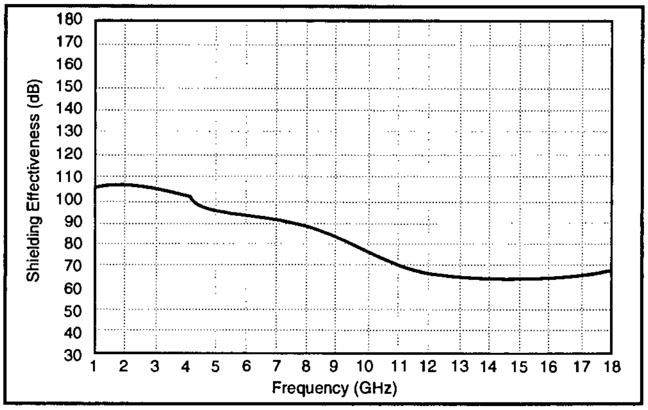

Figure 7. *High Frequency Shielding Effectiveness of 1-inch (i.d.) Brass Tubing.*

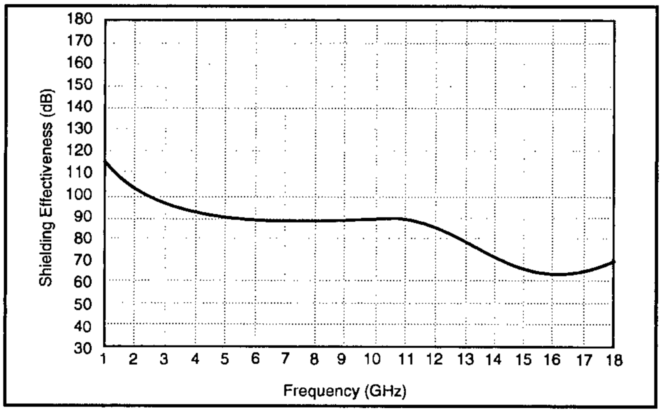

Figure 5. *High Frequency Shielding Effectiveness of 1-inch (i.d.) Nickel-Iron Tubing.*

manufactured from a nickel-iron alloy. Figure 6 shows testing for similar conduit made from stainless steel. The results for brass flexible conduit are given in Figure 7. All tests were in accordance with MIL-STD-1344, Method 3008 and cover the range 1 GHz to 18 GHz. The negative slope in shielding effectiveness above 1 GHz is representative of the decreasing dynamic range of the mode-stirred measurement system, which is unavoidable in practice. The actual shielding values of the tested conduit will be greater than the test results.

TERMINATIONS

Conduit must be furnished with a variety of termination devices to permit interconnection of conduit sections and a multitude of final application terminations such as connectors, bulkheads, and stuffing tubes. Braze-on connections provide a watertight assembly using o-ring seals. Transition fittings provide the physical connection between flexible metal conduit and electrical connectors or fittings. Accessory fittings provide the physical connection between flexible conduit and bulkheads or panels, and provide the means of coupling two lengths of conduit together.

Reusable fittings are attached to the conduit by gripping the conduit and braid by means of friction and captivation. Couplings are used to join two lengths of conduit. End fittings provide a standard thread size for attaching adapters. Adapters provide thread compatibility between end fittings and various devices such as hull fittings and connectors. These reusable fittings can be readily attached to or removed from conduit simply by tightening or loosening the gripping mechanism.

SUMMARY

Flexible metal conduit provides an excellent means of electrically and mechanically shielding sensitive electrical circuitry where the wire and enclosing conduit is subjected to motion, vibration, pulsation, or other flexing stresses. Many different types of conduit are available, including variations in size, inner core material, braiding method, braiding material, jacketing, and end fittings and terminations. High reliability conduit provides excellent strength and magnetic shielding properties. System designers must be aware of the differences in shielding effectiveness and mechanical properties associated with the various designs, enabling them to specify and select conduit that will be cost-effective and still reliably meet their needs.

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