Microwave Journal

Shielding Effectiveness of Microwave Cable Assemblies

Paul Pino
W. L. Gore & Associates Inc., Landenberg, Pa.

Shielding effectiveness of microwave cable assemblies: Why is it important? How does it impact system performance? What makes a "good shield" good and a "bad shield" bad? In this article, we will examine cable assembly construction and show an example of the shielding effectiveness of airframe cable assemblies.

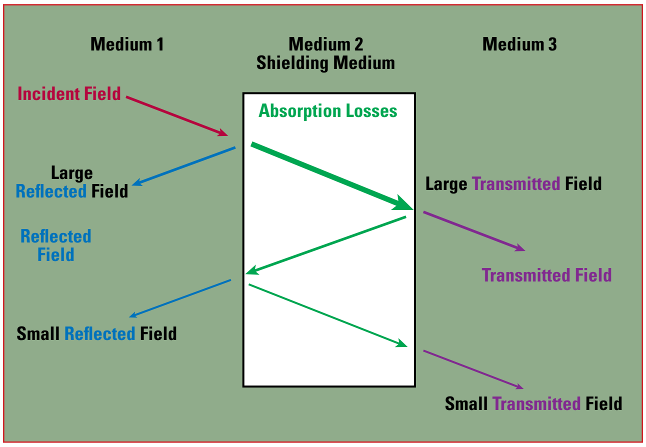

Fig. 1 Schellkunoff model of E-field shielding. Source: York EMC Services.

Before delving into shielding effectiveness, let's define the term. A shield is a conductive barrier that envelops and isolates an electrical circuit. For a microwave coaxial cable, the isolated electrical circuit is the center conductor, dielectric and outer conductor. Because of the skin effect, at microwave frequencies the return current on the outer conductor travels through a thin layer of the inner diameter of the outer conductor. This leaves the remaining portion of the outer conductor as the shield. Shielding effectiveness is defined as the ratio of the RF energy incident on one side of the shield to the RF energy transmitted to the opposite side.

Reflection and absorption are the two primary shielding mechanisms. A widely-accepted analytical representation of shielding, known as the Schellkunoff Model,[1] is illustrated in ***Figure 1***, where Medium 2 is the shield. A portion of the incident RF energy is reflected from the surface of Medium 2. The remaining portion of the energy penetrates Medium 2, and a portion of it is absorbed, with its power dissipated by the ohmic losses in the material. The remaining energy propagates through Medium 2 to Medium 3, where a portion is reflected and the remaining energy moves into Medium 3, which is the

Reprinted with permission of MICROWAVE JOURNAL® from the March 2018 Supplement.

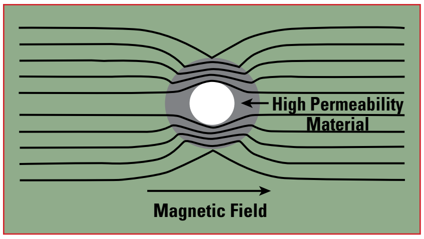

Fig. 2 Magnetic field shielding.

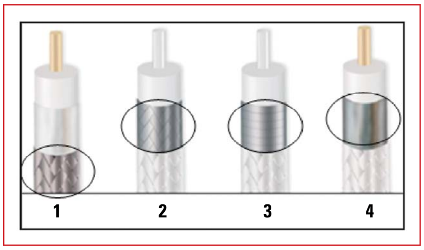

Fig. 3 Common microwave cable shield configurations. Source: Emerson Corp.

region intended to be isolated by the shield.

The majority of shield configurations only protect against E-field radiation. Magnetic field protection requires a different approach. As there is no practical means to block the magnetic field, it must be redirected around the electronic circuit by housing the circuit in a material having high magnetic permeability (see ***Figure 2***). The high permeability material, illustrated as a ring in the figure, distorts the magnetic field and isolates the center of the ring. This type of shielding is often employed when high energy, electromagnetic pulse exposure is anticipated.

SHIELD CONSTRUCTION

Microwave coaxial cable shields can take a number of forms. By far, the simplest and most effective shield is the outer conductor of a semi-rigid coaxial cable. The semi-rigid's construction employs a relatively thick, one-piece cylindrical outer conductor, formed from high conductivity material. This endows it with excellent shielding effectiveness, well in excess of 140 dB from 1 to 18 GHz.

Figure 3 shows four common shield types for flexible microwave cables. Type 1 is a braided round-wire shield, usually tin or silver-plated copper, and the most prevalent. This construction is highly flexible, easy to manufacture and serves a dual role as both a structural and electrical member. Its disadvantage is that the shielding effectiveness is directly proportional to braid coverage. With standard coverage, the typical shielding effectiveness is 40 dB through 18 GHz. Higher braid coverage will improve the shielding at the expense of cable flexibility, longer manufacturing times and increased material costs.

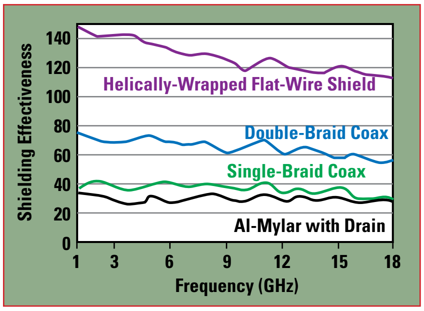

Fig. 4 Shielding effectiveness of the most common shield configurations.

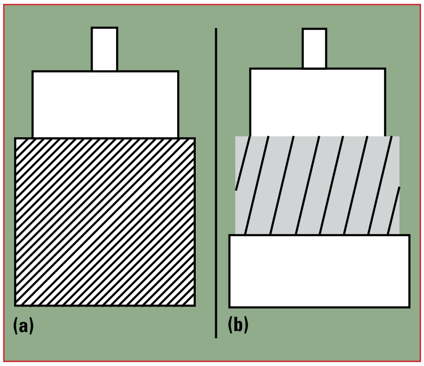

Fig. 5 Served round-wire shield (a) and served flat-wire shield (b) construction.

A braided, flat-wire shield (type 2 in Figure 3) is generally silver-plated copper. This type is structurally strong, has better shielding than type 1—typically 85 dB through 18 GHz—and the application time in manufacturing is short. However, it has higher contact resistance compared to a helically-wrapped, flat-wire shield and lower phase and amplitude stability with flexure. The helically-wrapped, flat-wire shield (type 3) improves phase and amplitude stability with flexure, reduces contact resistance, is highly flexible and can achieve a shielding effectiveness of 120 dB through 18 GHz. High quality cables use silver-plated copper flat wire. However, applying the shield is demanding, and the application process is slower than that of type 1 and 2 shields, raising the overall cost.

The fourth common shield construction (type 4) uses helically-wrapped, or "cigarette wrapped," metalized polymer foil, using Mylar®, polyimide or polyester. Polyimide offers high strength and chemical and heat resistance. Aluminum-polyester Mylar is inexpensive, light-weight and provides electrostatic discharge protection. The downside is lower performance shielding, requiring metal deposition to be conductive. The deposition process results in somewhat high contact resistance, which hurts shielding effectiveness and usually requires a "drain wire" to provide a low resistance ground path. The shielding effectiveness of the most common types of shields are compared in ***Figure 4***.

Two additional shield types are shown in ***Figure 5***: the served round-wire and served flat-wire shields. The served round-wire shield employs multiple, round-wire conductors wrapped in a spiral fashion around the dielectric. With the flat-wire version, thin, flat strips of metal, usually silver-plated copper, are spiral-wrapped about the dielectric and a layer of metalized polymer wrap is applied to bind the flat-wire bundle and reduce contact resistance. Served wire shields are used to enhance the cable's "feel," producing limp, flexible cables. Manufacturing is easy and quick, yielding low component cost. However, both types are prone to contact resistance changes with flexure, movement and temperature, reducing loss stability and shielding effectiveness.

The shielding effectiveness of a flexible coaxial cable improves as the outer conductor and shield configuration approach a continuous, one-piece construction, like the outer conductor of a semi-rigid cable. This assumes the material has a reasonably good level of conductivity at microwave frequencies. Designs that incorporate openings or gaps are susceptible to interference, i.e., receiving and radiating electromagnetic energy.

SHIELDING EFFECTIVENESS

Having discussed shielding types, we will examine the real world performance of microwave airframe cables. This particular cable type represents a unique subset of microwave cable technology, where the environment is the unpressurized portion of military combat and transport aircraft, and the cable assembly is generally used in radar and electronic warfare systems. These systems play a key role in threat detection, targeting, self-protection, communications and navigation; if the cables fail or malfunction, they risk equipment and, more importantly, lives. Because they reside in unpressurized environments, airframe cable assemblies must use a

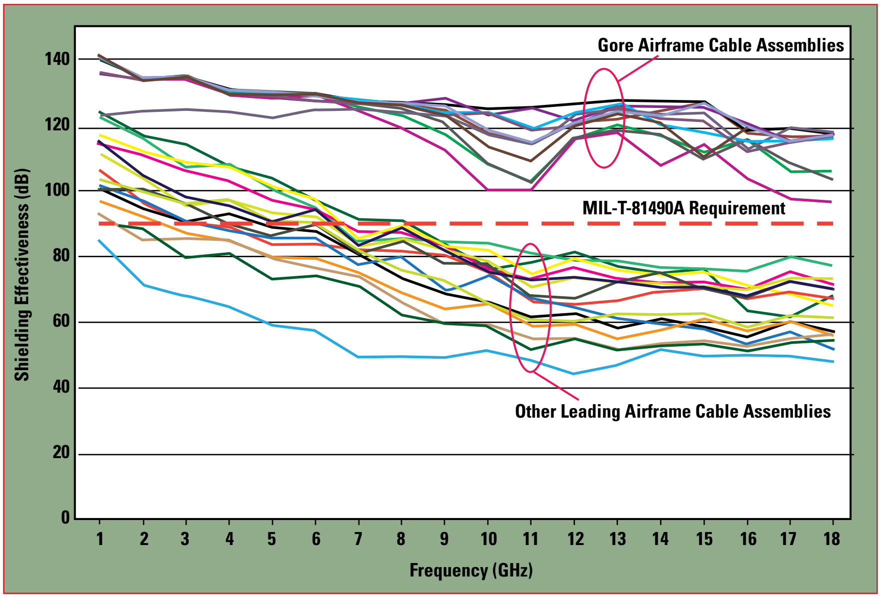

Fig. 6 Shielding effectiveness of microwave airframe cable assembly families from two companies. The minimum specification per MIL-T-81490A (AS) is 90 dB.

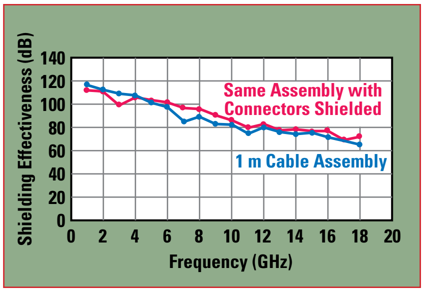

Fig. 7 Applying supplemental shielding to the connectors improves the shielding effectiveness of a 1 m cable assembly.

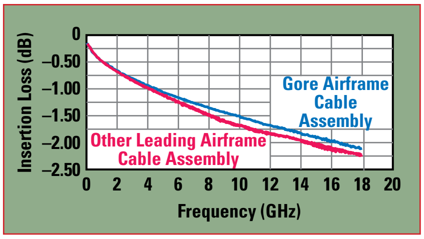

Fig. 8 Insertion loss of served flat-wire cable assembly vs. Gore helically-wrapped, flat-wire assembly.

sealed construction. If conventional, unsealed cables are used, moisture-laden air will penetrate the cable's dielectric with altitude-induced pressure changes, causing variation in electrical performance.

Microwave airframe cables used in U.S. military aircraft must comply with the MIL-T-81490A (AS) standard, which stipulates a shielding effectiveness of no less than 90 dB over the cable assembly's design frequency range. ***Figure 6*** compares the shielding effectiveness of two companies' microwave airframe cable assemblies, showing various models and assembly lengths and all rated to 18 GHz. Testing was conducted from 1 to 18 GHz per MIL-STD-1344, method 3008.

Why such a difference between the two sets of products? Connectors, connector termination and the cable are the three potential areas of RF leakage. To illustrate, ***Figure 7*** shows the shielding performance of a 1 m microwave airframe cable assembly and the improvement when the connectors and connector termination area is covered with supplemental shielding material: adhesive-backed copper foil, 0.07 mm thick × 25 mm wide. Overlapping wraps of material were used to cover the area. With additional shielding, the trace still has the same general downward slope vs. frequency; however, the performance improves notably from 6 to 12 GHz.

The poorer shielding effectiveness of the standard cable assembly from 6 to 12 GHz is significant enough to increase the insertion loss over the same frequency range (see ***Figure 8***), as the "dip" in shielding effectiveness represents radiated power which never reaches the end of the cable assembly. The energy is radiated outside of the cable.

Referring to Figure 7, note that the additional shielding applied to the connector area improved the 6 to 12 GHz dip yet did not affect the downward slope of the curve, which is likely an artifact of the cable's 3-mil-thick, served flat-wire outer conductor construction (see Figure 5b), wrapped overall with a thin, metalized, polymer tape. The served flat-wire configuration has continuous helical gaps running the entire length of the cable between each served flat-wire segment. These gaps are openings in the shield that act as electromagnetic radiators. To somewhat remedy this situation, a thin, metalized, polymer tape is applied over the serve, to cover the gaps and improve conductivity between each adjacent flat-wire segment. Because the primary shielding mechanism at low frequency is reflection, this works reasonably well at low frequencies. At higher frequencies, the primary shielding mechanism transitions to absorption, which is a function of the product $\sigma_r\mu_r$, where σ_r is the material's conductivity relative to copper and μ_r is the material's magnetic permeability relative to copper.[2] The polymer tape's conductivity and magnetic permeability are low compared to copper, and the tape itself is not in intimate contact with the flat wire, which further increases shield resistance. The thinness of the tape, on the order of 1.5 mils, compounds this, as well as the shielding effectiveness being directly related to shield thickness. The result of this construction, shown in the lower curves of Figure 6, is a constant reduction in shielding effectiveness above 1 GHz, falling below the MIL-T-81490A (AS) standard around 7 GHz.

The shielding performance of Gore's cable assemblies in Figure 6 is relatively flat and well above the 90 dB limit through 18 GHz. This performance can be attributed to the connector design, connector termination techniques and cable construction. The cable assembly uses a durable, helically-wrapped, flat-wire outer conductor; the flat-wire is silver-plated copper, with a thickness of 3 mils. The helical wrap ensures excellent mechanical and electrical contact between the overlapping wraps. The high conductivity of silver-over-copper provides good reflectivity at low frequencies, and the shield's overall thickness with the overlapping wraps results in excellent absorption at high frequencies.

CONCLUSION

This article addressed the shielding effectiveness of cable assemblies to provide users with a better understanding of construction techniques and how they impact microwave cable assembly performance, using airframe assemblies as an example. The shielding effectiveness of microwave cable assemblies is often ignored, since adequate performance is assumed and rarely verified.

When selecting a microwave cable assembly for airframe use, ask the supplier:

- Has the cable been expressly designed for airframe applications?
- Can it withstand the rigors of airframe installation without the RF performance being compromised?
- Will it meet military shielding effectiveness standards before and after installation?

Microwave airframe cable is a crucial component of many military systems and can shape system performance. Because of this, cable selection should be given careful and thoughtful consideration.■

References

1. S. A. Schelkunoff, "The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," *Bell System Technical Journal,* 1934, pp. 532-579.
2. D. D. L. Chung, "Electromagnetic Interference Shielding Effectiveness of Carbon Materials," *Permagon Press*, July 2000.

THE OUTSIZED ROLE OF CABLE ASSEMBLIES

An anechoic chamber creates a free-space environment by suppressing the reflection of electromagnetic energy, achieved by lining the chamber floor, walls and ceiling with electromagnetic absorbent materials. The Benefield anechoic chamber, operated by the U.S. Air Force, is the world's largest, measuring 264 ft x 250 ft and 70 ft (see ***Figure 1s***)—big enough to house virtually any aircraft (see ***Figure 2s***). The nearly ideal free-space environment is used to test electronic warfare, radar and other electronic systems with defined routines in a controlled environment, simulating actual flight scenarios.

During testing, the aircraft is irradiated with RF energy to stress the EW system to its design limits. The facility's test equipment transmits signals into the chamber and the aircraft's EW system monitors and records the data; modern EW systems can independently track and record the system's responses. Once testing is completed, the facility provides a comprehensive data package to the customer. The data package allows the customer to assess how their system responded to various threat stimuli during the simulation.

In the real world, engagement times are very short, and it is difficult and costly to fly controlled and repeatable scenarios. Assume an engagement where an enemy fighter launches a subsonic air-to-air missile against a friendly fighter. At the time the missile is launched, the two aircraft are four miles apart, converging at a closing speed of 1,200 mph. Optimistically, the friendly EW system has less than 12 seconds to identify the threat, alert the pilot and initiate countermeasures. The effectiveness and reliability of the fighter's radar, EW and communications systems is clearly crucial to the pilot's survival.

Asked what system performance problems consistently surface during testing at Benefield, facility personnel answered, "shielding issues with coaxial cables and instrumentation enclosures," observing that cable assemblies are often damaged during installation. Once compromised, they are susceptible to receiving interference and becoming sources of interference. EW systems gather data from the electromagnetic environment surrounding the aircraft to determine threat types, severity, proximity and location. Poorly shielded cable assemblies or those with damaged shields can "confuse" the EW system, leading to misinterpreted data and extended processing time. EW systems are designed to detect a threat at least 2x the threat's striking distance; interference can compromise the system's ability to detect threats at this range.

Benefield staff observed that damage to microwave airframe cable assemblies is usually caused during the installation of the cable or other components near it, not during system use or maintenance. It is not enough that an airframe cable has a good shield design; the cable must withstand the rigors of installation and potential damage when adjacent components are installed in the aircraft.

Fig. 1s Aerial view of the Benefield anechoic chamber.

Fig. 2s Interior of the anechoic chamber with a B-52 Stratofortress staged for testing. Pyramidal objects in foreground are electromagnetic absorbers. Source: Edwards Air Force Base