RF CABLE ASSEMBLIES ENABLE RELIABLE AUTONOMOUS AND UNMANNED AIRCRAFT OPERATION

GORE

Microwaves&RF

Introduction

Autonomous and unmanned aerial defense systems present significant challenges in transmitting RF analog data. The aircrafts' compact platforms require upfront design integration, and cable assemblies cannot be an afterthought. Cable assemblies must be durable and undergo thorough and rigorous testing to ensure they can tolerate extreme conditions, maintain reliability, and reduce downtime for maintenance and repairs while keeping platforms mission-ready. In addition, they should be modular and flexible, supporting swappable components such as sensors and payloads to maximize mission adaptability and effectiveness. In short, autonomous systems must operate without effort, as there is no pilot override. For example, there is no pilot who can evaluate and turn off an erroneous radar warning from a malfunctioning receiver. The system must operate reliably and consistently in every mission.

The process of testing cable assemblies in accordance with standards such as MIL-T-81490 for Transverse Electromagnetic Mode (TEM) transmission lines presents significant challenges. Expensive and complicated automated test systems can help ensure the quality of systems incorporating many cable assemblies, but these systems take extensive training to use, and teams may be swapped out every six months or so, making the systems difficult to maintain. You can reduce the need for such systems by choosing reliable cable assemblies thoroughly tested by the manufacturer.

Design Tradeoffs

An effective design will define and prioritize trade-offs up front with the goal of building a system that will be reliably available and perform as expected. Weight, fit/size, scalability, up-front costs, and life cycle costs are all critical. "Swappability" is a key consideration because some platforms will serve multiple different missions, where one size does not fit all. Swappable components allow for maximizing the performance and minimizing the weight and size of a standard platform for the specific mission it is targeting.

In all aircraft applications, weight savings are crucial for increasing payload capability, extending range, maximizing fuel efficiency, and maximizing time on station. Therefore, employing lightweight cable solutions without sacrificing signal quality or durability is critical. Minimizing weight and size does present challenges. Airborne cable assemblies must tolerate

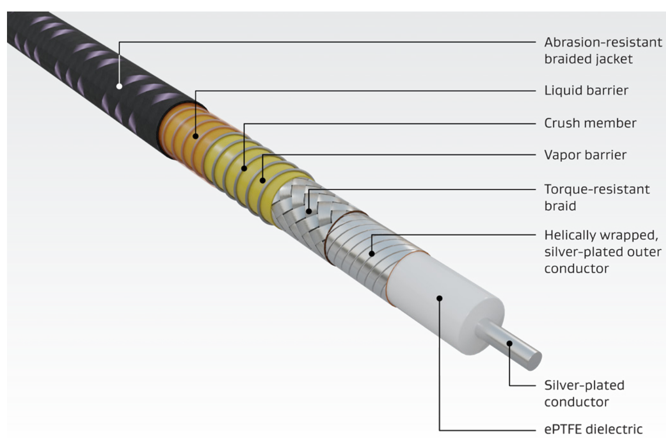

Figure 1. Low-weight construction of GORE-FLIGHT® Microwave Assemblies, 6 Series.

extreme conditions, including rapid temperature and pressure changes and exposure to contamination from fuel, oils, and corrosive atmospheres, while maintaining signal integrity. Figure 1 illustrates the lightweight but rugged construction of GORE-FLIGHT® Microwave Assemblies, 6 Series, which combine an abrasion-resistant braided jacket, liquid and vapor barriers, a crush member, and a torque-resistant braid.

In addition, they include a silver-plated conductor separated from a helically wrapped silver-plated outer conductor by an ePTFE dielectric. All these components combine to provide a compact, rugged, lightweight assembly that optimizes signal integrity and is qualified to the most stringent specifications for airborne applications. Gore is able to achieve this ruggedness and performance through vertical integration that enables the company to control the entire manufacturing process, including purchasing raw materials, creating proprietary dielectrics, manufacturing the complete assembly, testing it, and shipping it. Each assembly is 100% tested for vapor leakage, dielectric withstand voltage, voltage standing-wave ratio (VSWR), insertion loss, impedance, and velocity of propagation.

Fiber-optic cables offer an alternative to copper for transmitting high-rate data streams. Fiber-optic cable is lighter weight than copper and is inherently immune to EMI, RFI, and crosstalk. In addition, recent expanded beam-connector innovations have enhanced fiber optic assemblies' resilience to environmental contaminants, giving fiber optics the serviceability and reliability of copper. GORE® Fiber Optic Cables, 1.8 mm Simplex, offer the crush resistance necessary for airborne applications, and the cables weigh only 2.6 pounds per 1,000 feet. In contrast, GORE-FLIGHT® Microwave Assemblies, 6 Series, weigh from 27 to 84 pounds per 1,000 feet.

Finally, size and weight considerations extend beyond the cable itself to include the connectors. Push-on connectors, perhaps with locking mechanisms, will increasingly find use to maximize space savings.

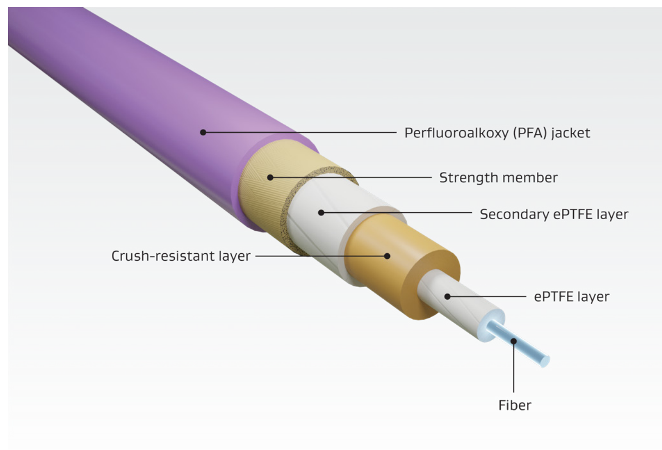

Figure 2. Compact Design of GORE® Fiber Optic Cables, 1.8 mm Simplex.

Leveraging Technologies to Enable Scalability

Designers are designing not only for today's systems. They are creating systems and capabilities that can be transferred to future platforms. The goal is to ensure solid engineering on an initial system so the designer and end user can reuse the engineering effort to easily create subsequent systems at lower costs. This reuse and scalability is the driver behind initiatives such as the U.S. Department of Defense's Modular Open-System Approach (MOSA) and the Open Group's Sensor Open-Systems Architecture (SOSA®).

Finally, nothing in cable-assembly design for unmanned and autonomous aircraft can be an afterthought, where every tenth of an inch is going to matter. With 3D modeling widely available, every assembly should be modeled upfront. But while mechanical modeling can solve the form and fit aspects of "form, fit, and function," it can't guarantee success. You cannot choose a connector without knowing what cable it will attach to, and vice versa.

Guaranteeing Aircraft Microwave Assemblies' Installed Performance

Cables must not only perform dependably prior to installation — they must perform reliably throughout the rigors of the aircraft's flight envelope. Many military aircraft manufacturers have found that microwave cable assemblies are often compromised during installation, and that these assemblies often exhibit degraded signal-integrity performance, especially when exposed to normal flight conditions. To address the issue, Gore has developed an installation simulator (Figure 3), which applies multiple typical stressors that can occur during installation to help ensure microwave assemblies deliver the same reliability after as well as before installation.

The simulator has three main features: mandrels with diameters compliant with the specified minimum bend radius of the cable under test, plastic and metal routing guides, and an abrasion bar. Prior to using the simulator, Gore measures the assembly under test's insertion loss and VSWR over the specified

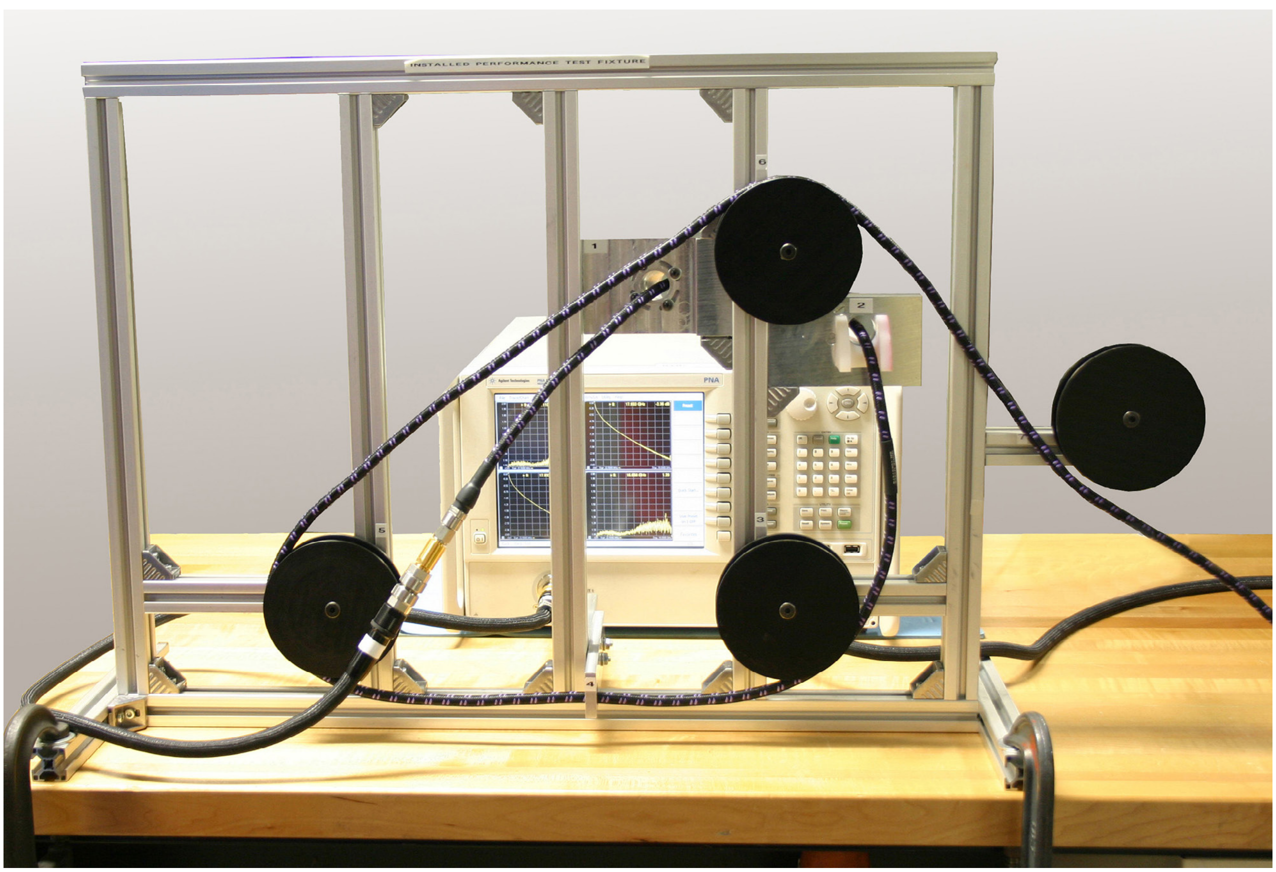

Figure 3. Installation simulator.

operating frequency range using a vector network analyzer (VNA). The simulator then uses its mandrels to simulate routing the assembly around the internal structure of an airframe, with routing guides inducing torque as the assembly is pulled through the simulator with a tensile force of 20 to 40 pounds as measured by a digital force gauge. Finally, the assembly is pulled across an abrasion bar to simulate routing across sharp edges or through access holes. After the simulation, Gore again uses the VNA to measure the insertion loss and VSWR and compares it with the pre-simulation baseline. Depending on the results and customer requirements, the assembly may be routed through the simulator multiple times to verify its durability.

Withstanding Harsh Environments

Cable assemblies serve as an autonomous defense system's lifeline. They must deliver reliable performance over a system's lifespan, even in the face of severe electrical, mechanical, and environmental stress.

To best prepare for harsh environments, first develop a list of the constraints your application will impose, including electrical, mechanical, and environmental factors, and share this list with your cable-assembly manufacturer so it can select appropriate materials and construction and perform thorough testing and data analysis. Also, take into account the total cost of ownership, including costs of failures.

When it comes to electrical constraints, you will want to consider susceptibility to EMI both from external sources and from within the cable assembly itself.

In addition, consider crosstalk, which results from unwanted coupling between two transceiver lines, and insertion loss. And for power lines, you will want to consider conductor DC resistance.

Various other factors will affect the electrical performance, including mechanical stress, which occurs not just during installation but whenever cable systems are subject to movement — such as when the position of a flight control surface changes. Bend radius influences cable life in any flex application, as does the rate at which the flex occurs. Cable placement also has an effect. If a cable flexes and comes in contact with other components, abrasion may occur, and sharp edges can sever a cable.

Environmental factors can also play a role. Low temperatures, for example, can make cable assemblies brittle, while high temperatures can make them too soft. Pressure can also have an effect, with a vacuum (lack of pressure) and rapid pressure changes potentially leaching fuel and contaminants into a cable assembly. Gases and liquids can destroy some cable materials.

In addition, the reduced size of unmanned and autonomous platforms can lead to wiring systems becoming more densely populated. This density increases the risk of signal interference from both external sources as well as sources internal to the platform. Testing at the platform level can give an overall sense of signal leakage, but such testing often doesn't evaluate the effect one system may have on another. It will be important to ensure that component-level performance, including cable shielding, meets system specifications.

Once you have brought these issues to the attention of your cable manufacturer, it can choose the proper dielectrics and other insulation and jacketing materials. The list of available materials is long and includes polyurethane, polyethylene, and polyimide. Fluoropolymers offer many benefits for insulation and jacket materials, such as high dielectric withstand voltages and the ability to tolerate extreme temperatures.

Gore's material expertise brings capabilities to engineer enhanced physical, chemical, and electromagnetic properties. For example, Gore can engineer fluoropolymers to have a very low dielectric constant of 1.3, enabling small cable diameters and reduced weight. Gore also engineers fluoropolymer cable jackets to have extremely high abrasion resistance.

Reducing Life Cycle Costs

Premature replacement of failing autonomous aircraft components before their expected end of life can be expensive and compromise mission readiness. Yet a majority of aerospace industry companies expect assemblies to fail before the anticipated end of an aircraft's service life, incurring downtime for repair and test. To avoid downtime, these companies require assemblies that withstand the rigors of installation and the extreme conditions of flight without degradation and failure. In addition to applying the installation simulator, Gore has conducted shake stability tests, after which Gore compared the assembly's insertion loss to the 0-dB normalized pre-shake value. As shown in Figure 4, GORE-FLIGHT® Microwave Assemblies, 6

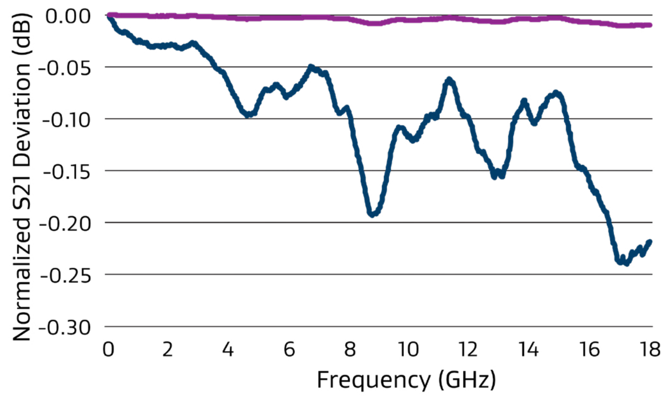

Figure 4. Insertion loss (S21) after shake test.

Series, achieved less than 0.02 dB of change through 18 GHz, whereas a competitor's assembly exhibited nearly 0.25 dB degradation. High-quality cable assemblies deliver lower life cycle costs and more reliable performance over a system's expected lifetime.

Consider an example of an airframe with 100 vapor-sealed microwave assemblies costing from $750 to $3,000 each and assume that 29 will fail prematurely and require replacement. The direct cost of these replacements will range from $21,750 to $87,000, with labor (at $100 per hour for eight to 24 hours per assembly) adding from $23,200 to $69,600, for a total cost of $44,950 to $156,600. The actual costs for your application will vary, but it is important to conduct a similar cost analysis to determine the full impact of cable failure before choosing a microwave assembly.

In addition, avoiding maintenance cost is only part of the benefit. Replacing the assemblies could take the aircraft out of service for one to three days, making the system unavailable when needed.

Key Specifications

MW/RF cables come in a variety of sizes for fit and weight versus performance trade-offs. Because of the constraints of unmanned and autonomous aircrafts, custom solutions are often required, with cable lengths typically specified down to 0.1 inch. Once you have determined the mechanical requirements, you can specify insertion loss, VSWR, dielectric constant, power-handling capability, and frequency range, and you can determine whether you need phase matching between sets of cable assemblies. To help you convert your specifications into a specific product, Gore offers an online configuration tool that helps you quickly order what you need. If you are new to specifying cables or are beginning a new design rather than adapting an old one, you might want to consult a Gore applications engineer before using the online tool.

Conclusion

When you need high-performance cable assemblies, do not just look for a component supplier. Choose a company that is a thought leader and can serve as your strategic partner. Gore stands ready to become deeply invested in your success, providing solutions tailored for your unmanned and autonomous aerial defense systems, offering unmatched durability, reliability, and adaptability. Gore will deliver mission-critical RF cables and assemblies that exceed your performance expectations, solving your design challenges with lightweight, high-performance solutions that improve system readiness and promote long-term mission success.