GORE® Cables and Cable Assemblies

IMPROVING CABLE PERFORMANCE IN HARSH ENVIRONMENTS

White Paper

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Abstract

Cables are often the last component considered when designing an electronic system. However, cables are really the system's lifeline — if a cable fails, the entire system can stop functioning. For example, if the cable system used for data transmission in a spacecraft fails, the communication between the craft and mission control could be lost. Cable performance is based on reliability, durability, and signal integrity, all of which can be compromised by electrical, mechanical, and environmental stress. The ideal cable system should be engineered to last the life of the product in any environment.

Introduction

Selecting the Right Cable System for Your Environment

Cables are often the last component considered during system designs. In many situations, cables are really the system's lifeline — if a cable goes down, the entire system can stop. For example, if the cable system used for data transmission in a spacecraft fails, the communication between the craft and mission control could be lost. Cable reliability is based on both durability and signal integrity, and the ideal cable system should be engineered to last the life of the product in any environment.

The environments in which cable systems are being used today are becoming more challenging. A harsh environment is one in which a cable's reliability, signal integrity, and life performance can be compromised by the environment in which it is used. In essence, a harsh environment is one in which a standard or "catalog" cable will not perform in your environment. For example, cables are being exposed to such things as extreme temperatures, chemicals, abrasion, and extensive flexing. Additional factors can include the need for smaller, lighter packaging for cable systems that last longer and cost less. Regardless of the application for which you are designing an electrical system, it is essential to identify all of the potential factors that can affect the electrical performance of the cable system. These variables have a direct impact on the materials used for cable insulation and jacketing as well as the construction of the cable. Using a systematic approach will help ensure that you select the best cable for your application — an approach that includes the following:

- List the constraints that will affect performance, including electrical, mechanical, environmental, and application-specific factors.
- Share this list with your cable manufacturers so they can select the best materials and construction; through testing and data analysis, the manufacturer should demonstrate that the cable will, in fact, perform in your environment.
- Understand your total cost of ownership. How much does it matter? What is the cost of a failure?

Identifying Constraints

Many of today's applications have environmental influences that require unique materials and mechanical properties to ensure reliable cable performance. First you need to consider the electrical, mechanical, and environmental stress that the cable will encounter in your application. In addition, most applications have unique issues that can stress a cable system, such as extreme temperatures in a geophysical application or vibration in aerospace applications.

Electrical performance is probably the first and foremost consideration in a cable system, and many factors can potentially compromise signal integrity, such as

- electromagnetic interference (EMI) from both sources inside the cable and external sources;
- crosstalk, which results from unwanted coupling of signals between two transmission circuits;
- attenuation, which ultimately determines the maximum length of a signal cable; and
- conductor resistance, which affects voltage drop over a power line.

Electrical performance is typically very reliable when there are not other environmental factors; however, when you add mechanical, environmental, or application-specific stress, it can become very difficult to maintain reliable electrical performance.

Mechanical stress occurs when cable systems are exposed to movement, often in tight spaces at high speeds, such as in automation and aerospace applications. Movement includes random, rolling, and torsion types of motion. Bend radius is the greatest influence on cable life in any flex application. The quantity of motion is also important. For example, bending and flexing a cable only during initial installation is not as critical as the repeated high flex cycles of automated devices. These types of flexing create kinetic energy in the cable, which can cause severe damage if not properly managed. When cables move, they rub against each other, the cable chain, or other hardware in the system, generating friction that can result in jacket abrasion. Also, when cables move in a harsh environment, they can come into contact with sharp surfaces that can cut cables or expose them to severe abrasion. When the complexities of compensating for extreme acceleration and vibration are added, mechanical stress can significantly compromise signal integrity and cause premature failure of a cable.

Environmental stress results from the physical area in which the cables are used and exposed. Extreme temperatures affect cable materials, with low temperatures making them brittle and high temperatures causing them to become very soft. Like extreme temperatures, extreme pressures can have a significant impact on cables. Vacuum, which is just a very low level of pressure, leaches oils and additives out of a cable, contaminating the work surface such as in a clean manufacturing process for semiconductor chips. On the other hand, hydrostatic pressure, like that found in geophysical exploration, causes gas or liquids to permeate insulation or cable jackets. Gases and liquids such as cleaning fluids, fuel, lubricants, chemicals, and steam destroy some cable materials. Radiation can damage both insulation and jacket materials, depending on the type and dosage level. Friction, which is caused by cable movement, can compromise cable jackets by causing particulation, while contaminants such as mud, chemicals, or metal chips, can damage the cable jacket. Environmental stress can significantly shorten the life of a cable, so these issues must be taken into account when designing a cable system.

Application-specific stress results from constraints that are unique to the application in which your product will be used. For example, aerospace applications need cables to be as light and small as possible in order to minimize mass during take-off, and in clean manufacturing environments, particulation is a critical issue. In addition, if the cables are used in areas where the general public may come in contact with them, such as transportation and automation applications, you need to consider such safety issues as flammability, voltage, and the use of halogens.

One of the added complexities of designing a cable system for a harsh environment is that electrical, mechanical, and environmental performance are interwoven. Each has a direct impact on the other, so as you design a cable to ensure high performance in one area, you must evaluate the impact on the others.

Designing the Cable System

Once you have identified the operating and environmental issues that may have an impact on cable performance, the next step is to design a cable system that will withstand all of the factors of your environment. This process involves selecting the right materials for cable construction and ensuring that sufficient testing has been done to verify that the cable will survive in your application. Selecting a manufacturer with extensive expertise in a variety of cable materials, harsh environments, and your specific industry ensures that the cable system will function reliably. Consider how different the issues are that can affect a cable's performance in a spacecraft, aircraft, cleanroom, or oil exploration application.

Choosing the Right Material

Choosing the right materials for cable insulation and jacketing is crucial for achieving reliable performance. Ensuring high-quality signal integrity means evaluating the insulation and jacket materials for attributes that account for the harsh elements of your application. The dielectric materials used in signaling cables affect the signal integrity as well as robustness of the cable. The insulation material used in an outer jacket or in a hook-up wire application affects maximum voltage and resistance to abrasion. Jacket materials should have good mechanical properties and protect interior components from the external environment (temperature, impact, friction, liquids, and gases, for example). The list of possible materials used in cable insulation and jacketing is very long, and many of these have been developed for specific applications such as transportation, power, and data transmission. Because these materials all have unique properties, some are more appropriate than others for harsh environments, including polyurethane, polyethylene, polyimide, fluoropolymers, and engineered fluoropolymers to name a few.

Polyurethane (Figure 1) is a good jacket material, but its dielectric withstanding voltage is low when compared to other materials. Mechanically, polyurethane is flexible, and it is very resistant to cut-through and abrasion. Treatment for flame-resistance does not reduce its flexibility; however, the more flexible grades tend to be sticky or tacky, which results in a higher coefficient of friction. Environmentally, polyurethane is resistant to solvents, UV rays, radiation, and fungus. Polyurethane has a limited temperature range; it becomes brittle around -40°C, and its upper temperature limit is around 100°C.

Figure 1: Properties of Polyurethane

	Pros	Cons
Electrical	Overall electrical performance	Dielectric withstanding voltage
Mechanical	Cut-through resistance Abrasion resistance Flexiblility Flame treatment doesn't reduce flexibility	Tacky in high-flexibility grade
Environmental	Solvent resistance UV resistance Radiation resistance Fungus resistance	Temperature resistance Contaminant resistance
Application Constraints	Primarily used for jacketing	

Polyethylene (Figure 2) has a relatively low dielectric constant, which can be further reduced with the addition of foam. Mechanically, polyethylene is abrasion resistant, but as it is treated to increase abrasion resistance, it becomes stiffer, so it is not as flexible as other materials. Like polyurethane, polyethylene's temperature range is rather limited, and it is difficult to bond cable boots to polyethylene cable jackets. The overall mechanical properties of polyethylene are reduced by flame-retardant treatments. Polyethylene is most appropriate for conductor insulation because when used in jackets, it tends to be stiff.

Figure 2: Properties of Polyethylene

	Pros	Cons
Electrical	Dielectric constant Insulation resistance	—
Mechanical	Abrasion resistance Wide range of grades	Stiff in abrasion-resistant grades
Environmental	Chemical resistance Low coefficient of friction Moisture resistance	Temperature resistance Adhesion Flame retardance
Application Constraints	Used for conductors and jackets	Flexibility

Polyimide (Figure 3) has very good electrical properties, such as high dielectric withstanding voltage. It is a durable material with good cut-through and abrasion resistance. Polyimide is used in flexible circuits for many consumer products, and as primary wire insulation, it is often combined with polytetrafluoroethylene (PTFE) and other fluoropolymers. For many space applications, polyimide is a good choice because of its wide temperature range, high radiation resistance, and low out-gassing properties. Polyimide is not a good choice for applications in which water or water vapor is present because it is hydrophilic and easily absorbs water — a chemical reaction known as hydrolysis. This reaction can result in decomposition of the insulation. Polyimide is also vulnerable to arc-tracking when a damaged wire sustains a momentary short circuit and creates a carbon path in the insulation. This conductive carbon path can later support an arc that ignites the wire and other wires in the bundle.

Figure 3: Properties of Polyimide

	Pros	**Cons**
Electrical	Dielectric withstanding voltage	Arc tracking High dielectric constant
Mechanical	High cut-through resistance Abrasion resistance	Embrittlement Cracking
Environmental	High temperature High radiation resistance	Hydrophilic Hydrolysis
Application Constraints	Primarily used for conductor insulation, flex circuits	Not appropriate for wet environment

Fluoropolymers and Engineered Fluoropolymers (Figure 4) such as FEP, PFA, PTFE, and engineered PTFE are excellent as insulation and jacket materials, particularly in applications when the cost of system failure is high. The dielectric withstanding voltage of fluoropolymers is among the highest of any insulation material. Fluoropolymers can withstand extreme temperatures, but each material has its own range: FEP can handle temperatures ranging from -250°C to 150°C, while PFA ranges from -250°C to 200°C. PTFE is suitable for temperatures from cryogenic to 260°C without losing flexibility. Fluoropolymers can also withstand exposure to chemicals, acids, and aggressive solvents, and they are naturally flame retardant, which enables them to meet safety and performance standards easily. PTFE and its co-polymers also have the benefit of low outgassing, critical for ultra-high vacuum (UHV) environments. Most fluoropolymers are flexible, but like temperature-resistance, flexibility varies depending on the specific material, with PFA being the stiffest, then FEP, PTFE, and engineered PTFE being the most flexible. In addition, anything that is added to a cable’s insulation, jacket, conductors, or shield wires will outgas in a vacuum. Outgassing is not bad in itself; however, when materials outgas, the gas condenses on cooler surfaces, which are typically the work surfaces in the application area. For example, in a satellite, optics can become fogged by silicone oil or other processing lubricants that outgas from a cable. PTFE is chemically inert and does not contain any process additives, oils, lubricants, or plasticizers, which makes it the best material for vacuum environments.

Figure 4: Properties of Fluoropolymers

	Pros	Cons
Electrical	Dielectric withstanding voltage Dielectric constant	—
Mechanical	Flexibility Tensile strength	Abrasion and cut-through resistance
Environmental	Liquid and gas resistance Temperature and UV resistance No outgassing Coefficient of friction	Radiation resistance
Application Constraints	Used as insulation, dielectric, and jackets Flame resistance Performance standards	Additional processing required

One of the few weaknesses of fluoropolymers is that they are not very resistant to abrasion and cut-through. Certain fluoropolymers can be engineered to enhance their physical, chemical, and electromagnetic attributes, which improves a cable's ability to withstand the specific challenges of an application. For example, ethylene tetrafluoroethylene (ETFE) can be irradiated to improve its mechanical properties and chemical resistance; however, irradiation increases stiffness, so there is a significant decrease in flexibility. On the other hand, PTFE is naturally thermal-resistant and chemically inert, so its excellent temperature and chemical properties are not altered when engineered to enhance electrical or mechanical attributes. The microstructure of PTFE can be modified, which creates billions of nodes and fibrils. These structures can be engineered in very specific ways to enhance the properties of PTFE. Re-enforcement of polymer resins creates composite films with high durability, thermal stability, and excellent electrical performance.

W. L. Gore & Associates has developed proprietary technologies that allow fluoropolymers to be engineered so it can withstand a wide variety of environmental and mechanical challenges (Figure 5). For example, the dielectric materials used to insulate conductors can significantly affect attenuation, cable size, and flexibility. The lower the dielectric loss, the less attenuation the cable exhibits. Typical fluoropolymers used in cable insulation have a dielectric loss of 2.1. If cable size is an issue, fluoropolymers can be engineered to have a dielectric constant of 1.3 — the lowest dielectric constant of any material used as a dielectric in cables and a value that approaches the dielectric constant of air. A low dielectric constant means that less material is required to achieve the desired impedance, which in turn means a smaller cable diameter and reduced weight. Or, dielectric withstanding voltage can be increased, resulting in improved electrical endurance at the same wall size, or conversely, smaller wall size without compromising electrical performance. Gore's engineered fluoropolymers are incredibly consistent, allowing for excellent impedance control, minimal impedance variation, and excellent signal balance, which reduce common mode conversion.

Another version of engineered fluoropolymers can be made semi-conductive and used to increase the effectiveness of a cable's shield. For issues of abrasion or cut-through resistance, Gore has engineered fluoropolymers to attain a tensile strength that is 50 times greater than standard PTFE. And for extreme temperatures, Gore has engineered fluoropolymers to withstand temperatures from cryogenic to 300°C. Most important, however, is that these attributes can be enhanced while maintaining the other favorable properties of PTFE such as temperature range, low coefficient of friction, chemical resistance, and low outgassing. This ability to engineer the physical and electromagnetic attributes of fluoropolymers results in Gore's cables being smaller and more flexible without compromising signal quality.

Figure 5: Enhanced Properties of Gore's Engineered Fluoropolymers

	Properties
Electrical	Dielectric constant Dielectric withstanding voltage
Mechanical	Abrasion and cut-through resistance Flexibility Tensile strength
Environmental	Temperature and UV resistance Chemical resistance Coefficient of friction Outgassing
Application Constraints	Liquid and gas resistance Biocompatibility Weight and size

Verifying the Cable Design

The second phase of designing a cable system is verifying that it is, in fact, fit for the intended application. It is critical to select a manufacturer that understands the challenges of your industry and your application. After all, the issues that affect a cable's performance in a spacecraft are not necessarily the same as those that affect a cable in a clean manufacturing environment. To avoid cable failure in harsh environments, it may be necessary for the manufacturer to develop tests that evaluate electrical performance while simulating mechanical and environmental stress similar to that in your application. At Gore, we have a core value that we call 'fitness for use,' which means that our products do what we say they do. Therefore, we have developed state-of-the-art labs around the world where we test the electrical, mechanical, and environmental performance of cable systems.

Most manufacturers perform some level of electrical testing on every cable design before it is approved for delivery, so your basic electrical requirements can be checked against the specifications for the cable. Some industries have defined safety, environmental, and performance-related standards for cables, but many applications in harsh environments force you to go beyond the standards. In these kinds of situations, you should find out what level of performance testing, if any, the manufacturer has done to ensure that the cable will perform reliably in your application. What's most important is having a thin wall insulation with high dielectric withstanding voltage. For example, if the cable has 100 Ohm differential pairs that will be used in a flexing application, then the cable's impedance should be monitored while flex testing is performed. It is essential to monitor electrical performance and signal integrity throughout testing, and the specific type of testing that is needed depends on the environmental constraints of your application.

Mechanical testing verifies electrical performance while the cable is working in the conditions of your application — conditions such as crushing, abrasion, potential cut-through, tight bending, continuous flexing, shock, and vibration. For example, if the cable is to be used on a robot in a manufacturing environment, its signal performance and attenuation should be tested while the cable is being flexed at the same rate and under the same conditions in which it will actually be used. Not only should you ensure that the cable can withstand the mechanical stress, but you also need to know that it will maintain signal integrity for the life of the system.

The cable's electrical performance should also be measured while simulating the environmental conditions in which it will operate — conditions such as temperature, altitude, and pressure extremes; vibration and acceleration; exposure to liquids or gas; or humidity. For example, if you are designing a cable used in an aircraft, temperature cycling and altitude testing will simulate the environment in combination with several mechanical tests. Adding a clamp force during the temperature cycling test allows monitoring of the insulation's dielectric withstanding voltage to see how the jacket and conductor change. Also, it is important to monitor impedance during altitude change, mechanical shock, and vibration tests. After the cable is put through these tests, the manufacturer should again verify the electrical performance, insulation, and jacket materials because you want to ensure that the cable will perform reliability throughout the life of the system.

Understanding Total Cost of Ownership

Throughout the cable selection process, it is important to consider the total cost of ownership because unfortunately cost is frequently a determining factor. For products that will be used in harsh environments, the consequences of the cable system being compromised or failing are usually high, and the total cost of ownership includes much more than the initial cost to purchase the cable. Total costs should include installation, maintenance, and replacement costs; manufacturing downtime and losses due to bad product; and most of all, safety issues. For example, in the aerospace industry reducing mass is a critical issue because every gram of weight adds an additional $60 to the cost of launching a spacecraft. Gore has developed extremely durable cable systems that bundle engineered fluoropolymers with other materials specifically for lightweight applications. These systems have enabled aeronautical engineers to reduce cable size by as much as 40 percent, which directly relates to reductions in their launch costs. Another example is a semiconductor manufacturer that was losing millions of dollars in wasted product due to particulation in the production line. By switching to cables specifically designed to eliminate particulation, yield has significantly increased and downtime has decreased, which has reduced total operating costs. Both of these examples illustrate the impact that cable systems have on total cost of ownership. Before selecting any cable system, you should do a similar cost analysis to ensure that you have considered the full impact of cable failure.

Sample Applications in Harsh Environments

Although most cables offer reliable electrical performance that meets industry standards, maintaining consistent signal integrity when exposed to harsh conditions requires going beyond minimum industry standards. The interaction among electrical, mechanical, environmental, and application-specific constraints can quickly compromise a cable's performance and life if it is not engineered to withstand challenging conditions of applications such as clean manufacturing, oil and gas, aircraft, and spaceflight.

Clean Manufacturing Applications

Signal integrity and EMI shielding are critical for operating the equipment in clean manufacturing applications such as semiconductor and flat panel inspection (Figure 6). The signal lines are affected by the power supplies, motors, and power cables that are close by, so the cable shielding must attenuate all the external noise while be continuously flexed. Coaxial and twisted pair shields, which also affect signal attenuation and impedance, must remain stable during flexing, or critical video and control signals will be lost.

Eliminating particulation is one of the biggest issues in clean manufacturing environments. These applications usually require high acceleration and continuous flexing, which can cause abrasion on the cable jacket and extreme stress on the cable components. When cables flex, they rub against other cables and surfaces like cable chains, which can create particulates if the cable jacket is not abrasion-resistant.

Planar cables offer excellent signal integrity and flex life because the jacket manages all of the signal and power lines. This construction eliminates corkscrew action that occurs as round cables flex. Also, the flat geometry of planar cables reduces friction by distributing force, which results in less particulation. With a bend radius of less than two inches (51 millimeters), these cables have a longer flex life. Planar cable architecture allows components to be organized and grouped for easier termination and improved routing.

Figure 6: Clean Manufacturing Constraints

	Properties
Electrical	EMI Conductivity Attenuation Impedance
Mechanical	Acceleration Abrasion Flexing
Environmental	Friction
Application Constraints	Routing issues Cable size Particulation

Oil and Gas Applications

Wire and cables are critical in supplying power to the motors, generators, and heaters used in underground oil and gas applications (Figure 7). Downhole environments have extreme mechanical demands. For example, cables can be exposed to hydrostatic pressures exceeding 10,000 psi (70 MegaPascals) and temperatures above 200°C. Wires are pulled through machined passages and can be scraped or cut on a variety of sharp edges. And the use of steam, water, and very aggressive chemicals (e.g., synthetic oil, hydrogen sulfide, acid, and methane) can compromise the jacket materials. Cable size is also crucial in these applications because space for cable is limited by tubing size and machined passages.

Very few insulation materials can survive this environment because they must have a high resistance to creep or cold flow and a high resistance to notch propagation. Conductor insulation with high dielectric withstanding voltage can reduce the size of the cable while still meeting voltage requirements. Jacket materials should be carefully evaluated to ensure that they will withstand exposure to the harsh chemicals and abrasive environment in which they are to be used.

Figure 7: Oil and Gas Constraints

	Properties
Electrical	Dielectric withstanding voltage Power transmission
Mechanical	Scrape and cut abrasion Tensile strength Creep resistance
Environmental	Chemical and hydrolysis Extreme temperatures High pressure
Application Constraints	Small size Chemicals at high temperature and pressure

Aircraft Applications

The two most important issues for aircraft applications are safety and weight (Figure 8). Cable shielding is very important due to many sources of electromagnetic interference (EMI) found on an aircraft. The increased use of composite materials in aircraft structures has completely changed the electrical characteristics of modern aircraft in terms of EMI. Improving shielding at the cable bundle level is required to protect electronic systems from these effects.

Mechanical stress includes vibration, acceleration loads, and potential damage during installation and maintenance. It is really important to note that any force that changes the geometry of the cable has the potential to create signal integrity issues. For example, tie-wraps and clamps can cause permanent damage to data cables. This damage can cause signal reflections and other losses in the cable. Signal integrity can also be affected by cable length and the choice of dielectric material.

The aircraft environment exposes cables to contaminants such as de-icing fluids, hydraulic fluids, cleaning solutions, and water. Cables are also exposed to extreme temperatures based on proximity to hot zones on the aircraft and the effects of altitude.

Operating costs and capability are directly related to the weight of the aircraft, so wire and cable materials should be electrically and mechanically robust, but they should not add significant mass to the aircraft. The ideal cable provides maximum performance with smallest size and lowest weight.

Figure 8: Aircraft Constraints

	Properties
Electrical	Conductivity Attenuation EMI
Mechanical	Vibration Abrasion
Environmental	Temperature Contaminants
Application Constraints	Lightest weight Smallest diameter Performance criteria

Spaceflight Applications

Spaceflight applications have demanding requirements that must be guaranteed for the life of the mission (Figure 9). After all, hardware cannot be repaired or replaced after launch. High-performance cables are required to provide reliable data transmission between spacecraft systems. The safety and success of the mission relies on the reliability of those cables. Data cables should provide low capacitance, low signal attenuation, and constant characteristic impedance along the entire length of the cable.

All components of the spacecraft must withstand the shock and vibration levels of launch. Repeatable and stable performance with flexure is important, and jacket materials need to be able to withstand the abrasion that occurs with flexure. Cables in spaceflight are exposed to temperatures ranging from -200°C to +200°C.

Good material selections can result in reduced cable diameters. Small cables are easier to route and their lighter weight helps address mass budgets. It is important to use materials that provide mechanical durability without compromising the weight savings. Standard flexible cables with fluorocarbon jackets and dielectrics deteriorate when exposed to high levels of radiation. Therefore, material selection becomes critical to ensure that cables remain structurally sound during radiation exposure and can achieve the required electrical performance.

Figure 9: Spaceflight Constraints

	Properties
Electrical	Attenuation Conductivity EMI
Mechanical	Vibration Flexure
Environmental	Radiation Temperature
Application Constraints	Lightest weight Smallest diameter Performance criteria

Cable Selection Checklist

The following checklist will assist you in identifying the issues you need to discuss with your cable manufacturer when selecting the right cable for your specific application and environment. Although you may not be able to complete all of the sections, it will be helpful if you are as specific as possible in the data you can provide.

Type of Application

☐ In-flight space:	☐ Ground test space:
☐ Military aircraft:	☐ Commercial aircraft:
☐ Military equipment:	☐ Microwave/RF:
☐ Geophysical:	☐ Cleanroom:
☐ Other:	

General Requirements

Cable use length:	Maximum cable diameter:
Total number of cables:	Minimum cable diameter:
Data transmission: ☐ Digital ☐ Analog	Protocol/data rate:
Other:	

Potential Electrical Issues

Voltage rating:	Signal/noise requirements:
Impedance:	Crosstalk:
Electrostatic discharge: ☐ Yes ☐ No	Attenuation:
Electromagnetic Interference: ☐ Yes ☐ No	
Other:	

Potential Mechanical Issues

Flexing required: ☐ Yes ☐ No Cycles:	Flex type: ☐ Rolling ☐ Tic-toc ☐ Torsion ☐ Random
Bend radius/torsion angle:	Stroke length:
Acceleration rate:	Speed:
Other:	

Potential Environmental Issues

Sharp edges: ☐ Yes ☐ No	Abrasion: ☐ Yes ☐ No
Maximum temperature:	Minimum temperature:
Humidity: ☐ Yes ☐ No	Chemical exposure type:
Liquid exposure type:	Gas exposure type:
Other contaminants:	Outgassing: ☐ Yes ☐ No
Shock/vibration: ☐ Yes ☐ No	Radiation: ☐ Yes ☐ No
Vacuum (Torr):	Cleanroom class:
Other:	

Application–Specific Issues	
Weight: ☐ Yes ☐ No	Specific weight requirement:
Routing: ☐ Yes ☐ No	Cable track used:
Human manipulation: ☐ Yes ☐ No	Crush protection: ☐ Yes ☐ No
Connector type:	Regulatory requirements:
Backshell:	
☐ Other:	
Total Cost of Ownership	
Installation costs:	Impact on operating costs:
Maintenance frequency:	Maintenance costs:
Replacement frequency:	Replacement costs:
Manufacturing downtime frequency:	Downtime costs:
Bad product percentage:	Bad product costs:
Safety considerations:	Safety costs:
Other:	

Application Notes:

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