Technical Information

Do Slip Rings Fit in the Digital World?

Introduction

As the analog world gives way to the digital in more and more applications, design engineers are faced with replacing traditional analog components with their digital equivalents. Nowhere is this more evident than in the electro-mechanical world. Analog resolvers are being replaced by digital encoders and digital drive circuitry has become commonplace for motor control. When part of the system has to rotate, and a rotary connection for power and digital data is required, what does the designer do? Can the traditional slip ring with its sliding electrical contacts handle the job?

The Problem

Slip rings were originally designed to carry AC and DC power from a rotating platform to a stationary structure, or vice versa. Many applications also required, and still require, the transmission of relatively low bandwidth analog and digital control signals. In this environment, the traditional slip ring performs extremely well. Modern control systems now also require the transmission of high bandwidth analog and digital signals through the slip rings. Typical examples are analog and digital video signals. Until recently, bandwidths measured in the tens of megahertz were generally adequate. Today, and in the future, bandwidths will be required that are orders of magnitudes higher.

Basic Slip Ring Configuration

A basic slip ring, shown schematically in Figure 1, is composed of four elements, or components:

- A ring assembly that provides one or more circuit paths. Each ring is electrically conductive and provides a circuit path over a full 360 degrees of rotation of the ring assembly.
- Brushes provide electrical contact between the rotating (usually the ring) and the stationary parts of the assembly. The brushes ride on the ring, and are mounted in a brush block assembly, usually on the stationary structure.
- Input and output leads that connect the ring and brushes to the outside world.
- Connectors that connect to the slip ring assembly wiring. Connectors are optional, and are often specified by the customer.

Factors Affecting Slip Ring Performance

The following factors will determine the data rate that can be transmitted through a slip ring:

- The frequency response, or insertion loss, of the rings and brushes.
- The impedance, as a function of frequency, of the assembly.
- The differential time delay, as a function of frequency, through the device.
- Crosstalk between circuits.
- Frequency response of the leads and connectors.

The primary factor is frequency response, or bandwidth. Digital data streams will begin to suffer errors from insufficient bandwidth when the digital signal is attenuated, or distorted, to such an extent that the digital receivers cannot properly recognize the received signal. A digital signal is composed of a fundamental frequency at the basic signaling rate, as well as the odd harmonics of the fundamental. The required bandwidth of the slip ring may be several times the data rate.

For example, a 1 MHZ square wave may require a bandwidth of 5 or 7 MHz (5th and 7th harmonics). As the data rate is increased, eventually the harmonics is matched to the external system input and output impedances. Using transmission line theory, the designer will vary ring geometry, spacing, and dielectric material, to obtain the needed impedance. Often a ring and brush impedance of 70 to 150 ohms is obtainable, which should be well suited for many of today's digital systems. As a rule of thumb, a smaller diameter ring will result in a higher data rate. For very high data rates and / or large ring diameters, multiple taps and multiple brushes are often used to minimize signal path lengths.

For optimal performance, high frequency digital signals should be driven differentially, and connected to the slip ring using twisted pair, shielded cable such as CAT5 or CAT5e. This same wiring, including the shield, should be continued through the slip ring. Ideally, the internal slip ring wiring would also be twisted pair shielded cable, however, this may not always be possible due to physical constraints. Connectors, if used, must also be designed, or chosen, to have an impedance and frequency response consistent with system requirements.

Crosstalk between sensitive circuits will also be minimized by proper lead routing and shielding. Sensitive circuits (victims) should be routed within the slip ring as far away from noisy circuits (sources) as possible. Also, all unused circuits should be terminated in the characteristic impedance of the cables used.

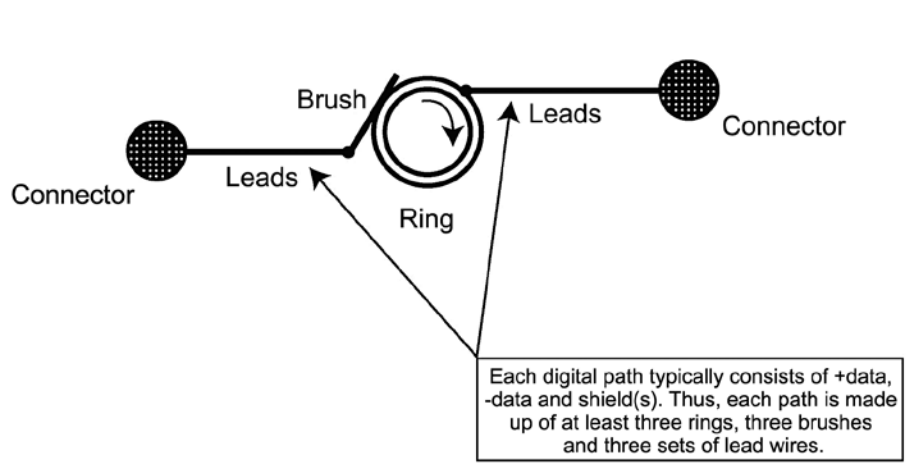
Specifying a High Performance Slip Ring

This article has attempted to make users aware of factors that determine slip ring performance, and of the limitations imposed by the total system in which the slip ring must operate. It is no longer adequate to simply request a device "that will transmit 50 mbs." The best solution is obtained when the entire system is known and understood, and usually requires a compromise between performance, size, weight, number of circuits, external factors, and cost.

The following parameters should be specified to assure satisfactory operation in a specific application:

- Data bus used to transmit data, i.e. Profibus, Ethernet, Firewire
- Cable type used to connect to the slip ring
- Maximum cable length between transmitter and receiver
- Maximum data rate
- Maximum error rate that can be tolerated

Figure 1 - Basic Slip Ring



- Maximum size, i.e. diameter and length
- Number of circuits and their ratings, i.e. voltage, current
- Maximum operating speed of rotation
- Operating environment

Moog Components Group has thousands of slip ring designs, including many standard “off the shelf” designs. Our engineering staff is available to modify an existing design or to provide a completely new design, if required. However, customers are encouraged to evaluate a standard design before requesting modifications that may not be needed.

We have tested many of our standard designs for high data rate performance. Devices with through bores of up to six inches have been tested. Testing has included insertion loss, frequency response, bit error rates, differential time delay, and impedance over frequency. In some cases we have identified, and implemented, design modifications to significantly improve performance. As a general statement, all devices that have been tested will support digital data rates of at least 50 mbs. This verifies that our standard units will operate successfully in a wide variety of standard data systems in use world–wide. These include, but are not limited to: Device Net, CAN Open, Profibus, and Ethernet 10Base T. Additionally, several models tested are suitable for Ethernet 100Base T, and Firewire at 400 mbs.

For the most demanding applications, we have integrated single channel and multiple channel fiber optic rotary joints (FORJs) into our standard slip ring assemblies. The FORJ is used to carry the very high data rate signals, or those circuits requiring very low cross talk or high noise immunity, while conventional slip ring technology is used for transmitting power and other control signals. We can also provide the hardware to perform the electrical- to optical- back to electrical conversion.

Slip Ring Fundamentals

A standard slip ring has four elements, or components:

- A **ring assembly** provides one or more circuit paths. Each ring is electrically conductive and provides a circuit path over a full 360° of rotation of the ring assembly.
- **Brushes** provide electrical contact between the rotating (usually the ring) and the stationary parts of the assembly. The brushes ride on the ring, and are mounted in a brush block assembly, usually on the stationary structure.
- Input and output **leads** connect the ring and brushes to the outside world.
- **Connectors** link to the slip ring assembly wiring. They are optional and often specified by the customer.

Applications

Industrial and Commercial

- Semiconductor equipment
- Industrial machinery
- Robotics
- Medical equipment
- Packaging machines
- Cable reels
- Laboratory equipment
- CCTV camera mounts
- Lighting
- Rotary index tables
- Rate tables
- Medical CT scanners
- Amusement rides
- Flight simulation

Aerospace and Military

- Inertial navigation systems
- Missile weapon systems
- Satellite assemblies
- Unmanned aerial vehicles
- Airborne camera platforms
- Shipboard communication systems
- Radar
- Tanks
- Light armored vehicles
- Helicopters
- Aircraft

Marine

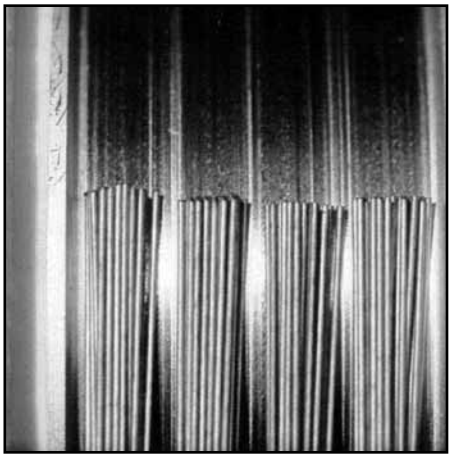
- Remote operated vehicles (ROV)
- Seismic surveying
- Oceanographic winches
- Subsea communications and control
- Floating production, storage and offshore loading (FPSO)
- Diving
- Marine instrumentation
- Downhole / wirelogging and drilling

Moog Components Group fiber brush contact technology was initially developed to solve a critical problem in military / aerospace applications. With many years of successful performance in highly critical slip ring applications, the fiber brush technology is available in commercial products as well.

Fiber Brush Technology For Commercial / Industrial Applications

For many years the traditional design for rotary contact slip rings used either a lubricated monofilament brush or a self-lubricating composite brush. While these traditional approaches have proven to be successful through testing and field experience, improved performance is always desirable. To that end, we developed the fiber brush technology. A chart comparing the advantages of different contact technologies is shown on page 161.

Today’s industrial / commercial equipment slip ring requirements are becoming more and more demanding. High operational speeds, long life, no maintenance, and data transfer capability, are the general expectations in slip ring performance. Taking advantage of the developments done in our Advanced Materials Research and Development Department, we have transferred the fiber brush technology to cost effective



commercially available products to address today’s critical applications.
Military / aerospace applications require slip rings that provide minimal debris generation, low electrical noise, both high and low current transmission capabilities, low outgassing and a long operational life. They must also operate flawlessly in a wide operating temperature range, and at a variety of brush ring surface speeds, as well as in air or vacuum conditions.

Fiber Brush Contact Technology

Fiber brush is the term for a particular design of sliding electrical contacts. Fiber brushes are simply a group of individual metal fibers (wires) that are collimated by and terminated into a metal tube as illustrated in the photo on the left. In this cantilevered design, the free, unterminated end of the fiber brush bundle rides in a groove on the ring surface.

Many Advantages

Fiber brushes have many distinct and measurable advantages over conventional slip ring contacts in military / aerospace applications:

- Multiple points of ring contact per brush bundle
- Ability to perform in ambient conditions as well as in vacuum conditions
- Contact surfaces that do not require lubrication
- Long life
- Low contact force per fiber
- Low contact wear rates
- High power circuit density
- Low dynamic contact resistance (noise)
- High and low current carrying abilities
- Low outgassing
- Very little debris generation
- Wide operating temperature range
- Wide range of brush / ring surface speeds

Proven Performance

As an alternative to traditional sliding contact designs, Moog Components Group fiber brush was developed to meet the increasing demands of slip ring performance. The technology has been used in many demanding applications such as:

- CT Scan systems
- High speed testing
- Robotic welding systems
- High-speed, in-line inspection systems
- Radar platforms

A Growing History

Moog Components Group started in 1953 as a supplier of high reliability slip rings to the military and aerospace community. Over the years we have developed a reputation as a quality and precision supplier for space, weapons, aircraft and other mission critical program requirements. It is this stringent quality and technology that has now carried over to our commercial products group. We have adapted technology designed and produced for defense applications for use in our growing line of standard commercial products.

All of our experience and expertise helps our customers in a very real measurable fashion. We make a point to fully understand our customers' applications and by teaming with our customers we are able to efficiently coordinate their needs with our engineering and production departments. We have for years had a Commercial Slip Ring Team that provides focus allowing us to slash lead times and develop special designs fast and accurately.

Technology Comparison

Generally, aerospace slip rings and brushes (sliding electrical contacts) are designed using traditional contact technologies such as lubricated monofilament wire brushes or self-lubricated composite brushes. These approaches have been proven successful many times through testing and actual flight experience. There are, however, some disadvantages to these approaches.

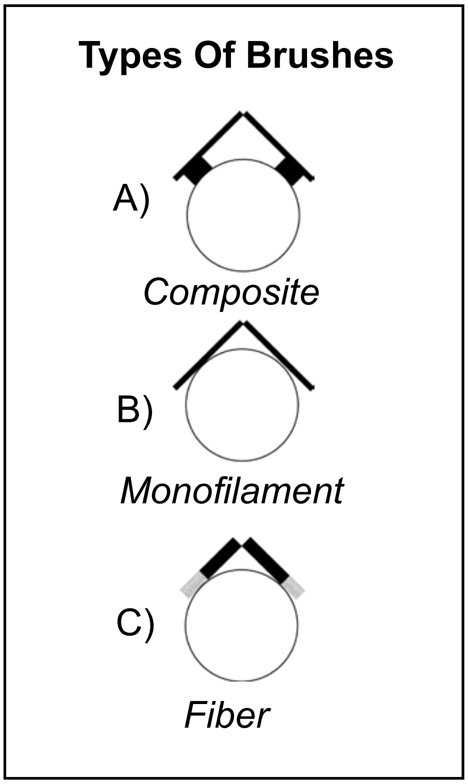
Composite Brushes

Unlike monofilament brushes, composite brushes provide their own lubrication through the addition of an embedded solid lubricant to the composition of the brush. The nature of this lubrication mechanism requires that the brush must experience wear to transfer the lubricant from the brush to the ring. This wear results in some amount of electrically conductive debris being generated within the slip ring. While small amounts of this debris can generally be tolerated if proper design procedures are followed, the extended life requirements of new aerospace slip rings could result in the generation of intolerable amounts of this conductive debris.

Also, the contact materials used in composite brush slip ring designs can be contaminated by absorption of airborne gasses. The principal form of this contamination is silver sulfide, which appears as tarnish. When exposed to temperatures of less than 178°C, these films have semiconducting properties (increase in electrical conductivity with increased temperature). The presence of silver sulfide films at low temperatures may cause unacceptably high contact resistance on low current circuits. Below is a chart that summarizes the characteristics of the different types of contact technologies.

Monofilament Brushes

Aerospace rated monofilament brushes depend on intentional lubrication of the contact surfaces to perform properly. Many of the liquid lubricants used will not meet NASA outgassing requirements, and the ones that do typically have poor viscosity characteristics at low temperatures. Designs using this contact technology must be analyzed to ensure that sufficient lubrication is maintained throughout the system life requirements.



Materials Choices

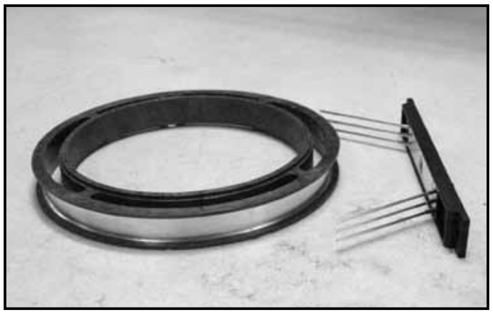
One of the most important features of any military or aerospace design is the choice of component materials. Materials must be carefully chosen to reduce outgassing, control dissimilar thermal expansions, reduce galvanic corrosion, and provide nuclear hardening, among other concerns. Materials choices for fiber brush slip rings are much the same as used in traditional slip ring designs with the major exception of the contacts. Fiber brush contacts (fiber and ring surfaces) can be manufactured using alloys of copper, gold, silver and palladium. The actual choice of contact materials depends largely on the electrical requirements of the slip ring. Moog Components Group controls all materials and materials suppliers to verify and ensure consistent quality.

Commercial Fiber Brush Products

Our commercial fiber brush products include a variety of products with power capabilities up to 100 amps and down to low level data transfer, all within the same housed design. These products are highly configurable to meet your requirements with readily available products.

Commercial Separate Products

These products are highly configurable to meet your requirements with readily available products.



In addition to these enclosed slip ring capsules we also provide fiber brush separates. When a "self-contained" capsule is not practical due to system size or cost constraints, fiber brush separates are an excellent alternative. These separates are available in the following configurations:

Bore Size	Current
1.8"	2 amps
2.8"	5 amps 10 amps 30 amps 50 amps
4.0"	10 amps 30 amps 50 amps

Properly mounted and aligned, fiber brush separates provide the same exceptional performance characteristics of our self-contained capsule designs.

Our Staff

Our staff includes electrical, mechanical, manufacturing and software engineers, metallurgists, chemists, physicists and materials scientists. Our emphasis on research and product development has provided us with the expertise to solve real-life manufacturing problems. Using state-of-the-art tools in our complete analytical facility, our capabilities include a full range of environmental test, calibration and inspection services. We have recognized expertise in tribology (the science of friction and wear), precision gearing, magnetic circuit design, PWM amplifier design and in the supporting materials sciences.

Our engineers can work from your designs, or create a custom design for you.

Consistent Quality

Moog Components Group places a continuing emphasis on quality manufacturing and product development to ensure that our products meet our customer's requirements as well as our stringent quality goals. We have committed to the Total Quality Management Program with a policy of "Do It Right the First Time" and a goal of "Zero Defects". We are ISO 9001 Certified to ensure the consistent quality and reliable performance of our products.

The newest initiative of our division is Demand Flow® Technology (DFT). DFT is a demand driven manufacturing flow system that economically manages in-process inventory. The concept operates with a "line-of-sight" premise which provides visibility for all in-process work. This concept has helped the division be more efficient and flexible to customer schedule changes, reduced inventories and improved organizational operations. Benefits include streamlined processes to accommodate jobs with a quick turn-around, reduced cycle time to cut costs, and greater customer responsiveness.

(1) Roberts E.W., Sliding Electrical Contracts in Space: Observations on Existing Technology and New Trends in Low-Speed Applications, European Space Tribology Laboratory.

Demand Flow® is a registered trademark of the J_c-I-T Institute of Technology, Inc.

Comparison of sliding electrical contacts for space applications.

Composite Brushes Ag / MoS_2 / Graphite	Monofilament Brushes Lubricated	Fiber Brushes Unlubricated
Most flight history	Considerable flight history	Growing flight history
Meets outgassing requirements	Does not meet outgassing requirements	Meets outgassing requirements
Self lubricating contacts (solid lubricant in brushes)	Requires liquid lubricant on contact surface	No oil or dry film lubricant application required
Requires largest ring-to-ring axial pitch	Requires smallest axial pitch (50% of composite brush pitch)	Requires less axial pitch than composites (70% of composite brush pitch)
Manufacture subject to greatest number of process variables	Manufacture subject to few process variables	Manufacture subject to few process variables
Greatest amount of wear debris generation (approximately 100 times the wear rate of fiber or monofilament brushes)	Much smaller amount of wear debris generation than composite brushes	Smaller amount of wear debris generation than composite and monofilament brushes
High electrical noise if operated in humid environment	Low electrical noise in air and vacuum	Low electrical noise in air and vacuum
Must operate in vacuum or dry inert atmosphere	Operational in air or vacuum with lubricant present	Operational in air or vacuum
Wide operating temperature range	Viscosity limited operating temperature range	Wide operating temperature range
Wide range of surface speeds	Limited range of surface speeds	Wide range of surface speeds