Application Note

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ENABLING TECHNOLOGIES

ARMORED VEHICLE SLIP RING

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INTRODUCTION

There are five key technologies that could be considered “enabling” for current, state-of-the-art armored vehicle turret rotary joints 1) the fiber brush contact system; 2) fluid rotary joint (FRU) technology; 3) broadband slip ring technology 4 fiber optic rotary joints (both on-axis and off-axis), and 5) multiplexing technologies. Not every platform requires all of these technologies, but turret designers should understand the advantages that they offer to new designs. These solutions will be discussed to review the advantages of each technology in armored vehicle turret applications.

Fiber Brush Contact System

Although many new turret slip rings have fluid transfer and high data rate functionality requirements, it should be emphasized that the power carrying function is critical and presents some unique issues due to the increased voltage levels over traditional turret slip rings and some very high current ratings. The ideal slip ring contact material for a high reliability slip ring application would have the following properties:

1. Low wear debris generation
2. Good conductivity
3. Scaleable to allow high power as well as low power as well as signals
4. Low wear rate for long life and high reliability
5. No maintenance required

MCG has developed fiber brush technology which meets all of these requirements. The fiber brush design involves the bundling of multiple metal filaments into a compact multi-fiber electrical contact. Fiber brushes provide long life, high current densities, and low wear debris. Typically, these fibers are noble metal and the ring on which the brush operates is noble metal plated. The use of noble metals prevents oxides and coating from forming on the contacts and allows very light contact forces. A very low wear rate, often without the use of contact lubricant, is achieved by the fiber brush technology primarily as a result of very low contact forces. The multiple metal fibers provide good conductivity and high current density, so the fiber brush can be used for both power and signal. The fiber brush is also less sensitive to the humidity and environmental concerns of the traditional graphitic power contacts. As a final benefit, and the most important to meet high reliability requirements, the fiber brush produces negligible wear debris. Figure 1 shows a comparison of sliding contact technologies.

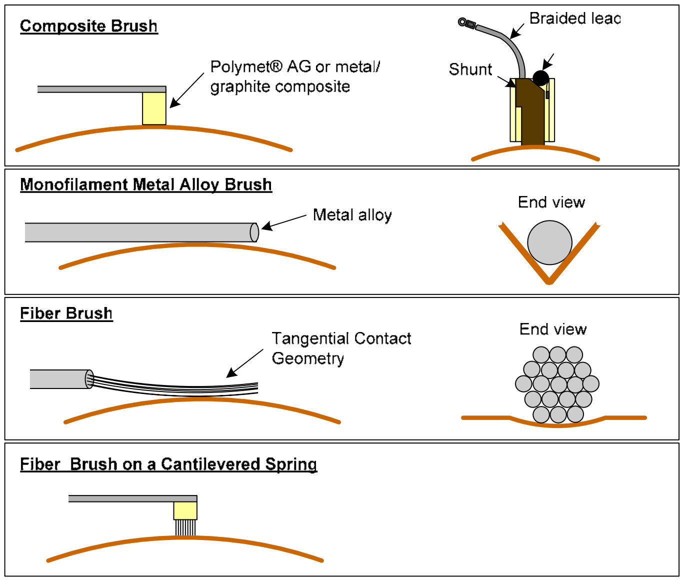

Figure 1. Comparison of Sliding Contact Technologies

The advantage provided by this technology in high power, armored vehicle applications is the avoidance of the risk of short circuits in the power section due to excess wear debris. Many new vehicles are utilizing higher voltage busses, e.g., +/- 305 volts, 200+ amps DC, and these provide a very challenging design task using traditional graphite composite brushes. Large brush tips must be used to carry the high current. These large brush tips produce large amounts of wear debris which reduces the circuit to circuit and circuit to ground voltage isolation. +/- 305 volts can produce significant problem in the presence of large amounts of wear debris.

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The fiber brush solves this design problem using several important characteristics. The fiber brush is a very effective conductor of high current. Tests have demonstrated that the fiber brush has a current density capability of over 10 times that of a standard graphite/ metal brush. This results in a smaller brush to safely carry the rated current. Fiber brushes were initially developed to carry very high currents in high power DC motor and generator applications.

The fiber brush also produces very little wear debris. This means improved long term reliability, lower maintenance, and smaller size and weight of the slip ring assembly. Fiber brushes for the power contacts leaves the slip ring designer with the option of fiber brushes or monofilament brushes on the signal circuits without being concerned about dealing with the graphite dust in the signal section.

This fiber brush design has been proven in a multitude of long wear, extreme environment slip ring applications. Four notable harsh environment applications that have benefited from fiber brush technology have been helicopter rotor de-icing slip rings, radar pedestal slip rings, wind turbine slip rings, and armored vehicle slip rings. Each of these applications requires long life, high conductivity for high power transfer, and operation in very difficult environments.

Although the fiber brush contact force is quite low for low wear and long life, it should be emphasized that the fiber brush is a sliding contact system and produces a wiping action on the contact surface to keep the contact surface clean promoting low contact resistance. This is a distinct advantage of various rolling element solutions that have been around for many years; without this wiping action these rolling contact systems have proven quite unreliable in harsh environment applications.

Fluid Rotary Union

A critical feature of some armored vehicle slip rings is that they transfers coolant and in some cases hydraulic power across the hull-to-turret interface. To decrease assembly size and weight it is important to integrate that fluid transfer capability into the structure of the slip ring assembly. Several features are critical to the success of this design:

- ***Leakage:*** It is critical that proper design techniques be utilized to avoid leakage of the fluid into the slip ring or into the hull environment. Features such as back-up seals, leakage containment features, and special materials and coatings are all important features to consider.
- ***Pressure drop:*** Fluid must be delivered across the SLIP RING without excessive pressure drop.
- ***Maintenance:*** Frequently, commercial rotary unions and fluid lines and are high maintenance items. The integrated fluid rotary union must meet maintainability requirements.
- ***Reliability:*** MCG uses vital lessons learned in earlier armored vehicle slip ring programs to deliver a high reliability seal design in the difficult armored vehicle environment.
- ***Integrated assembly:*** The FRU design is usually integrated into the structure of the slip ring to reduce weight, size, and utilize the cooling properties of the fluid.

The use of radial lip seals for armored vehicle applications is the most practical design approach. This application is well within acceptable parameters of lip seal design. There have been some significant developments in seal technology recently, driven primarily by the automotive industry. The range of polymeric materials has been extended and the types of coating for metal wear surfaces continue to improve in number and quality. Some of the recent studies in shaft surface finish characteristics have been especially helpful in improving lip seal performance. Improved shaft finish processes along with specialized shaft coatings have virtually eliminated shaft wear from seal life considerations. Life predictions for armored vehicle FRU design suggest that a reasonable design goal is 30 million cycles, well in excess of the typical armored vehicle slip ring requirements.

Figure 2 shows notional layout for the fluid rotary joint using a radial lip seal design. This design shows both an “excluder seal” and a back-up seal to help protect the primary seal and to provide leakage control.

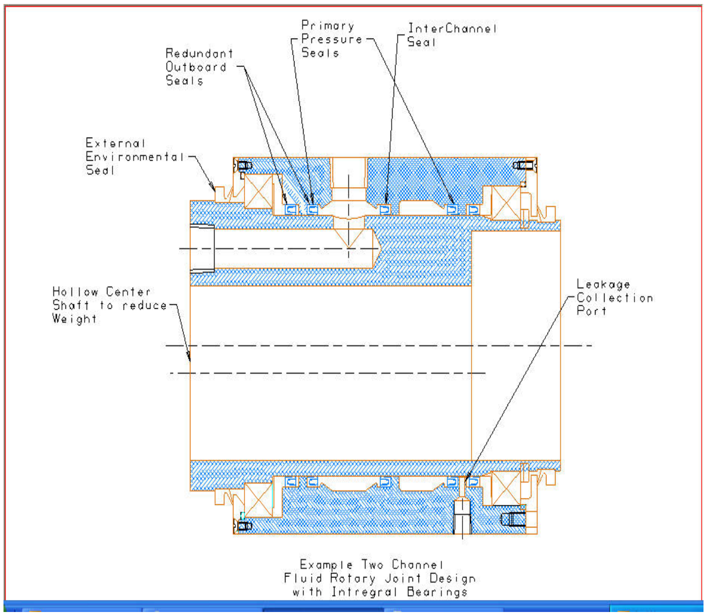

Figure 2. Fluid Rotary Joint with Standard Lip Seal Design

Figure 2 shows two fluid channels that reflect the application requiring a device that will handle a supply and return line. It can be assumed that this supply line will have a positive pressure differential to the return line. This "supply-and-return" design provides individual seals for the supply pass and only one additional (external) seal for the return pass. The two paths share the internal seal. Rotational torque, overall length, and weight are all reduced by this arrangement. The intermediate seal, which faces the high-pressure supply channel, will prevent cross flow between the supply and return.

MCG testing has demonstrated that environmental sealing is critical to long life of the fluid seals, especially in ground applications. The ingress of sand and dust into the fluid-sealing region promotes accelerated wear of the fluid seal. MCG has developed an "excluder seal" design that prevents the introduction of contamination into the fluid seal region and, thereby, improves fluid seal life.

Broadband Slip Ring Technology

MCG has anticipated the requirements for the electrical transmission of error-free high speed data for advanced systems in its research and product development for the past ten years. Various techniques have been developed and patented for the electrical transmission of high speed data through slip rings by matching line impedances and providing good crosstalk isolation between circuits. Various micro-stripline design techniques have been adopted to match the slip ring impedance to the line impedance. The goal is to minimize the transmission line mismatch, as well as the length of the mismatch. One of the best measures of the ability of a slip ring to handle high-speed data is to look at the time domain response and the transformed frequency bandwidth.

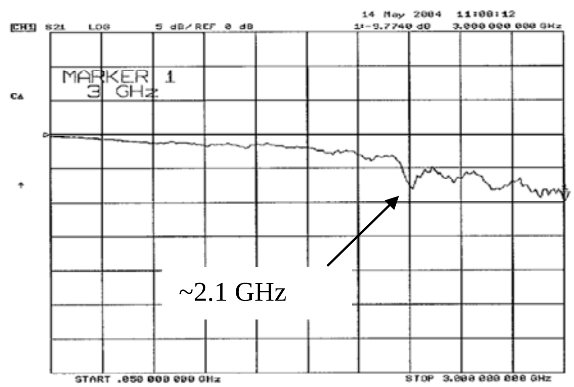

Figure 3. Insertion Loss vs. Frequency on Broadband Slip Ring Design

Much of the analysis and design of these special data lines is performed in the time domain using the analytical techniques discussed in section. However, it is simpler to measure and test the performance in terms of frequency response and bandwidth. A typical expression for this purpose is: 0.5/ rise time (10 to 90% of the waveform) expressed as a frequency bandwidth. As discussed earlier, each digital data format has a transmission line bandwidth requirement that allows the data stream to be transmitted without distortion. Figure 3 for example, shows a slip ring with an effective frequency response out to 2.1 GHz. In addition to the flat frequency response, the techniques utilized in the broadband design provide good crosstalk isolation due to the use of ground planes, good shielding and grounding practices, and the avoidance of big impedance mismatches which result in crosstalk producing radiated fields. The broadband technology is used to produce very clean and isolated serial data and video channels through the slip ring.

Fiber Optic Rotary Joint (FORJ)

MCG has a 25 year experience base with FORJs and it is this FORJ technology that can be used to carry optical high speed data channels through a slip ring assembly. There are two designs that will be utilized in slip rings. In most cases slip rings can utilize on-axis multi-channel FORJ (similar to the MCG's part number FO5707) as shown in Figure 4. However, if the slip ring requires a through-bore an off-axis solution FORJ solution is required. The advantages of the optical solution are immunity from EMI, upgradeability of the optical path for higher data rates, and commonality with present commercial off-axis FORJ designs. The other available options, such as capacitive, RF, and contacting coupling do not offer these advantages, nor do they offer the bandwidth capability that the optical solution does.

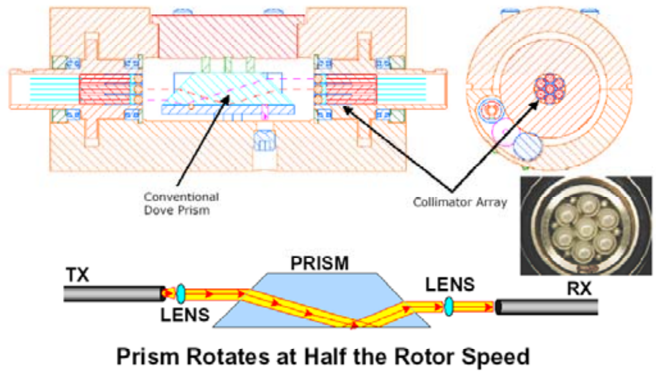

Figure 4. Multichannel On-axis FORJ

On-Axis FORJ

MCG has a number of patents for on-axis FORJs. Development work began on this product in the mid-1980s and product improvements continue. A good example of a FORJ that can be integrated into a slip ring assembly is the Moog multichannel FORJ. The basic feature of this FORJ is the use of a prism as the optical de-rotation media. This FORJ technology uses a common optical path for the transmission of multiple optical signals. This approach allows variability in the number of input and output signals without a change to the core optical device. The number of channels that can be successfully transmitted through the device is a function solely of how many fibers are bundled into the optical aperture. Figure 4 shows 7 fibers, but using small fiber arrays allows as many as 60-70 individual channels to pass through this optical device.

Careful trade-offs should be made to consider the optimum number of discrete optical channels through the FORJ. The number of inputs and outputs are limited by spacing and alignment of the input and output fibers. The goal would be to limit the number of input and output fibers (through multiplexing) to the minimum number. This final number will depend upon a number of overall vehicle system variables (e.g., redundancy techniques, data security requirements, and specific system requirements). These variables will determine the most appropriate discrete signal/ multiplexing strategies.

Off-axis FORJ

MCG began its development work on off-axis fiber optic rotary joints in the 1980s. Several designs were developed to provide a passive fiber link from rotating to stationary end, but these solutions were typically too "lossy" to provide a workable solution to the general user. Whereas prisms and other similar "intermediate optical devices" can be used when the FORJ can occupy the center line, when the centerline is not available, the solution becomes more difficult. The most cost effective and practical approach is to use an "active" design, i.e. signal conditioning is used to offset the "lossy" nature of the off-axis device. Figure 5 shows one of the earliest designs of the off-axis multi-channel FORJ. This assembly has applications in military, as well as industrial applications.

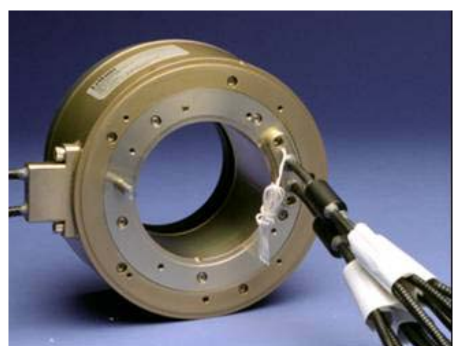

Figure 5. Off-axis Optical FORJ

Multiplexing

In a paper presented to the 2005 Intelligent Vehicle Symposium, MCG stated:

> *There has been a significant amount of investigation into robust, fault tolerant local area network (LAN) architecture of vehicle systems. The primary role of this intravehicle network is to provide the data communications infrastructure for controlling various devices and subsystems within a vehicle. It is also likely that other data buses will exist for various sensor data. The movement towards single or multiple vehicle networks should serve to reduce the number of discrete channels or circuits required through cable harnesses and across rotating platforms as more devices become nodes on a the network. In the case of fiber optic cables there should be a concerted effort to take full advantage of fiber bandwidth to reduce the number of optical fibers required. In many cases this could mean multiplexing some or all of these high- speed data lines onto one or two. Of course redundancy, security, and maintainability requirements will play a critical role in this MUX strategy.*

This summarizes the challenge of today's armored vehicles. With the tremendous bandwidth requirements of the vehicle, multiplexing is essential to allow full utilization of the bandwidth capabilities of optical fibers. Time division multiplexing (TDM) and wavelength division multiplexing (WDM) are the two most commonly used multiplexing techniques and both will play a different and important role in fully utilizing the bandwidth of optical fiber in the SLIP RING.

Time Division Multiplexing (TDM)

Time division multiplexing (TDM) is commonly used to combine video and/or relatively low-rate (typically under 10 Mbps) digital signals. The various signals to be multiplexed are combined into a single high-speed signal that can be subsequently converted to an optical signal or left as a high-speed electrical signal. This multiplexing is accomplished by assigning discrete parts of each signal a time slot (thus "time" division multiplexing) in the outgoing data stream. The single high-speed signal is then transmitted along the appropriate high-speed transmission line and then reconstructed, or broken out into the discrete signals, at the receiving end by a de-multiplexer. Asynchronous signals can be combined by over-sampling using a common clock. Although the output is often an optical signal, TDM is essentially an electronic process and normally accomplished using electronic parallel-to-serial converters like the Agilent G-Link or the Cypress Hotlink.

Figure 6 shows the principle of combining a number of signals and launching them as an optical signal onto an optical fiber. The rotational interface is accomplished with a FORJ and then de-multiplexed at the output end. This illustration shows bi-directional communication using different wavelengths of light through a single channel. This TDM multiplexing technology has an extensive heritage in harsh-environment unmanned vehicle applications. This technology is used extensively in tethered, remotely operated vehicles (ROVs) for underwater applications. These work-class ROVs are used in structure inspection, structure repair, and exploration. Many of these vehicles transmit multiplexed control data lines, video, and all other signals bi-directionally on one or two fiber cables, many kilometers long, through a fiber optic rotary joint at the cable winch. This application illustrates the survivability of the FORJs and MUXs in harsh environments.

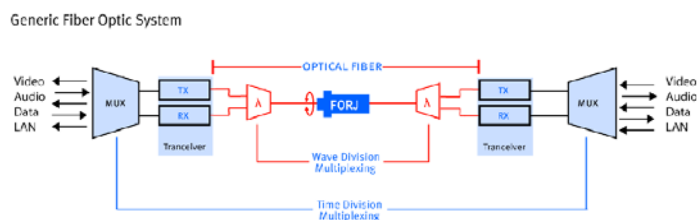

Figure 6. Multiplexing Solution for Multiple Signal Paths with Bidirectional Light Transmission

At present, affordable components limit the top end bandwidth to about 2.5 Gbps, but the presence of devices that allow aggregate data rates of 10-40 Gbps for telecommunications applications suggest that the bandwidth ceiling of reasonably priced components will rise quickly. TDM is typically the first step in maximizing the bandwidth potential of optical fiber by combining many low speed signals into one high-speed signal. These high-speed optical signals can subsequently be combined using a process known as wavelength division multiplexing.

Wavelength Division Multiplexing (WDM)

Wavelength division multiplexing (WDM) is the technology that allows fiber bandwidth to be utilized to the fullest. This technique is used to transmit different signals on different wavelengths of light on the same optical fiber. Different wavelengths (or colors) of light can be transmitted on the same fiber without interference. Special passive devices that employ optical filters or gratings are used to combine and separate the signals. This is an optical process and therefore is not limited by the speed of electronic hardware. WDMs for 1310 and 1550 nm are common and, as pointed out earlier, are commonly used to provide bi-directional transmission on a single fiber. These are compact (2mm x 50 mm) fairly inexpensive devices.

Dense wave division multiplexing (DWDM) uses precision, temperature controlled filters and lasers to achieve 80 or more channels on a single fiber. Although commonly used in the telecommunication industry, this is currently not a very practical technology for military vehicle applications due to the cost of components and the need for precise temperature control to maintain the precise wavelength output from the lasers.

However, in the past few years coarse wave division multiplexing (CWDM) has become commercially available. This technology can optimally provide around 8 channels with around 20 nm wavelength spacing. Figure 7 illustrates the wavelength separation for an 8 channel CWDM multiplexer. High reliability commercial transceivers and WDMs are available, but at this time the temperature requirements of military vehicles limit the availability of some components.

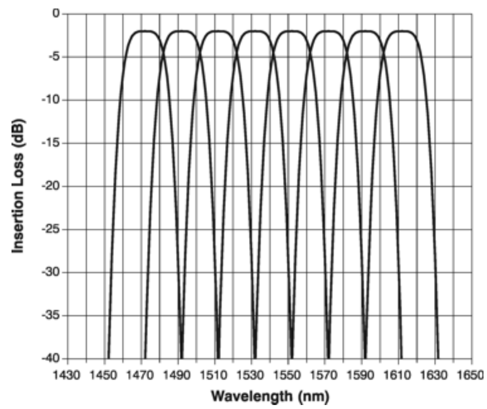

Figure 7. Typical Wavelength Division of 8-channel Coarse Wave Division Multiplexing (CWDM)