MOOG
COMPONENTS GROUP

Technical Brief

FIBER OPTIC ROTARY JOINTS

We have the motion solutions.™

Document Number 303

Moog Components Group has been involved in the design and development of fiber optic rotary joints (FORJs) since 1983. Our products have since been the choice of the offshore oil and gas, oceanographic, seismic and maritime defense industries since 1988. Leadership in FORJ design and manufacture has opened new rotary coupling applications in remotely operated vehicles, naval and geophysical towed arrays, advanced radars, FPSO swivels, armored vehicles, material handling systems and industrial automation markets.

Fiber Optic Rotary Joint Features

Hybrid packages that combine fiber, electrical and fluid rotary joints

- Custom designs to meet emerging requirements and adaptation to customers' size requirements
- Packaging for harsh environments including underwater
- Explosion proof for hazardous locations
- Accommodation of cable, connector and mechanical interfaces
- Laboratory and testing facilities to ensure performance to specification
- World-wide sales support

Technology and FORJ Products

Fiber optic rotary joints fulfill the mating requirements of a connector while allowing continuous rotation between the two bodies, which are attached. The technical challenge is to passively transmit and collect light over 360 degrees of rotation with minimum light loss, dispersion and crosstalk between adjacent channels. The difficulty is that light is directional and can only be redirected through reflection, refraction or interference.

The simplest FORJ configuration is a single pass design. This can be achieved by the use of coaxial opposed fibers, terminated with lenses. The most commonly used lens is a graded index or GRIN lens also known by the trade name SELFOC® (for self-focusing). GRIN lenses are similar to a segment of graded index optical fiber in which the refractive index varies as a function of the distance from the centre of the fiber (decreases with an approximately parabolic profile). Light entering the lens follows an approximately sinusoidal path with the period of the wave called the pitch of the lens. Any lens, which is an odd multiple of 1/4 pitch, produces a collimated beam of light from a spot or point source. If this collimated beam is directed into another 1/4 pitch lens, it is focused back to a point as shown in Figure 1. A single pass FORJ is made by allowing one of the fiber-to-lens assemblies to rotate using a suitable bearing configuration.

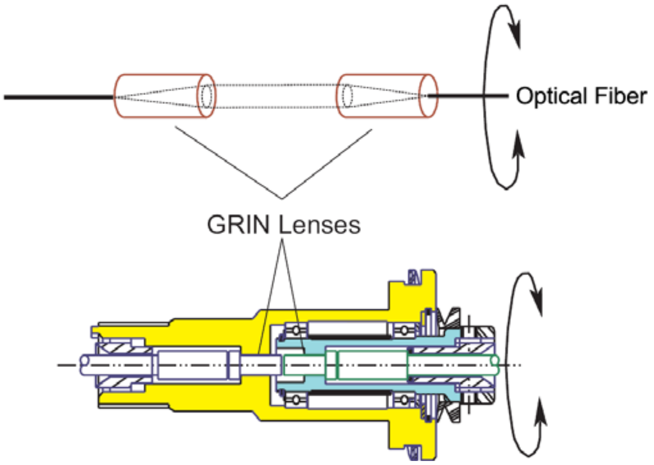
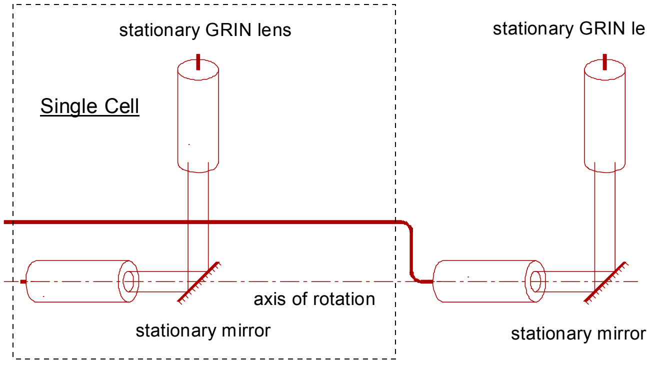


Figure 1 - A) Fiber to fiber coupling using 1/4 pitch GRIN lenses. A FORJ is created by allowing one lens and fiber element to rotate with respect to the other. B) Cross sectional view of a single pass FORJ assembly.

Configuration for Multiple Fibers

Considerably more complex arrangements are required for multiple fibers. Collimation of the light between the fiber ends using lensing as discussed above is key in the multi-pass case as it permits the introduction of some necessary lens separation to permit the introduction of various mechanical and optical components such as mirrors. An example is the Model 190, the first commercial multi-pass multimode design shown schematically in Figure 2 and in cross-section Figure 3.



Can stack ‘N’ cells - two are shown

Figure 2 - Optical schematic of the operating principle of the Model 190 FORJ for the case of two fibers showing how the rotary translation for each fiber pair is staggered axially based on a modular or independent cell-based design. See text and Figure 3 for further detail.

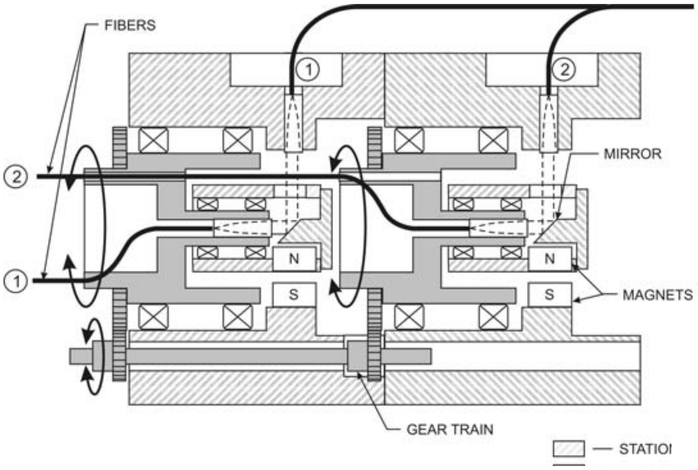


Figure 3 - Cross sectional view of two cells of a Model 190 FORJ. See text for a complete explanation.

The patented operating principle of the Model 190 FORJ is based on a magnetically-coupled mirror / gear train technique. The design is a modular one in which each fiber pass consists of one lens-terminated fiber on the axis of rotation reflected into a complementary lens-to fiber assembly through a mirror. Two cells or modules are shown in section in Figure 3. The mirror is mounted within the rotor in its own bearing assembly and magnetically coupled to the stator for a continuous optical “connection”. The magnetic coupling permits a clear annulus around the rotor through which the fibers for each subsequent module can pass with each module being driven synchronously by a gear-train mechanism. The “downstream” fibers do pass through the expanded pass through the expanded beam in each module (except the last one) accounting for the increased attenuation over some 7-degree portion on the rotation. But the beam diameter at this point is 4 or 5 times the diameter of the fiber used and so the block is only partial - there is no loss of signal and the total insertion loss never exceeds 5-6 dB. The Model 190 housing is designed complete with seals for optional (factory) fluid filling. When mounted in an electrical slip ring housing, it is well protected from the environment and can be used in submerged applications.

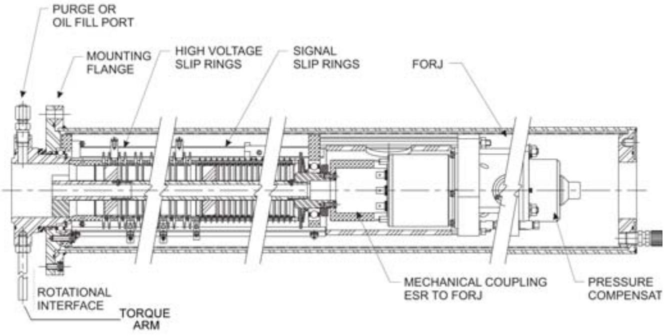


Figure 4 - Cross sectional view of a combination electro-optic slip ring based on the Model 176 ESR and the 190 FORJ. The configuration shown is suitable for use underwater when oil-filled and pressure compensated.

Many applications include both electrical and fiber optic passes as shown in Figure 4. Despite its apparent complexity, the Model 190 is a very stable and reliable unit with over 1100 units in service comprising over 4500 cells mainly marine applications, e.g. ROV’s and seismic streamers.

Two-Pass Configurations

The demand for smaller configurations, specifically for two-pass multimode configurations, prompted further product development leading to the design of the Model 215.

Using a patented in-line optics scheme, the Model 215 achieves a drastically smaller size than the two-pass version of the Model 190 (see Figure 5). The absence of any gears or drive components, also allows the Model 215 to be used in high-speed and long-life applications. The compromises are some restrictions on wavelength multiplexing options and some crosstalk on one channel, albeit very small (<-55 dB) and not an issue for most digital systems.

A requirement for a two-pass FORJ with large core plastic fiber led to the development of the Model 257, which borrows many of the design characteristics of the Model 215 including an in-line optical configuration.

For some applications, especially those where a FORJ is required to fit inside a small or length restricted slip ring, the envelope size of the Model 215 can still be too large. The solution is the Model 292 in which every aspect of the Model 215 has been further miniaturized.

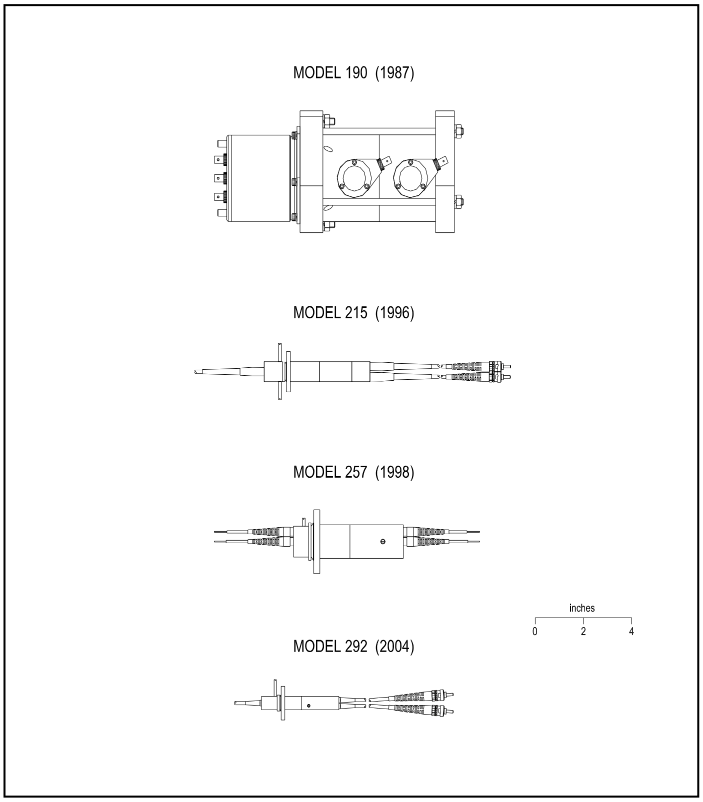


Figure 5 – Two Channel FORJ Evolution

Singlemode Systems

Moog Components Group has produced a 2-6 pass singlemode FORJ, the Model 242, since 1998. The design is based on the Model 190 plus an older discontinued two-pass design, the Model 214, which used mirrors mounted to gear-driven glass windows, combined with the singlemode lens technology of the Model 206. The Model 242 has been very successful with the general shift from multimode to singlemode fibre in many applications. As of January 2008, there were over 1600 Model 242 assemblies in service.

Smaller, Lower Cost Configurations

Further demand for smaller, lower cost products, prompted the recent introduction of three more FORJ Models into the product line, the Model 285, 286 and 291. The Models 285 and 286 are sized-reduced versions of the singlemode Model 206 and the multimode Model 197, respectively. The smaller size and lower cost are traded-off against the improved environmental performance and the ability to mount connector receptacles on the Models 206 and 197. The Model 291 is a lower cost, scaled down version of the Model 242. With its shorter lens-to-lens path length the insertion loss per pass is greatly reduced when compared to that of the Model 242 and up to 9 singlemode passes are possible.

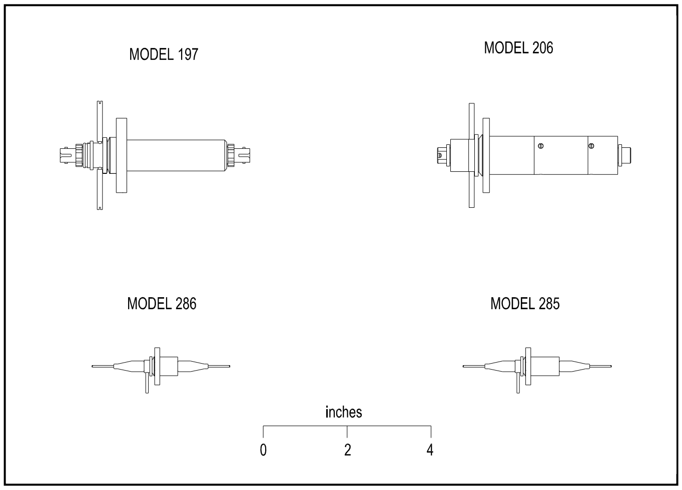


Table 1 – Focal FORJ Models By Type

No. Fibers	Multimode	Singlemode
1	Model 197 Model 228 Model 145 Model 286	Model 206 Model 282 Model 285
2	Model 215 Model 190 (2 Pass) Model 292 Model 257 (1000 Φm POF)	Model 242 (2 Pass)
3 or More	Model 190 (2 - 17)	Model 242 (2 - 6) Model 291 (2 - 9)

Table 2 – Recommended Bandwidth Limits

Fiber Type	Transmitter Type	FORJ Bandwidth
Multimode	LED	LED Bandwidth
Multimode	Laser Diode	≤ 400 – 1000 Mbps[1]
Singlemode[2]	Laser Diode	≤ 50 fs / nm

Performance Specifications

Tables 2-4 summarize the basic optical performance of FORJ's. Further detail including environmental specifications can be found on the individual data sheets.

Table 3 – Insertion Loss

Model	Fiber Type	No. Passes	Typical (dB)	Maximum (dB)	Availability
197 / 145	mm	1	1.5 – 2.0	3	In Production
228	mm	1	2.0 – 2.5	4	In Production
286	mm	1	1.5 – 2.0	3	In Production
215	mm	2	1.0 – 1.5 (Pass 1)	3	In Production
			3.5 – 4.0 (Pass 2)	5.5	
292	mm	2	1.0 – 1.5 (Pass 1)	3	In Production
			3.5 – 4.0 (Pass 2)	5.5	
257	mm	2	4.0 – 4.5 (Pass 1)	7	In Production
			6.5 – 7.0 (Pass 2)	10	
190	mm	2 - 17	2.0 – 2.5	6.5	In Production

Table 3 – Insertion Loss Continued

Model	Fiber Type	No. Passes	Typical (dB)	Maximum (dB)	Availability
206	sm	1	1.5 – 2.0	3.5	In Production
282	sm	1	2.0 – 3.0	4	In Production
285	sm	1	1.5 – 2.0	3.5	In Production
242	sm	2 - 6	2.0 – 2.5 (Pass 1)	3.0	In Production
			2.5 – 3.5 (Pass 2)	4.0	
			3.0 – 4.0 (Pass 3)	5.0	
			4.0 – 5.0 (Pass 4)	6.5	
			4.5 – 5.5 (Pass 5)	6.5	
			5.0 – 6.0 (Pass 6)	7.5	
291	sm	2 - 9	2.0 – 2.5 (Pass 1)	3.0	In Production
			2.0 – 3.0 (Pass 2)	3.5	
			2.5 – 3.5 (Pass 3)	4.0	
			2.5 – 3.5 (Pass 4)	4.0	
			3.0 – 4.0 (Pass 5)	5.0	
			3.5 – 4.5 (Pass 6)	5.5	
			4.0 – 5.0 (Pass 7)	6.5	
			4.5 – 5.5 (Pass 8)	6.5	
			4.5 – 5.5 (Pass 9)	6.5	

Table 4 – Return Loss

Lens Configuration	Fiber Type	Dry (Surface) (dB)	Fluid-Filled (Underwater) (dB)	Availability
Standard Lens	mm or sm	≤ -18.0	≤ -18.0	In Production
8° Angled Facet Lens	sm	≤ -20.0	≤ -20.0	In Production
4° Double Angled Facet Lens	sm	≤ -40.0	≤ -40.0	In Production
8 / 1° Angled Facet Lens	sm	≤ -75.0	Not Tested	In Development

Notes:

1. The performance of laser-based or few mode multimode systems will vary with the particular transceiver and fiber used as well as the launch conditions, and may be limited by modal noise. Sometimes this can be allowed for in the optical budget. With the Model 215, for example, testing at fiber channel rates (1.062 Gbps), modal noise could be accommodated with a 1-2 dB flux budget penalty. The Model 190 represents the worst case due to the fiber shadow in all but the last cell. While systems have been demonstrated at 500 Mbps to over 1.4 Gbps, there remains a finite possibility that under some combination of environmental conditions (laser temperature and fiber vibration) that the system may momentarily pass no data. Again, the transceiver choice and launch conditions are key.

2. Modal noise is, by definition, not present in the singlemode case which is limited by chromatic dispersion and possibly return loss or back reflection which can increase laser noise and hence limit transmission rate. In the latter case, this will vary with the specific laser used. This value of 50 fs / nm is multiplied by the line-width of the laser used to provide an estimate of the expected dispersion due to the FORJ. The bandwidth is approximately 0.35 divided by the dispersion. Testing to 20 GHz shows a completely flat response.