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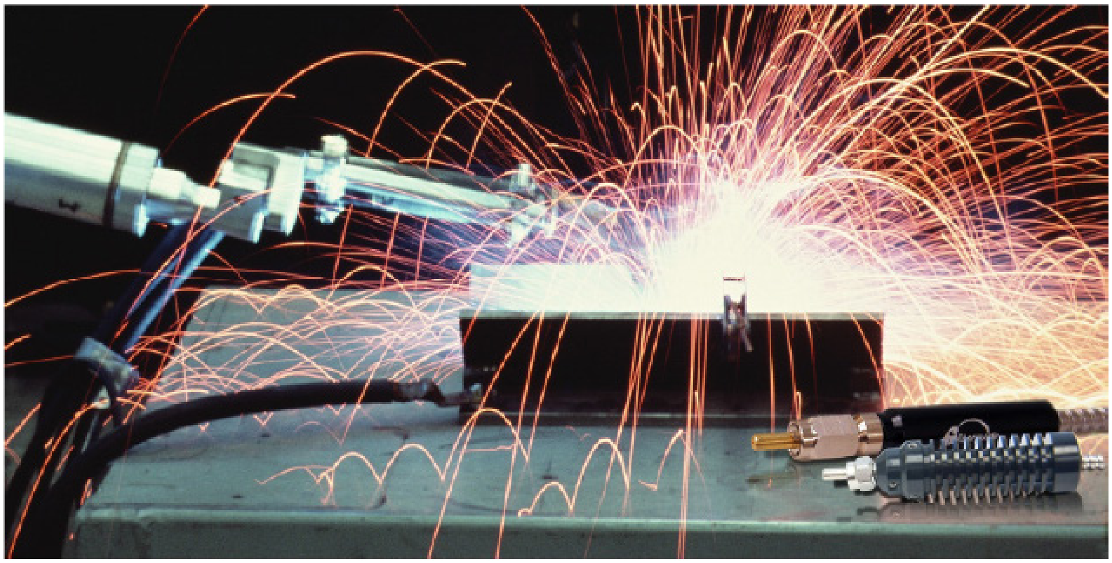
High Power Laser Assemblies



Fiberguide's High Power Assemblies use our High Power SMA and High Power Industrial FD-80 connectors to provide a fiber optic link between the laser source and the target. These are ideal for laser cutting, welding, drilling, and marking applications.

STANDARD SPECIFICATIONS:

- Fiber Type: Step Index Multimode
- Core Sizes: 100µm, 200µm, 300µm, 400µm, 600µm, 800µm, 1000µm, 1500µm
- Wavelengths: Standard OH: UV - Vis: 190nm – 1250nm / Low OH: Vis - IR: 300nm – 2400nm
- Numerical Aperture (NA): 0.20, 0.22
- Connector Options: High Power SMA, High Power FD-80, High Power FD-80 with Sapphire
- Connectors above available with or without integrated Mode Stripper
- Sheathing Options: PVC Coated Stainless Steel Monocoil, Bare Stainless Steel Monocoil
- Power Handling Capacity: Up to 750W depending on fiber size and laser specifications
- Standard Temperature Range: -40°C to +100°C / -40°F to +212°F
- Lengths: < 100 meters

FEATURES & BENEFITS:

- High Power SMA and D-80 Compatible connector options that offer superior thermal management while minimizing connector stress for NA conservation
- Epoxy Free Cantilevered Nose design allows thermal energy to safely dissipate without burning the surrounding material
- Laser Polished end faces maximize power handling capability
- Available with Anti-Reflective (AR) coating

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SPECIFICATIONS:	
Optical Fiber Type	Step Index Multimode
Fiber Core/ Cladding Sizes (µm)	1:1.1 Ratio: 200/220, 300/330, 400/440, 600/660, 800/880, 1000/1100, 1500/1650 1:1.2 Ratio: 105/125, 200/240, 300/360, 400/480, 600/720, 800/960, 1000/1200, 1500/1800 500µm Uni-Clad: 100/500, 200/500, 300/500, 400/500 Other: 100/250, 600/750, 800/1000
Fiber Coating Type	Nylon, Tefzel, Acrylate, Polyimide, Aluminum, Gold
Numerical Aperature (NA)	0.12 ±0.02 (14° Full Acceptance Angle) 0.20 ±0.02 (23° Full Acceptance Angle) 0.22 ±0.02 (25° Full Acceptance Angle) 0.26 ±0.02 (30° Full Acceptance Angle)
Operating Wavelength (λ)	High OH / Ultraviolet (UV) ~ Visible: λ = 190nm ~ 1250nm Low OH / Visible ~ Infrared (IR): λ = 300nm ~ 2400nm
Temperature Range	-40°C to 100°C / -40°F to 212°F
Connector Type	HP SMA: High Power SMA (Maximum Power = 650W) MSHP SMA: Mode Stripped High Power SMA (Maximum Power = 650W) HP FD-80: High Power FD-80 (Maximum Power = 750W) MSHP FD-80: Mode Stripped High Power FD-80 (Maximum Power = 750W) *NOTE: FD-80 Connectors are available with and without sapphire*
Sheathing Type	HP SMA: 5.5mm ~ 8.0mm OD Polymer Coated Stainless Steel Monocoil MSHP SMA: 3.8mm OD Stainless Steel Monocoil HP FD-80: 7mm OD Stainless Steel Monocoil, 8mm OD Polymer coated Stainless Steel Monocoil MSHP FD-80: 7mm OD Stainless Steel Monocoil, 8mm OD Polymer coated Stainless Steel Monocoil
Mode Stripper Performance	MSHP SMA: Removes up to 25W of Cladding Power (λ = 532nm ~ 1064nm) MSHP FD-80: Removes up to 30W of Cladding Power (λ = 532nm ~ 1064nm)

Power Handling Capability

Core Size →	100µm	200µm	300µm	400µm	600µm	800µm	1000µm	1500µm
HP SMA	85W	340W	650W	650W	650W	650W	650W	650W
MSHP SMA	85W	340W	650W	650W	N/A	N/A	N/A	N/A
HP FD-80	85W	340W	750W	750W	750W	750W	750W	750W
MSHP FD-80	85W	340W	750W	750W	N/A	N/A	N/A	N/A

High Power Laser Assemblies

Design Considerations

When selecting optical cable assemblies for power delivery systems, designers must consider the power limitations of the three main components of the cable assembly: the base material, the input connector, and the mode stripper (if used).

The first consideration is the base material, more specifically the base material interface. Fiberguide's high power assemblies are built with our Step Index Multimode fiber. This fiber has a pure fused silica core and fluorine doped cladding. The fused silica is extremely high purity and, as a result, can handle enormous amounts of optical energy. The challenge is getting the optical energy into the fused silica, and this is governed by the air-silica interface that exists at the input connector. Fiberguide uses a proprietary laser polishing technique to maximize the amount of power that this interface can handle, but it can still limit the overall power handling capability of the assembly.

The failure mode for Continuous Wave (CW) Lasers is thermal, caused by microscopic irregularities in the air-silica interface absorbing the laser's energy. For Pulsed Lasers, the failure mode can either be thermal or a dielectric breakdown at the atomic level, depending on the laser's characteristics. In either case, there is a maximum power per unit of area, referred to as the damage threshold, that can be coupled into the assembly. This is expressed in W/cm^2 (irradiance) for CW lasers and J/cm^2 (fluence) for Pulsed Lasers. The reason for this difference is that Pulsed Lasers operate as a series of repeating energy bursts, or pulses. The duration of the pulses and their repetition rate determine the Peak Power and Average Power for the laser. Since a Joule (J) is the amount of energy required to produce one Watt (W) of power for one second, this unit of measure is used to remove the time factor so comparisons can be easily made.

Determining if a laser will damage a fiber involves calculating the irradiance or fluence for the laser by dividing the CW Power, or the Energy per Pulse, by the area of the beam where it makes contact with the fiber. This value must be adjusted to compensate for wavelength in a CW laser, and wavelength and pulse duration in a Pulsed Laser. If the adjusted value is below the damage threshold, the beam size and fiber size are suitable for the laser. If the adjusted value exceeds the damage threshold, the beam size and / or the fiber size should be increased until the irradiance or fluence is below the damage threshold. The charts and tables on the following pages show maximum irradiance and fluence values for various fiber core sizes by wavelength for CW lasers, and by wavelength and pulse duration for Pulsed Lasers.

The power handling capabilities for the other two main cable assembly components, the input connector and the mode stripper, must also be examined. The failure mode on these is always thermal and there are detailed sections on each of these components in the following pages.

High Power Laser Assemblies

Table 1: Background & Assumptions

CW Air-Silica Fused Interface Damage Threshold	~1.5 MW/cm^2 (CW Laser @ λ: 1064nm) Damage Threshold is λ dependent, and behaves relatively linearly in the range from 190nm ~ 2400nm with the shorter wavelengths being more destructive.
Pulsed Air-Fused Silica Interface Damage Threshold	~16.0 J/cm^2 (Pulsed Laser @ λ: 1064nm and τ: 1ns) Damage Threshold is λ dependent, and behaves relatively linearly in the range from 190nm ~ 2400nm with the shorter wavelengths being more destructive. Damage Threshold is τ dependent, and scales with the square root of the pulse duration from 10ps to 1µs with the shorter pulse durations being more destructive. **NOTE: The CW and Pulsed Air-Fused Silica Interface Damage Thresholds above have been adjusted to compensate for the peak intensity in the Gaussian Beam Profile.**
Spot Size Diameter	≤ 85% of the Fiber Core Diameter
Alignment & Beam Waist	X & Y Alignment within ± 5% of the core diameter / Z Position beyond source beam waist
Numerical Aperture (NA)	Fiber NA ≥ Source NA + 10%
Beam Shape & Quality	The spatial profile and quality of the beam will greatly affect high power performance. This analysis assumes a Gaussian Beam where the peak fluence is given by 2 E/p*(W_o)^2", meaning that the peak power is approximately double the 1/e^2 specified power.
Connector Polish, End Face, & Flatness	The connector end face must be factory laser polished to reduce microscopic inclusions and be cleaned prior to use. The endface must also be flat, <10% of the core diameter peak to valley, so it doesn't act like a lens and focus the laser energy inside the fiber.
AR Coating	None; when AR Coatings are applied to optical fibers, they will always become the limiting factor to power handling capability, so it is important to check the specifics of the selected coating.

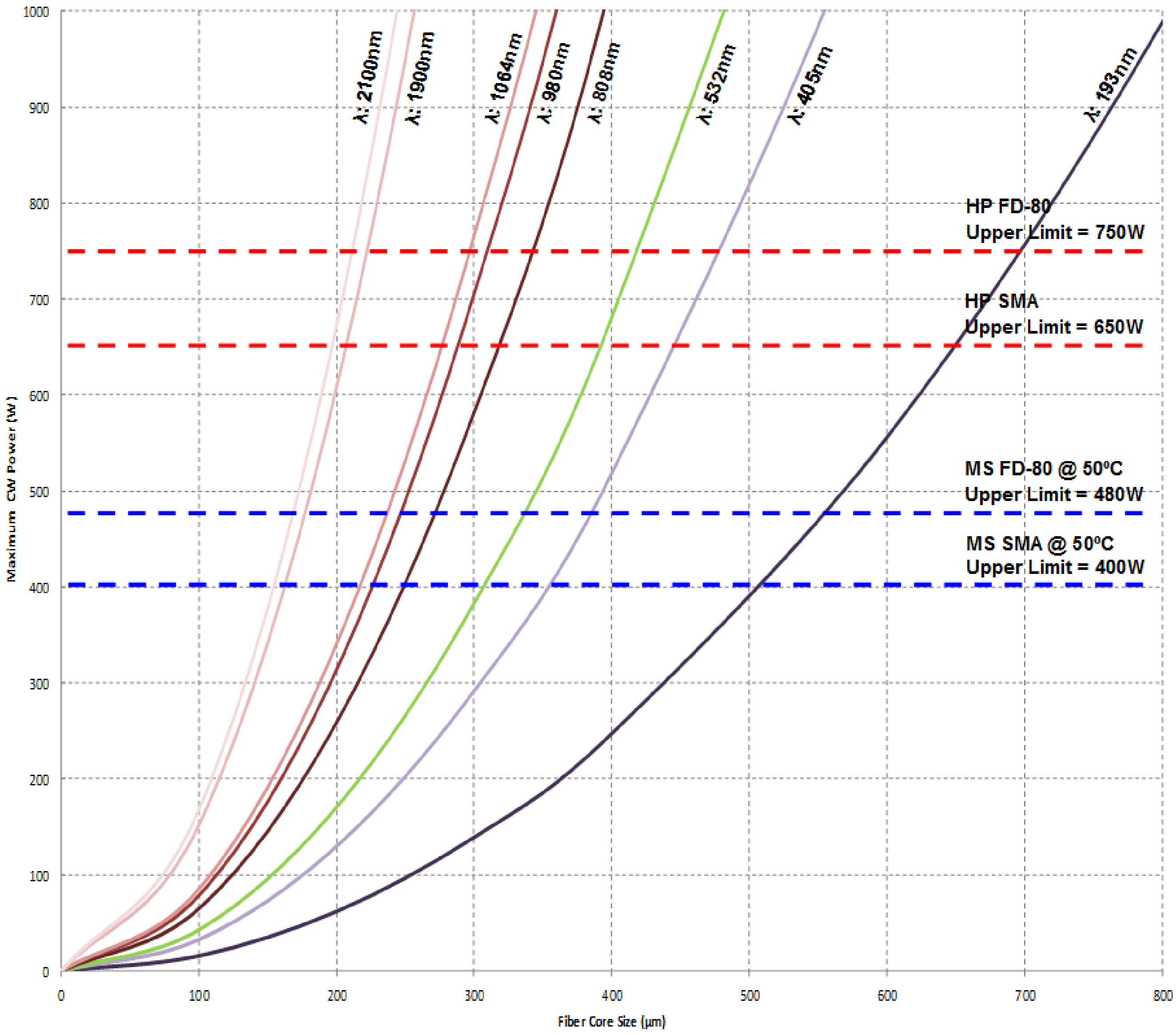
Please Note: This information provided is designed to help guide product selection, because each optical system is unique, Fiberguide strongly recommends thorough testing before committing to system critical components.

High Power Laser Assemblies

Continuous Wave (CW) Lasers

The following chart shows the maximum power that can be used for various fiber core sizes at common CW laser wavelengths. Depending on the power level and wavelength, either the air-silica interface damage threshold, the connector, or the mode stripper will be the limiting factor. The solid lines on the chart show the interface limits, the dashed lines on the charts show the connector and mode stripper limits. Please note that in order to illustrate the dependency of damage threshold on wavelength, the chart shows power levels that are far beyond what is possible / currently available for some wavelengths.

Chart 1: CW Power Maximimums (up to 1kW) for Fiber Core Sizes 100µm ~ 800µm with λ: 193nm - 2100nm



High Power Laser Assemblies

Maximum CW Power Level Table:

The following table shows CW Power Maximums. For fiber sizes ≤ 400µm, the air-silica interface damage threshold is more commonly the limiting factor for the assembly. For larger core sizes, the connector power limits typically govern the overall power handling capabilities of the assembly. Please note that In order to illustrate the dependency of damage threshold on wavelength, the table shows power levels that are far beyond what is possible / currently available for some wavelengths.

Table 2: CW Power Maximimums for Fiber Core Sizes 100µm ~ 1500µm with λ: 193nm - 2100nm

Fiber Core Size (µm)	Wavelength (nm)							
	λ: 193nm	λ: 405nm	λ: 532nm	λ: 808nm	λ: 980nm	λ: 1064nm	λ: 1900nm	λ: 2100nm
100	15	32	43	65	78	85	152	168
200	62	130	170	259	314	340	608	672
300	139	292	383	582	706	766	1368	1512
400	247	518	681	1034	1254	1362	2432	2688
600	556	1166	1532	2327	2822	3064	5472	6048
800	988	2074	2724	4137	5017	5448	9728	10752
1000	1544	3240	4256	6464	7840	8512	15200	16800
1500	3474	7290	9576	14544	17639	19151	34199	37799

High Power Laser Assemblies

Pulsed Lasers

When determining power limits for cable assemblies coupled to Pulsed Lasers, the Pulse Duration (τ) dictates which calculations are used. For Pulse Durations greater than 1 microsecond: 1µs (10^{-6}s), the failure mode is thermal, and the CW calculations / charts alone are used. In this case, the Laser's Average Power = Energy Per Pulse (J) x Pulse Frequency (Hz), is used in place of the CW power. For Pulse Durations smaller than 10 picoseconds: 10ps (10^{-11}s), the failure mode is 2nd order, non-linear phenomenon, such as Stimulated Brillion Scattering (SBS) or Stimulated Raman Scattering (SRS), which are always present in optical fiber and become dominant factors at very short pulse durations. In these cases, thorough testing of various beam and / or fiber sizes is the best way to determine what is appropriate.

For pulse durations between 10ps and 1µs, the failure mode tends to be a dielectric breakdown at the atomic level, and the Energy Per Pulse and the Fiber Size are the key factors in determining power maximums. To determine if a fiber size is suitable, the Energy per Pulse must be divided by the area of the beam where it makes contact with the fiber and the resulting number compared to the air-silica damage threshold. This is straightforward if the laser characteristics match those of the damage threshold, and an additional step is required if they do not.

In cases where the wavelength and / or pulse duration of the laser are different than those of the damage threshold (λ: 1064nm and τ: 1ns), Table 3 (next page) is used to determine the correction factor. The Energy Per Pulse of the laser is then multiplied by the correction factor to calculate the Equivalent Energy Per Pulse at λ: 1064nm and τ: 1ns. These are derived by scaling wavelength in a linear fashion where the shorter wavelengths are more destructive, and by scaling pulse duration in a square root fashion where the shorter pulses are more destructive.

Once the Equivalent Energy per Pulse at λ: 1064nm and τ: 1ns is known, Table 4 (next page) can be used to determine which fiber size(s) can potentially be used. These maximums are based on the assumptions stated in Table 1 in the previous section.

The final step for Pulsed Lasers is to also check the Laser's Average Power using the CW calculations / chart to take the duty cycle into consideration, where Average Power = Energy Per Pulse (J) x Pulse Frequency (Hz). All potential fiber sizes from the previous step must be evaluated to ensure they pass both criteria. These are ultimately the fiber sizes that can be used with a given Pulsed Laser Source.

High Power Laser Assemblies

Table 3: Correction Factors used to Convert Energy Per Pulse to Equivalent Energy Per Pulse at λ: 1064nm and τ: 1ns

Pulse Duration (Sec)	Wavelength (nm)							
	λ: 193nm	λ: 405nm	λ: 532nm	λ: 808nm	λ: 980nm	λ: 1064nm	λ: 1900nm	λ: 2100nm
10ps	55.13	26.27	20.00	13.17	10.86	10.00	5.60	5.07
50ps	24.65	11.75	8.94	5.89	4.86	4.47	2.50	2.27
100ps	17.43	8.31	6.32	4.16	3.43	3.16	1.77	1.60
500ps	7.80	3.72	2.83	1.86	1.54	1.41	0.79	0.72
1ns	5.51	2.63	2.00	1.32	1.09	1.00	0.56	0.51
5ns	2.47	1.17	0.89	0.59	0.49	0.45	0.25	0.23
10ns	1.74	0.83	0.632	0.42	0.34	0.32	0.18	0.16
50ns	0.78	0.37	0.28	0.19	0.15	0.14	0.08	0.07
100ns	0.55	0.26	0.20	0.13	0.11	0.10	0.06	0.05
500ns	0.25	0.12	0.09	0.06	0.05	0.04	0.03	0.02
1µs	0.17	0.08	0.06	0.04	0.03	0.03	0.02	0.02

Table 4: Maximum Energy Per Pulse (mJ) at λ: 1064nm and τ: 1ns for Core Sizes 100µm ~ 1500µm

	Fiber Core Size (µm)							
	100	200	300	400	600	800	1000	1500
Maximum Equivalent Energy Per Pulse (mJ)	0.9	3.6	8.1	14.5	32.6	58.1	90.7	204.2

High Power Laser Assemblies

Examples

Suppose a 532nm Nd:YAG Pulsed Laser emits 100ns pulses at a frequency of 100Hz, and the Average Power is 5W. Which fiber size(s) can be used?

The first step is to determine the Energy Per Pulse. This can be derived from either the Average Power or Peak Power. The Energy Per Pulse (J) = Average Power (W) / Pulse Frequency (Hz) -or- Peak Power (W) x Pulse Duration (sec). In this example, the Energy Per Pulse = 5 W / 100 Hz = 0.05 J or 50mJ.

Since this laser operates at a different wavelength and pulse duration than the damage threshold value (λ: 1064nm & τ: 1ns), a correction factor must be used to calculate the Equivalent Energy per Pulse. Using the table on the previous page, the correction factor for λ: 532nm and τ: 100ns is 0.20. Using this, the Equivalent Energy per Pulse = Laser's Energy per Pulse x Correction Factor = 50mJ x 0.2 = 10mJ. This means that a 10mJ pulse at 1064nm and 1ns has the same amount of energy as a 50mJ pulse at 532nm and 100ns.

Using the Maximum Energy Per Pulse Table on the previous page, one can see that fiber sizes 400µm and above will work for this Laser. To account for variations in systems, Fiberguide suggests testing with core sizes above and below the calculated limits for desired performance.

For Reference, the Peak Power for this Laser = Energy Per Pulse (J) / Pulse Duration (sec) = 0.05 / 100×10^{-9} = 500,000W or 500kW

Suppose a 1064nm Q-Switched Pulsed Laser emits 150ns pulses at a frequency of 30kHz, and the Peak Power is 75kW. Which fiber size(s) can be used?

The first step is to determine the Energy Per Pulse. This can be derived from either the Average Power or Peak Power. The Energy Per Pulse (J) = Average Power (W) / Pulse Frequency (Hz) -or- Peak Power (W) x Pulse Duration (sec). In this example, the Energy Per Pulse = 75kW x 150ns = 75,000 x 150 x 10^{-9} = 0.01125 J or 11.25mJ.

Since this laser operates at the same wavelength, but a different pulse duration than the damage threshold value (λ: 1064nm & τ: 1ns), a correction factor must be used to calculate the Equivalent Energy per Pulse. Since 150ns is not shown in Table 3, the correction factor must be calculated manually. The following formula is used:

$$\text{Correction Factor} = \frac{\text{Damage Threshold } \lambda}{\text{Laser } \lambda} \times \left[\frac{\text{Damage Threshold } \tau}{\text{Laser } \tau}\right]^{1/2} = 1064/1064 \times \sqrt{1/150} = 0.08$$

Using this, the Equivalent Energy per Pulse = Laser's Energy per Pulse x Correction Factor = 11.25mJ x 0.08 = 0.9mJ. This means that a 0.9mJ pulse at 1064nm and 1ns has the same amount of energy as a 11.25mJ pulse at 1064nm and 150ns.

Using the Maximum Energy Per Pulse Table on the previous page, one can see that fiber sizes 100µm and above will work for this Laser. To account for variations in systems, and in this case because the 100µm is right at the maximum, Fiberguide suggests testing with core sizes at and above the calculated limits for desired performance.

For Reference, the Average Power for this Laser = Energy Per Pulse (J) x Pulse Frequency (Hz) = 0.01125 x 30,000 = 338W

Please do not hesitate to contact Fiberguide for technical assistance in specifying fiber sizes for your application.

High Power Laser Assemblies

Input Connector

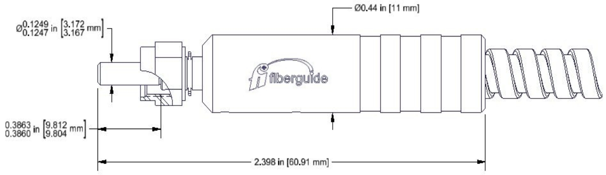
Fiberguide’s High Power Cable Assemblies use either an HP SMA or HP FD-80 Connector for the input. These connectors feature a precision machined, epoxy free, cantilevered (air gapped) nose design that allows thermal energy to safely dissipate without burning the surrounding material. The end faces of these connectors are laser polished to ensure a high quality optical finish to ensure maximum power handling capability. These connectors are designed to handle significantly more power than traditional flush polished SMAs or connectors with ceramic ferrules.

The main difference between the HP SMA and HP FD-80 connector is that the HP FD-80 is a keyed connector. The keying feature allows for repeatable angular positioning when the cable assembly is disconnected / reconnected. The HP FD-80 is larger and more rugged than the HP SMA, making it the ideal choice for industrial applications. The HP FD-80 is also available with a sapphire insert in the base of the nose.

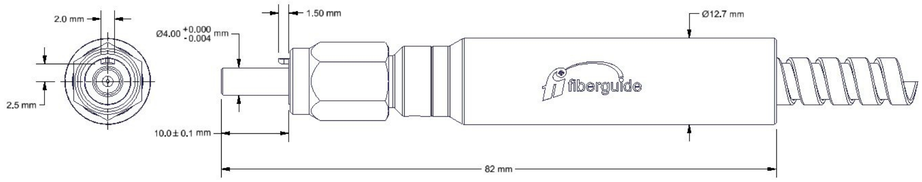
The failure mode for these connectors is thermal overload due to physical size and construction constraints which occurs when there is a breakdown of the materials (organics) used. The power handling limits for these connectors are independent of fiber size, or laser characteristics (laser type, wavelength, pulse duration, etc.) and is strictly an upper power limit.

Connector Type	Maximum Power
HP SMA	650W
HP FD-80	750W

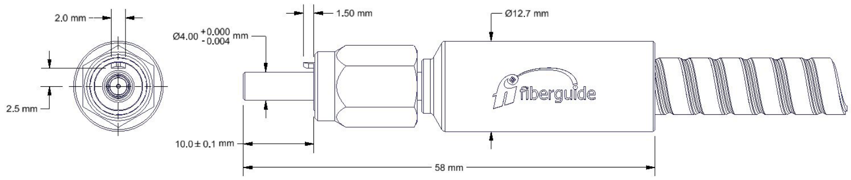
HP SMA - Dimensions



HP FD-80 - Dimensions



HP FD-80 (with Sapphire) - Dimensions



High Power
Laser Assemblies

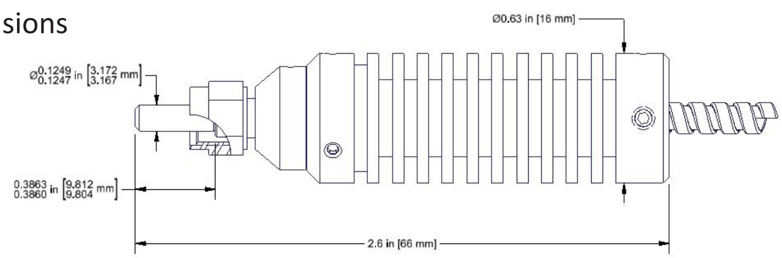
Mode Stripped Assemblies

Mode Strippers are designed to remove energy from the cladding of an optical assembly and dissipate it in the form of heat. They are most commonly used in fiber lasers where individual laser diodes are used to pump a lasing fiber. Removing the cladding modes at each individual pump prevents heat build up in areas where it cannot be managed and helps to maintain the numerical aperture (NA) of the system. Mode Strippers are also used in other applications where it is beneficial to remove the cladding energy in a predictable manner near the source. Examples include systems prone to poor input beams or poor alignment, and cable runs with sharp bends or fusion splices that could cause hot spots.

In a Mode Stripper, the more energy being removed, the hotter the connector becomes until internal thermal failure occurs. If this happens before the damage threshold of the air-silica interface is reached, or before the power maximum for the input connector is reached, the Mode Stripper can govern the maximum power rating of the assembly. In a typical system, 2% - 3% of the total system energy is present in the cladding, 2.5% was used in the calculations below. The maximum values are based on a CW Laser @ λ: 532nm ~ 1064nm operating at room temperature (~20ºC). Mode Strippers can be used for wavelengths outside of this range, but Fiberguide recommends that customers do thorough testing to ensure expected performance. The power handling / temperature limits for these connectors are as follows:

Connector Type	Max. Cladding Energy Dissipated	Max. Total Power
MSHP SMA	16.5W < 125ºC @ Connector	650W
	10W = 50ºC @ Connector	400W
MSHP FD-80	18.75W < 125ºC @ Connector	750W
	12W = 50ºC @ Connector	480W

MS SMA - Dimensions



MS FD-80 (With & Without Sapphire) - Dimensions