INTEGRATING SPHERE USER NOTES:
Integrating Spheres: P/Ns 7Z02470 /72 /74 /76 and 7Z02485-7Z02490
(P/Ns 7Z02475 /71 /73 /77 have been replaced by 7Z02487 /88 /89 /90)

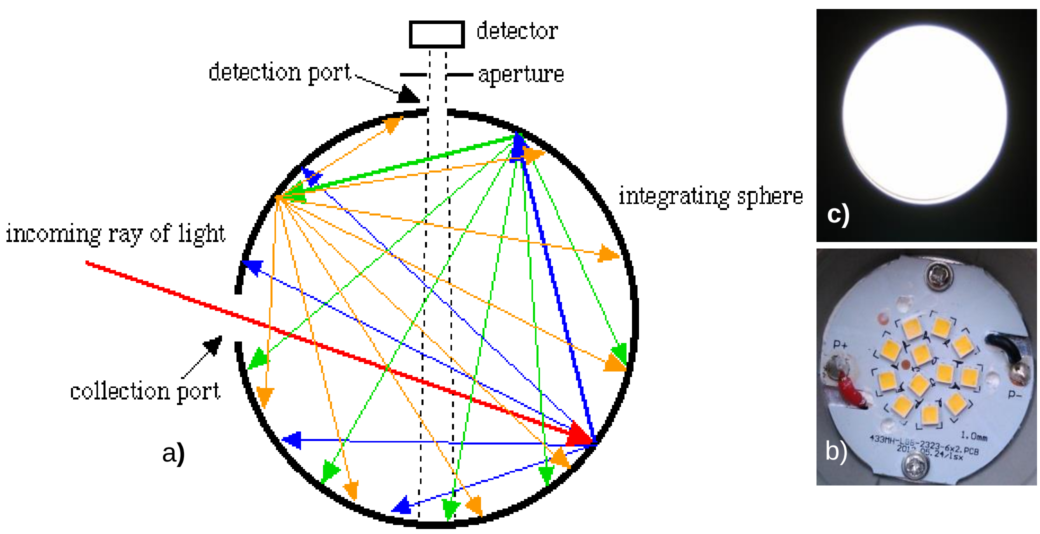
Integrating Spheres:

Integrating spheres are very useful tools in many light measurement situations. They come in handy for measuring light sources that are highly divergent or have unique spatial, angular and/or polarization characteristics which can affect the reading if measured directly on a sensor. Integrating Spheres allow us to make measurements independent of these factors. Configurations with multiple ports make it possible to perform simultaneous measurements with multiple detectors. Integrating spheres can also be used as highly uniform light sources.

Section 1: Principle of Operation

Light entering an integrating sphere undergoes multiple reflections from the diffuse, highly reflecting interior surface of the sphere. After a number of reflections the original spatial, angular and polarization characteristics of the light source are thoroughly mixed, and the result is a uniform light distribution spread across the entire interior surface of the sphere. A sensor can then be used to sample the uniform light and calculate the overall input flux entering the sphere. Figure 1 illustrates how this uniformity is achieved by mixing the initial light input over multiple reflections from the diffuse surface of the sphere's interior.

Figure 1 a) Multiple reflections within the integrating sphere effectively remove from the detected light any of the light sources' initial spatial, angular or polarization characteristics. b) Grouped LEDs on a PCB are a typical, highly non-uniform light source c) Light distribution at the sphere output is uniform with none of the spatial characteristics of the light source.



Since the light is uniformly spread over the interior surface of the sphere, the detected light is directly proportional to the total input flux. The factors that determine the relationship between the detected light and input flux are the sphere diameter, surface reflectance and the percent of the surface area that is non-reflective (i.e. open ports) – preferably less than 5%.

The sphere diameter and port sizes influence the quality of the spatial integration of a light source. For larger diameters the ratio of surface area to port area grows and the integration area is large, this results in lower sensitivity to input characteristics. Large diameters also allow for more powerful light sources, because a sensor of a given size will sample a smaller fraction of the total sphere surface area over which the optical power is spread.

The reflectance and the percent of non-reflective surfaces are used to define a unit-less quantity called the Sphere Multiplier. The Sphere Multiplier determines the number of reflections that occur within the sphere. This in turn helps determine the quality of spatial integration and the radiance of the inner surface. The general equation describing the radiance within an integrating sphere is:

$$L = \frac{\phi M}{\pi A} \qquad \left[\frac{\mathrm{W}}{\mathrm{m}^2}\right] \qquad \boldsymbol{eq.1}$$

Where Φ is the input flux in Watts. M is the Sphere Multiplier and A is the area of the sphere.

From the radiance equation it may seem that the best configuration would be for a large M and small A. However, since there is a tradeoff between the quality of spatial integration and radiance, a larger area is often preferable.

In order to ensure accurate measurements it is essential that the sensor see only the uniform radiance from the sphere walls. Hence it is very important that light entering the sphere not reach the detector directly without reflecting from the walls first. If the light source is collimated, the initial point of incidence on the sphere wall will be brighter than the rest of the surface, so the detector should not be permitted to view this portion of the wall. These requirements are achieved by placing a baffle inside the integrating sphere. The baffle limits the field of view of the detector, ensuring that only light from secondary reflections reaches the sensor (see below figure 4). The baffle is made of the same reflective material as the sphere itself so it has minimal impact on the performance of the integrating sphere.

Section 2: The Ophir 5.3" Integrating Sphere

Ophir large diameter integrating spheres have a highly diffusive PTFE lining, allowing for accurate measurements independent of beam size, position, divergence and polarization. PTFE has the highest broadband diffuse reflectance of any material used in integrating spheres. The reflectance of the diffuse surface is shown in figure 2.

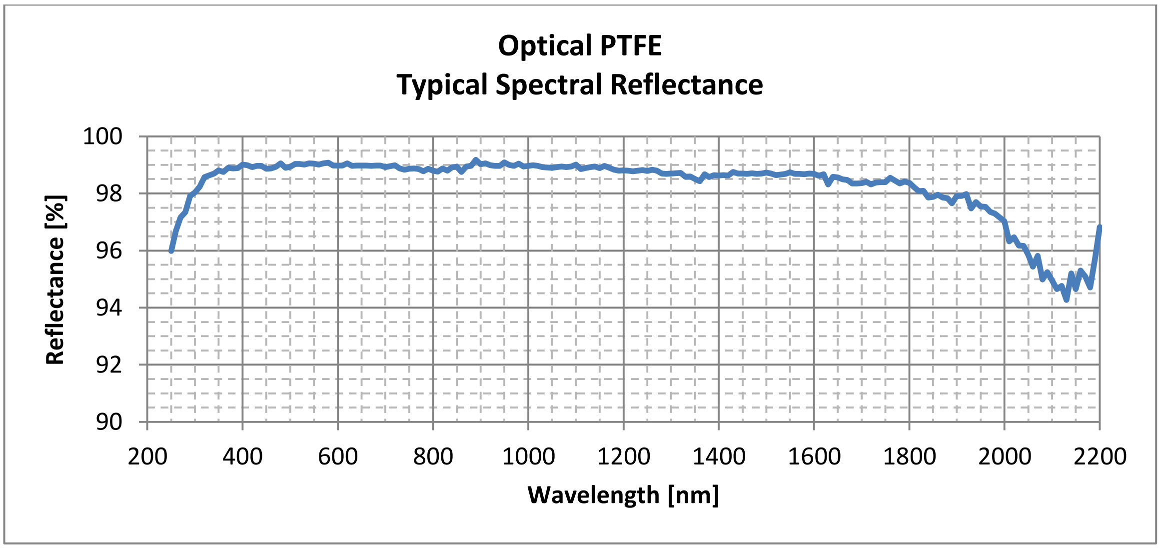
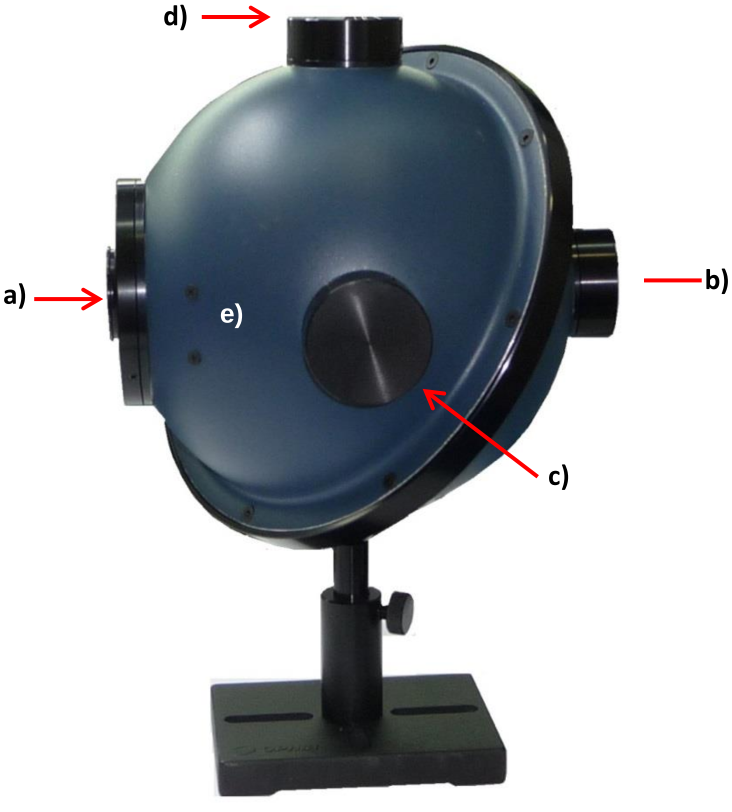


Figure 2 Spectral reflectance of the diffuse surface used in the Ophir sphere.

In order to enable multiple configurations, Ophir IS6 integrating spheres are based on a versatile 5.3" Integrating Sphere that has 4 ports. One port is large with a 2.5" (63.5mm) diameter and the other three ports are smaller with 1" (25.4mm) diameters. Figure 3 shows the various parts of the integrating sphere and their intended uses.

Figure 3 a) 2.5" port with reducer for divergent sources. b) 1" port for collimated sources, (shown with white port plug inserted). c) A detector port at 90 degrees to the input ports (shown with cap) d) 'North Pole port', a secondary port for additional spectral measurements or for an aux. light source (shown with black port cover). e) Internal mounting point of the baffle.



There are two basic configurations of the Integrating sphere, for either collimated or divergent sources. The divergent configuration uses the large 2.5" port and has the 1" collimated input port closed with white port plug. These spheres are supplied with a 2.5” to 1" port reducer installed on the input port. If the need arises the reducer may be removed for the full 2.5" aperture. It should be noted that products of this type that are supplied with detectors are calibrated with the port reducer installed and that removing the port reducer changes the calibration. See our blog, “*Changes in Your Sphere? Have No Fear”* that explains how to make calibrated measurements with the port reducer removed. For the collimated configuration the smaller port is open, and the large port is closed with a 2.5" plug. For very large collimated beams (>25 mm diameter) the large, 2.5” port can be used.

For divergent beams with extremely wide angles (approaching 180°), Ophir offers a specialized configuration, IS6-D-IR-170, that has a reflective input port. The front surface of the input port on this integrating sphere is made from an insulating material. Since extremely wide angle sources need to be placed very close to the input port, the insulating material is incorporated to avoid the possibility of causing shorts with any electrical leads to the light source or electrical leads on a PCB that the light source may be mounted on.

The North Pole port is provided as a secondary detector port and when not in use should be covered with a black port cover to prevent entrance of extraneous light to the sphere. A white port plug should not be used in the North Pole port since it would affect the reflectance of the sphere and change the calibration.

As explained above, only secondary reflected light should reach the detector. Therefore, it is important to use the divergent and collimated input ports as designated. This is due to the positioning of the baffle as illustrated in figure 4:

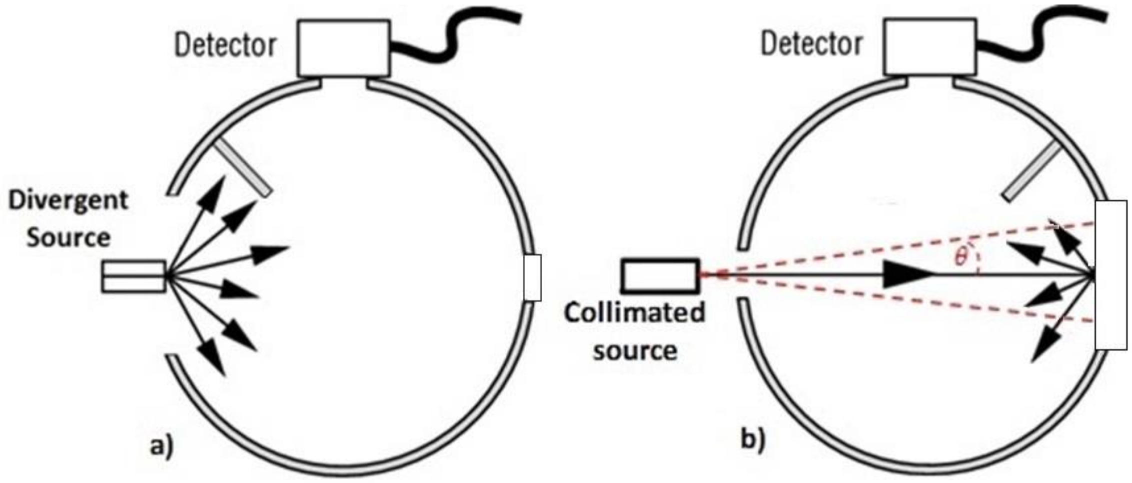


Figure 4 a) Sphere with the divergent beam configuration. The baffle is situated in such a way that the light source is blocked from the field of view of the detector. b) Sphere with the collimated beam configuration. The baffle blocks the initial strong reflection from the detectors field of view. $\theta = 15^o$ is the max. divergence angle of an imperfect collimated beam source for which the baffle is still effective.

The collimated sphere configuration is recommended for sources with divergence half angles up to 15º. Beyond this limit light from the source may strike the baffle and interfere with the reading. Any source with a divergence half angle above 15º should be treated as a divergent source.

The integrating sphere has various accessories that enable different measurement possibilities:

Port plugs use the same white reflective material as the Sphere itself in order to fill a port hole. They are used when converting between divergent and collimated measurements.

Port covers are regular black covers that do not change the reflectance of the sphere. They may be used to seal ports so that extraneous light does not interfere with measurements and dust does not contaminate the sphere; alternatively, they may serve as 'blanks' that can be used as a platform for a user defined purpose.

The 2.5” to 1” Port reducer incorporates the same white reflective material that is used in the interior of the integrating sphere. It reduces the input port diameter while increasing the sphere throughput. The port reducer has an acceptance angle of 120º (full angle) over the central 6 mm diameter of its aperture. For the central 12 mm, the acceptance angle is 100º. The 2.5” to 1” port reducer accepts 2 types of accessories, aperture masks and a flange mount.

Aperture masks for the 2.5” to 1” port reducer are designed to reduce the input port aperture without effecting the calibration of spheres with detectors. This is important when measuring small light sources that are adjacent to reflective surfaces. Measuring VCSELs, laser diodes or LEDs with wide divergence angles requires locating them very close to the input port. If they are mounted on printed circuit boards, reflective metallic surfaces on the PCB can contribute to the

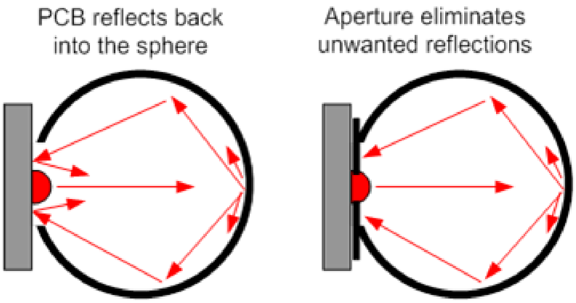


Figure 5 Benefit of input port aperture

sphere reflectance, changing the throughput. Aperture masks can be used to minimize this issue by matching the port aperture to the source size. They come in a 3 piece set of 5 mm, 7 mm and 10 mm aperture sizes, allowing the user to select the optimum size for his application. Aperture masks are magnetically held in a recess on the port reducer that centers them.

The **flange mount** accessory for the 2.5" to 1" port reducer provides the same dovetail mount that is provided on the IS6's 1" ports. It is held on to the port reducer by 4 screws with washers.

Fiber adapter ports provide for connection of optical fibers to the sphere. They can be used on the input port to interface with fiber light sources and on the detector or North Pole ports as detector interfaces. The North Pole port is frequently used with an optical fiber connected to a spectrometer.

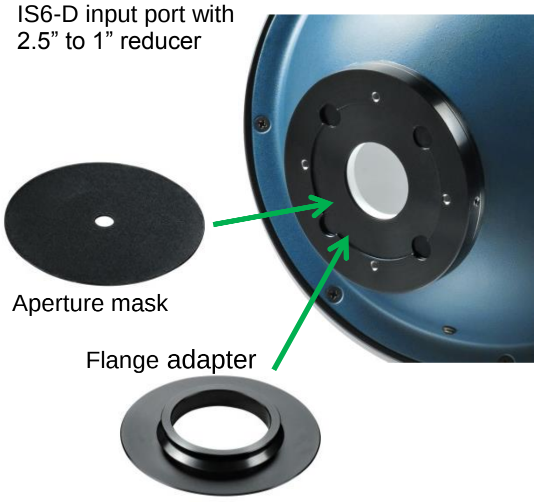


Figure 6 Aperture mask and flange mount accessories for 2.5" to 1" port redeucer

The **FPD to IS6 adapter** and **1" to SM1 adapter** are used to mount fast photodiode detectors to the IS6. Ophir offers a broad range of FPD Fast Photodiode Detectors that can be mounted to the IS6 North Pole port with the appropriate accessory. These detectors can be used to measure the rise time, pulse width and other temporal characteristics of light sources. Look for Pulse Characterization Detectors in the Ophir catalogue and web site.

The FPS-1 detector mounts to the IS6 with the 1" to SM1 adapter. The FPD sensors require the FPD to IS6 adapter. To use the this adapter, remove the M20x1 flange from the FPD using a Torx 6 screwdriver. The adapter is supplied with 4 black Philips head screws. Use these screws to attach the adapter to the FPD sensor and then attach the adapter to the North Pole port of the IS6.

When mounting an FPD sensor on the IS6, ND accessory filters can also be used if needed to avoid detector saturation. See the accessories for FPD products.

Figure 7 IS6-D-IR-170 with FPD detector mounted to North Pole port.

Section 3: Calibrated Spheres with Detectors

Ophir offers a selection of calibrated integrating spheres with detectors based on:

2 sphere configurations:
  a. Collimated
  b. Divergent
- 3 detector types:
  a. UV
  b. Visible
  c. IR
- 2 Special geometries
  a. Large beam diameters
  b. Very large beam divergence

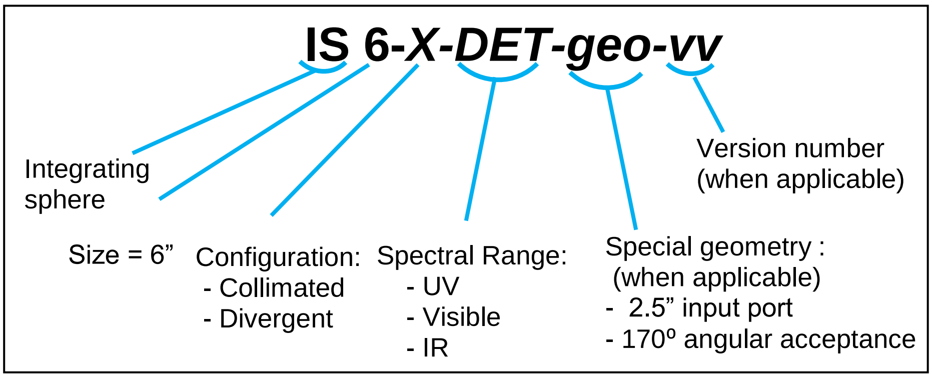


Figure 8: Model name explanation

The detector + sphere + associated accessories are calibrated as a complete sensor system. Calibrations are performed across the entire wavelength range of the sensor and the measured response is saved to the sensor's smart head. The complete configuration should be considered as a single measuring unit. Any changes in the configuration are likely to affect the sensor response so that the system calibration is no longer valid. This includes use of the sensor without the sphere, switching detectors between spheres and even adding or removing accessories. For example, D type integrating spheres are calibrated with the 2.5” to 1” port reducer attached. The port reducer may be removed in order to utilize the full 2.5" aperture, but in this configuration the reading will not be calibrated. Placing reflective surfaces (even the light source itself) near an open port can also affect the detector + sphere sensitivity. To make calibrated measurements with a configuration change, see our blog, “*Changes in Your Sphere? Have No Fear”*. Aperture mask accessories for the 2.5” to 1” port reducer are unique in that they are designed to be added to or removed from the integrating sphere without affecting the calibration. Their use is highly recommended for cases where the light source contains reflective or light colored surfaces next to its emitting area.

At very high power levels, elevated temperature of the integrating sphere system can affect the measurement accuracy. The sphere should be properly cooled to avoid this.

Section 4: Setup and Use

Divergent Sources:

1) Close collimated input port with white port plug.
2) Attach sensor to sensor port.
3) Per application attach fiber adapter or black cover to North Pole port.
4) Position source at entrance of divergent input port (1" with port reducer). The light source should not be placed within the sphere.
5) Set power meter to input wavelength.
6) Begin measurements.

Collimated Sources (divergence less than 15 deg.):

1) Close divergent beam input port with white port plug.
2) Attach sensor to sensor port.
3) Per application attach fiber adapter or black cover to North Pole port.
4) Position source so that the beam enters directly into the 1" collimated input port.
5) Set power meter to input wavelength.
6) Begin measurements.

Additional User Calibration:

The Ophir meter will identify the sensor in use, and the integrating sphere + sensor is used as an individual sensing unit with its own response. In cases where there is a need to use a sensor that was not calibrated with the integrating sphere a correction factor may be added by the user. The correction factor can be derived by checking the response of the integrating sphere + sensor against a reference light source whose spectral and power characteristics are known to the user. Application of this correction factor to measurements made by the sensor will calibrate the measurement at the wavelength of the reference source.

Section 5: Care & Maintenance

The high reflectance of the diffuse white surface inside the integrating sphere is critical to its operation. Any type of contamination, even if not readily visible, can reduce the reflectance level of the white diffusive surfaces. The following steps are recommended to preserve its high reflectance level:

1. Do not touch the interior surfaces of the integrating sphere or the white PTFE surfaces of port plugs and port reducers.
2. To avoid contamination from airborne substances, close all of the spheres ports whenever the integrating sphere is not in use. Each Ophir integrating sphere is provided with accessories for closing all of its ports.
3. Do not attempt to clean integrating sphere interior surfaces. If necessary, clean, dry, compressed air can be used to blow out dust. **Verify that the compressed air is free from oil and other contaminants beforehand.**

IS6-C

IS6-D

IS6-D-xxx

IS6-D-IR-170

IS6 Accessories

Accessory	Description	Part number
Port Plugs	Port plugs close ports with white sphere material, eliminating the port from the sphere geometry	
IS-1” Port plug	White reflectance material, PTFE, Ø25.4mm plug	7Z08280A
IS-2.5” Port plug	White reflectance material, PTFE, Ø63.5mm plug, for 2.5” port	7Z08283A
Port Covers	Port Covers close ports with a black matte surface. They prevent extraneous light from entering the sphere without changing the sphere configuration. These covers can also be used as blanks for making specialized port adapters	
IS-1” Port cover	Matte black coated Ø25.4mm cover	7Z08282A
IS-2.5” Port cover	Matte black coated Ø63.5mm cover, for 2.5” port	7Z08281A
Adapters and Reducers	The adapters are black coated and the reducers white coated	
1” SMA fiber adapter	SMA fiber input/output	7Z08285
1” FC fiber adapter	FC fiber input/output	7Z08286
FPD (except FPS-1) to IS6 adapter	For mounting FPD sensor series to North Pole port of IS6 series	7Z08350
1” to SM1 adapter	Female SM1 thread, used for attaching FPS-1 detector to IS6	7Z08289
1” to C-mount adapter	Female C-mount thread	7Z08290
1” to C-mount port reducer	Male C-mount thread with 11mm aperture	7Z08288
2.5” to 1” port reducer	Convert the 2.5” port into a 1” port PTFE	7Z08305A
Set of aperture masks	Ø5, Ø7, Ø10mm apertures, for use with 2.5” to 1” port reducer P/N 7Z08305A [(a)(c)]	7Z08307
Flange attachment	Dovetail flange for use with 2.5” to 1” port reducer P/N 7Z08305A [(b)(c)]	7Z08306

Notes
(a) This accessory is held on to port reducer 7Z08305A magnetically.
(b) This accessory is mounted to port reducer 7Z08305A with the included screws.
(c) IS6 P/N’s 7Z02471, 7Z02473, 7Z02475, 7Z02477 incorporate an earlier version of the 2.5” to 1” port reducer that is not compatible with this accessory. That port reducer can be replaced with the current version, P/N 7Z08305A, in order to use the new accessories

IS-2.5” Port Plug

IS-1” Port Plug

IS-2.5” Port Cover

IS-1” Port Cover

FPD to IS6 Adapter

2.5” to 1” Port Reducer

Aperture Mask

Flange Attachment

1” FC Fiber Adapter

1” to SM1 Adapter