

ADVANCED OPTICAL BEAM SPLITTER CHARACTERIZATION

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ABSTRACT

Part of the NASA's Origin program is to look for earth-like planets. These planets are dim and need large expensive telescope in orbit. A less expensive and more accurate alternative is use of interferometry technique. NASA/JPL are working in developing technologies for Terrestrial Planet Finder (TPF) mission in 2015. In the path to TPF there are several other missions including the Space Interferometry Mission (SIM) mission in 2009.

SIM, depending on its complexity, may requires a large number of laser beam, e.g. 32 laser in one design. It would be less expensive to design a system based on one relatively powerful laser and use optical beam splitter to generate the 32 beams. In this paper we will discuss the techniques that are being used to make optical beam splitter especially the state-of-the-art splitters, i.e., those with split capability of 16 or even 32. Technology for making reliable large beam splitter has not been matured enough, but it is developing rapidly mostly due to the need in the telecommunication industry. Characterization plots for the advanced optical beam splitter including 1x32 splitters will be also presented.

INTRODUCTION

NASA's Origins Program and Associated Optoelectronic Technology Development

Where do we come from? Are We Alone? To seek answers to these defining questions the NASA's Origins Program, has outlined four goals for the next several decades:

- To understand how galaxies formed in the early universe,
- To understand how stars and planetary systems form and evolve,
- To determine whether habitable or life-bearing planets exist around nearby stars,
- To understand how life forms and evolves.

To achieve these goals and press beyond our current limits, however, we need to use new technologies. One of these technologies is optical interferometry that has been used successfully at the radio wavelengths in the past. The development of the new technologies has allowed the use of interferometry in the visible and infrared wavelengths. The key for success is accurate measurement and calibration of the instrument including the distance between the telescopes. To make such precise measurements, even

though various techniques have been used, they all use lasers.

The first science mission in a series of interferometry missions is the SIM (see Figure 1). SIM scheduled for launch in 2009, it will determine the positions and distances of stars several hundred times more accurately than any previous program, e.g., about 100,000 more accurately than Hubble Space Telescope. This accuracy will allow SIM to measure the distances to stars throughout the Galaxy and to probe nearby stars for the earth-sized planets, opening up a new world of discoveries.

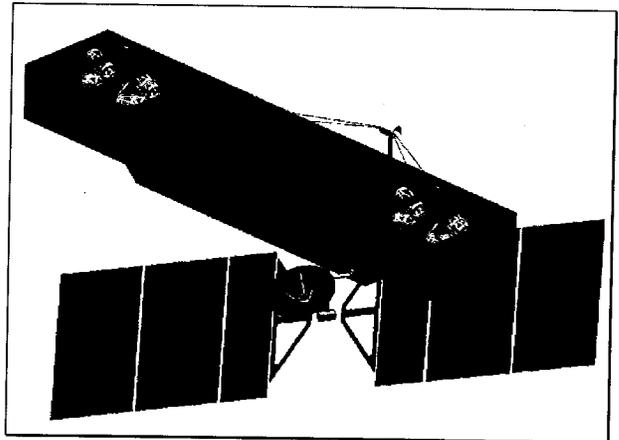


Figure 1 Schematic drawing of Stellar Interferometry Mission (SIM)

Several testbeds¹ have been developed at the Jet Propulsion Laboratory under the Interferometry Technology Program to address the requirements raised by the SIM. Figure 2 shows one of the SIM system testbed III (STB3) which is a new full 3-baseline interferometer mounted on a SIM-like full-scale flexible structure².

One of the main requirements of any interferometry system is accurate knowledge and measurement of the changes to the baseline length. To measure these changes SIM and STB3 testbed use a metrology system shown in Figure 3. Passive beam splitters are used to accommodate the 21 laser beam inputs. The beam splitters includes those that split/divide a laser input beam into 32 beams currently, two beam splitters of 1x32, one for each polarization. It also uses six smaller beam splitters, 1x2 splitters, each with different beam split ratio.

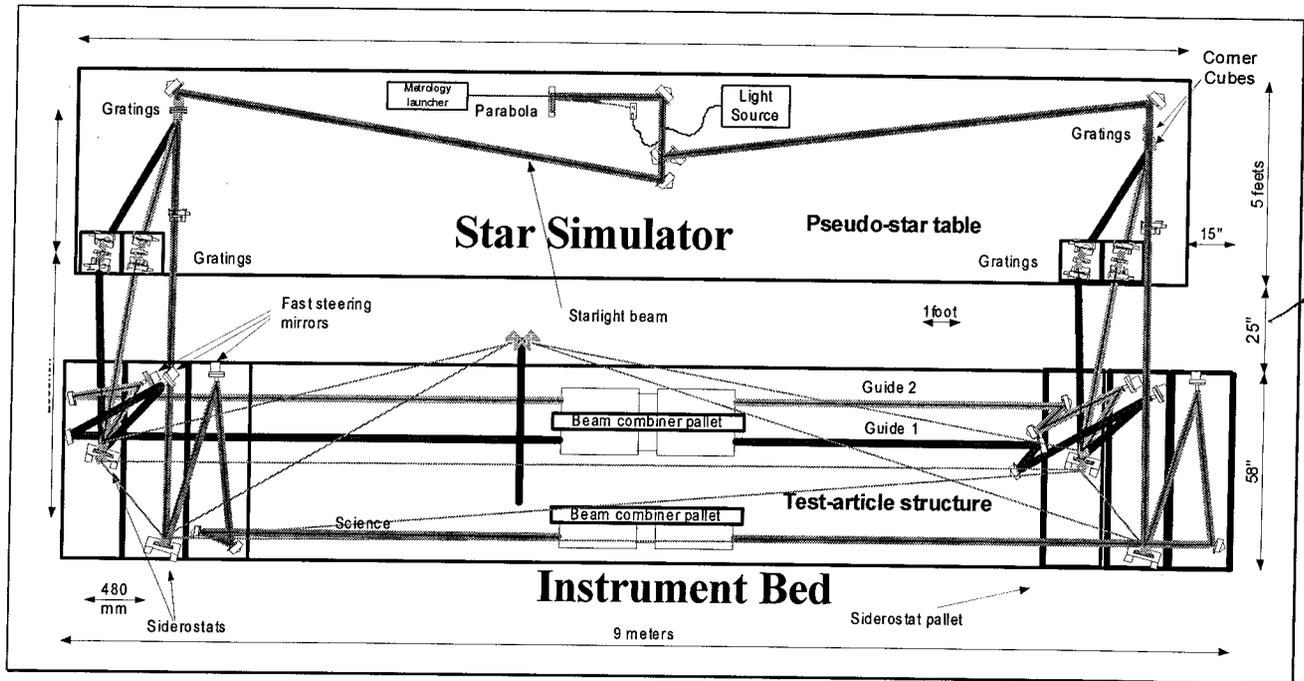


Figure 2 SIM STB3 Testbed, representative of a star with a dim light source, star simulator, and structure, instrument bed.

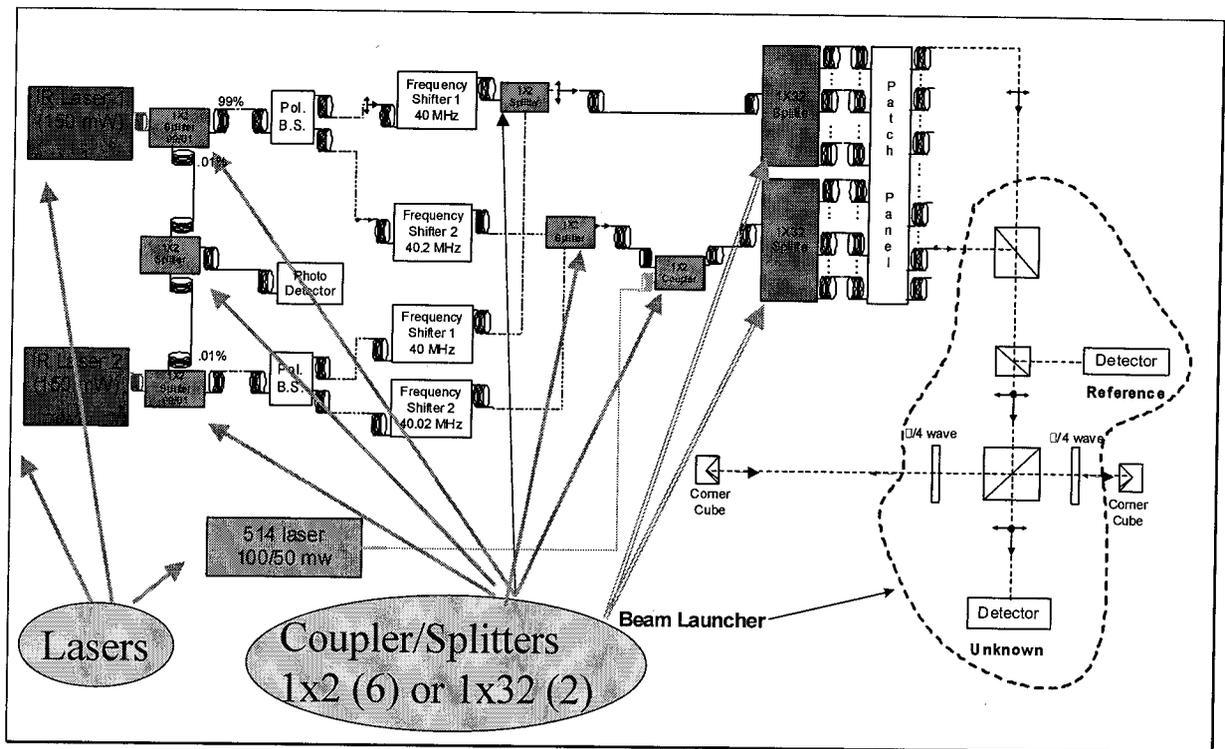


Figure 3 SIM Metrology systems which includes numerous optoelectronic systems including laser, splitter (coupler), and detector.

In the following key technology application similarity for SIM (laser, optical fiber, splitter) to those for telecommunication systems are described followed by detail description of different passive splitters (coupler), packaging, and their key performance characteristics. Behavior of two beam splitters were characterized and presented. Plots of signal intensity loss for various output ports and their non-uniformity among the outputs were also compared and presented.

SIM and Telecommunication

Many aspects of technologies being characterized under SIM are very similar to those being considered for telecommunication. Advances made or lessons learned for SIM will be beneficial to commercial industry. Beam of light for the SIM case is used for accurate measurement based on interferometry fringe patterns whereas for telecommunication case, beam of light is transmitted over a thin fiber glass for communication. Use of light through fiber is now common for telephone, local area network, data links, close circuit video links, sensor information, etc. Compared to copper wire, optical fibers cost less, weight less, have less attenuation, and dispersion, and provide more bandwidth.

Figure 4 shows a typical point-to-point optical communication link. This assembly includes, for example, the transmitter section that provides an input electrical signal to modulate a light source. The light source could be either an electrically controlled light emitting diode (LED), laser diode (LD), or vertical cavity surface emitting laser (VCSEL). The modulate signal into optical channel that may be free space or an optical fiber or a waveguide. At the receiver end of optical channel, the light is coupled into a detector including photodiodes, phototransistor, or photoconductor.

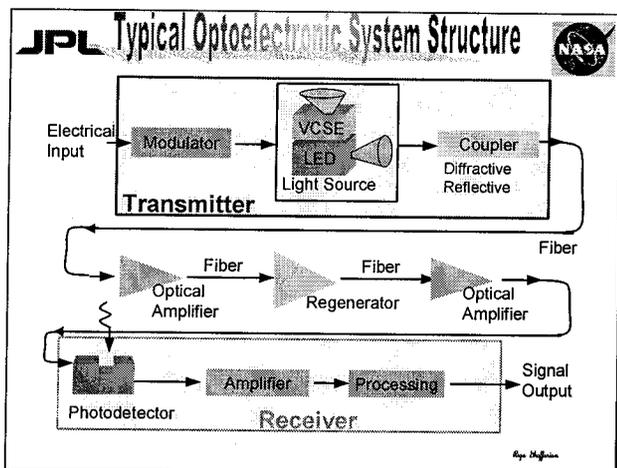


Figure 4 A typical optoelectronic system structure

Comparing Figure 3, SIM metrology system testbed and those in Figure 4, it is apparent that many of technologies used in telecommunication including laser and beam splitters are similar to those being evaluated for

telecommunication. Therefore, lessons learned in the SIM activities are pertinent and valuable to commercial industry. Example of beam splitter (coupler) is discussed in details below.

BEAM SPLITTER (COUPLER)

Connectors and splices join two fiber ends together to allow sending signals between two devices, but many applications require connecting more than two devices. Connecting three or more points is accomplished by coupler (splitter). Couplers differ from switches in that coupler make unchanging connections, but switches can alter the connections.

Optical signals are transmitted and coupled differently than electrical signal.

- There is no physical contact in optical coupling, light is directed into fiber core
- An optical signal is not a potential like, like an electrical voltage, but a flow of signal carrier (photon)

Therefore unlike electrical signal, splitting/division of an optical signal between two or more output ports is only possible when they are in parallel.

This need for parallelism, limits the number of terminals that can be connected to a passive coupler that merely splits up the input signal. With more ports, less signal reaches each one if the signal is divided equally. Each doubling of the number of outputs reduces signal strength by 3dB. This loss is 3dB for two output ports, become 6dB for four ports, 9dB for 8 ports, etc.

Active coupler, also split signals, but they work quite differently. An active coupler is essentially a dedicated repeater in which the signal from the receiver drives two (or more) transmitters, which generate optical and or electrical output signals.

COUPLER TYPES AND TECHNOLOGIES

Couplers have several distinct types technology base devised to meet performance requirements. Couplers are configured differently with the following four main categories:

- T and Y couplers, are three port-port devices that split one input between two outputs
- Tree or 1-to-n couplers, take a signal input and split it among multiple output
- Star couplers, a central mixing elements with fibers radiating outward like star
- Wavelength-selective couplers, distribute signal according to their wavelengths

In general there are two methods of making splitter or passive coupler, by fusing or polishing. Other less important methods include area splitting which split the area of fiber in two or more sections. This method mostly

used to create active and none bi-directional splitter. The ratio of the splitting is proportional to the splitting area.

In polishing (or diffusing) method two or more fibers are polished (length-wise) close to the core and are put together side by side. Due to evanescent wave coupling phenomena, the power of the input fiber is coupled to the output fiber. The coupling ratio depends on the length of polish section and proximity of the two fibers. Figure 5 shows this method. The evanescent coupling method cannot be used efficiently with multimode fibers.

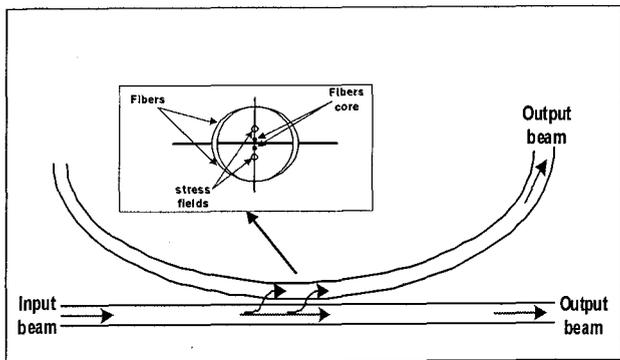


Figure 5 Schematic drawing of polishing (diffusing) coupler

The fused method uses the principle of radiative coupling. Biconical fused taper method is a more common for radiative coupling. In this method fibers are twisted, fused and elongated as shown in Figure 6.

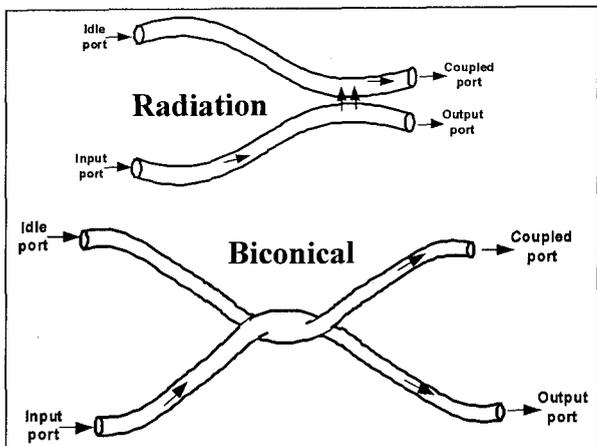


Figure 6 Coupling by Radiation and Biconical methods

To achieve a specific split ratio, signal outputs of coupler are monitored during pulling and it stops when the correct ratio is achieved. The fused fibers are then sealed for environmental protection. Since the fibers are fused together without breakage, this technique produces couplers with good thermal and vibration resistance characteristic and with minimum backreflection signal losses. In the case of Polarized Maintaining (PM) fibers, a

great care must be taken during pulling and heating to preserve the stress characteristics of the PM operation.

In the case of fused method, since the coupling is not mode-sensitive this method can be used for multimode fibers. It should be noted that a coupler can only combine the signals from two or more fibers; but not the power. Regardless of direction of the propagation of the light, the loss in each leg of a coupler is the same.

Large Size Coupler

Figure 7 shows the two methods that are used to fabricate large size couplers (1xN). These are Cascade and V-groove. In the cascade method several of the 1x2 couplers are cascaded together. Cascade method is an easy method to make large coupler, but there are issues with this approach including:

- Uniformity in signal for one coupler affects the uniformity of the subsequent cascades
- Unpredictable stress patterns at each coupler

Another method is using waveguide approach. One packaging technique uses ion-exchange in glass. This process involves several steps as depicted in Figure 8. This method will create a very uniform, repeatable device. The sizes of the channels in the waveguide characterize the operating wavelength.

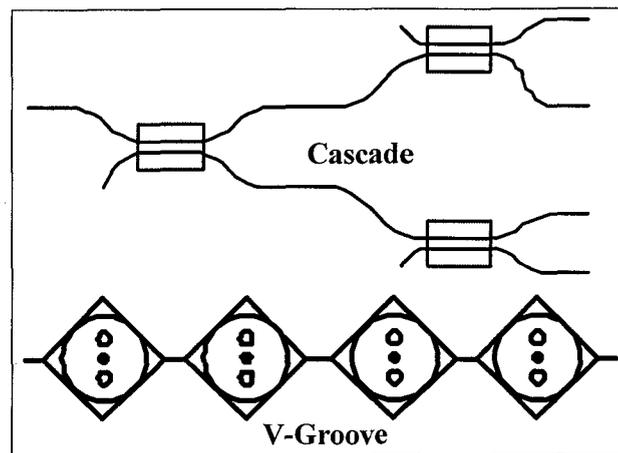


Figure 7 Increase number of output ports by cascading

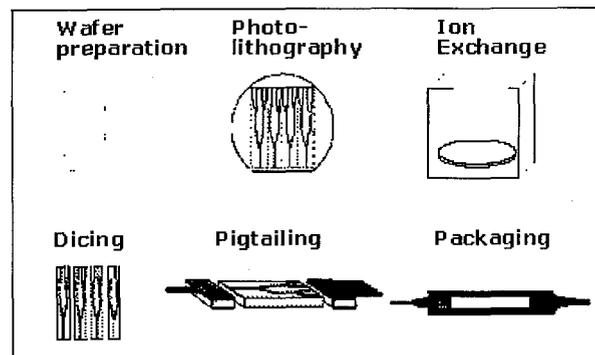


Figure 8 A typical ion-exchange packaging process

V-groove arrays could be used to align fibers to the waveguide. This method is especially useful for aligning PM fibers at the right polarization direction. Figure 7 shows few of these v-grooves with fiber oriented in the direction of slow axis.

COUPLER CHARACTERISTICS

Several optical characteristics determine the use and function of couplers. The most important of these are³ :

- Number of input and output ports, i.e., 1x2, 1x32
- Signal attenuation
- Signal uniformity among the splitters
- Directionality of light transmission
- Wavelength selectivity
- Type of transmission, single- or multimode
- Polarization sensitivity

Number of Ports

Depending on application, the number of input and output ports that are required will be different. For example for the SIM application, two splitters are used. The 1x2 splitter, splits one input between two outputs. Another splitter, 1x32, splits the input into 32 outputs. In this case, the input is distinct from the output, but in other couplers such as 10x10, the input/output is not automatically clear and may depend on technology chosen.

Signal Splitting and Attenuation

The number of ports alone does not indicate how the signal is being divided among them. Most couplers divide signals equally among all outputs, but some divide light unequally. For the SIM, the signal is divided equally among the output ports. However, for a coupler that follows an optical amplifier may split off 1% of the output signal to an optical performance monitor, which verifies that the expected optical channels are present in the output. Both signal splitting and excess loss, light wasted within coupler, contribute to port-to-port attenuation. Generally excess loss is small, but it is not safe to ignore.

TEST RESULTS

Two waveguide V-groove couplers with 1x32 input/output ports were characterized for insertion loss and uniformity across the ports. The results are plotted in Figures 9 and 10.

Losses for the two couplers tested varied approximately between 18 to 23 dB. Initially, these values were much higher and were unacceptable. Couplers were returned to manufacturer to be adjusted to achieve lower losses. In an ideal condition, the lowest loss for this coupler with 32 output ports is about 15 dB ($-10 \log(1/32)$). The losses were non-uniform and for the worst case a deviation of about 2.5 dB was measured. The spread in data was more for the coupler with a lower loss.

CONCLUSIONS

Depending on the application, various parameters become important in couplers. For SIM mission, insertion losses need be minimized and their uniformity across the output port need to be tightly controlled since they will adversely affect the laser power requirements, its mass, and associate thermal control accessory.

Coupler package processes affects insertion loss, increasing its level above the ideal condition. Losses may further degraded with environmental exposures during ground testing and mission life cycle. In the next phase of this task, representative packages will be characterized at various thermomechanical exposure to establish their stability with time/cycles.

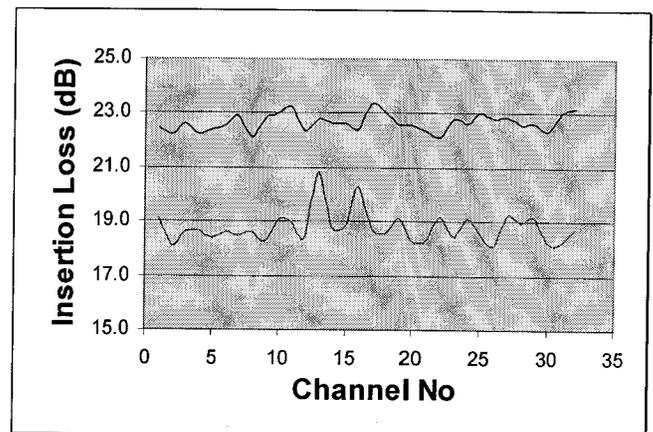


Figure 9 Insertion losses for two 1x32 coupler

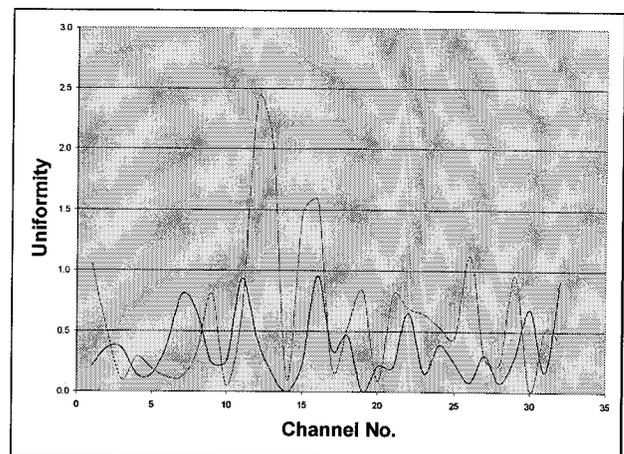


Figure 10 Uniformity characterization of 1x32 coupler

ACKNOWLEDGEMENT

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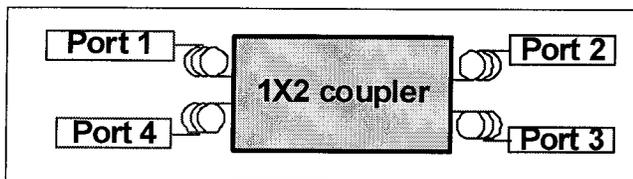
APPENDIX

In any optical systems specifically splitter, there are some parameters that define the characteristic of a device. Here we will define them.

As an example consider a 2x2 coupler is shown below with 100 units at port 1. The outputs are on port 2 and 3. There should not be any output from port 4. The measurement shows output of 56 units at port 2 and 41 units at port 3. The output from port 4 is 0.0005.

In optics characteristic of devices are defined in terms of dB ($-10 \times \log$). For example for the transmission of 50%, the loss will be $-10 \log_{10} (0.5) = 3.0$ dB.

The advantage of using dB is that because of the properties of logarithms, the total loss for a system can be calculated by just adding losses from each part in dB.



Excess Loss

The total power from ports 2 and 3 is 97 units (97% transmission). The excess loss is:

$$-10 \log_{10} (.97) = 0.13 \text{ dB.}$$

Insertion Loss

The loss in each port is represented by insertion loss, therefore:

$$\text{For port 2: } -10 \log_{10} (.56) = 2.5 \text{ dB,}$$

$$\text{For port 3: } -10 \log_{10} (.41) = 3.9 \text{ dB.}$$

Uniformity

Is the ratio of the two outputs on ports 2 and 3.

$$-10 \log_{10} (41/56) = 1.4 \text{ dB.}$$

Notice that you can get the same result by subtracting logarithms of losses in two ports:

$$3.9 \text{ dB} - 2.5 \text{ dB} = 1.4 \text{ dB.}$$

Directivity

$$-10 \log_{10} (0.0005/100) = 53 \text{ dB.}$$

Extinction Ratio

Another parameter which is important in the case of polarized fiber is extinction ratio. The extinction ratio is defined as the ratio of power of one polarization relative to the power of the orthogonal polarization.

$$-10 \log_{10} (P/P_{\perp}) \text{ dB.}$$

The axis carrying more power is indicated by P_{\perp} .