POLARIZATION SCRAMBLER

MODEL PS-   -A

User' s Guide

FIBERPRO

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MODEL PS-   -A

FIBERPRO

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1.0 GENERAL INFORMATION

Warning

- **Dangerous voltages, capable of causing injury or death, are present in this instrument. Use extreme caution whenever the instrument covers are removed. Do not remove the covers while the unit is plugged into a live outlet.**

- **To avoid electric shock, the power cord protective ground conductor must be connected to ground.**

- **No user serviceable part exists in this instrument. Refer all services to qualified personnel.**

Caution

This instrument may be damaged if operated with the line voltage selector set for the wrong AC line voltage or if the wrong fuse is installed. Before using the instrument, be sure to read through operation manual and data sheets to ensure its correct operation.

Line Voltage Selection

Polarization Scrambler can operate from any single-phase AC power source that supplies 100 ~ 125V or 210 ~ 250V at a frequency at 50 ~ 60 Hz. Before connecting the power cord to a power source, check if the line voltage selector, located in the rear pane1, is set correct. Conversion to other AC input voltage requires adjusting the line voltage selector.

Line Fuse

The fuse used by this instrument is 0.5A / 250V (slo-blow).

Line Cord

This instrument has a detachable, three-wire power cord for connection to the power source and to a protective ground. The exposed metal chassis of the instrument is connected to ground via the power line cord to protect against electrical shock. Always use a socket outlet that has a properly connected protective ground.

Service

Do not attempt to service or adjust this instrument unless an authorized person is present. Do not install substitute parts or perform any unauthorized modifications to this instrument. Contact FIBERPRO or your local distributor to ask services.

List of Abbreviations

DFB LD : Distributed FeedBack Laser Diode

DOP : Degree Of Polarization

IL : Insertion Loss

PC : Polarization Controller

PDG : Polarization Dependent Gain

PDL : Polarization Dependent Loss

PMD : Polarization Mode Dispersion

PMF : Polarization Maintaining Fiber

PS : Polarization Scrambler

SMF : Single Mode Fiber

SNR : Signal to Noise Ratio

SOP : State Of Polarization

SPECIFICATIONS

General

AC power input	: 100~125V, 210~250V, 50/60Hz
Power consumption	: < 50VA
Dimensions	: 110(h) x 295(w) x 330(d) mm^3
Weight	: approx. 5kg
Operation temperature	: 15 °C ~ 35 °C (DOP < 5%[(1)])
Storage temperature	: 0 °C ~ 60 °C
External control	: TTL enable/disable
	RS-232 (9-pin male) interface

Optical characteristics

All the optical characteristics are specified with regard to PS-155-A.

Degree of polarization	: < 5%[(1)]

Modulation frequencies : Factory set between 600kHz ~ 1.2MHz[2]

Frequency difference : Factory set between 100kHz ~ 200kHz[3]

Center operating wavelength : 1550nm[4]

Operating wavelength range : 40nm (DOP < 5%)[1]

Average PMD : < 0.3ps

Insertion loss : <1.5dB (with connectors)

PDL : < 0.05dB (with connectors)

Back reflection : < -65dB (without connector)

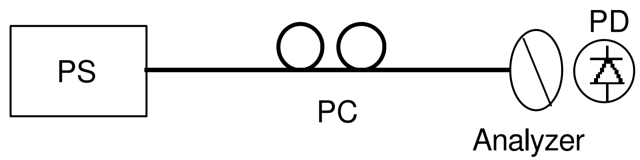
< -60dB (FC/APC)

< -40dB (FC/PC)

Input/Output connectorization : FC/PC (Standard)[5]

NOTES

(1) DOP (Degree Of Polarization) at PS output is measured with a polarization controller and an analyzer. The detector bandwidth is 10kHz.



PS : Polarization Scrambler

PC : Polarization Controller

PD : Photo Detector

Suppose that we obtain the maximum and minimum intensity, I_{max} and I_{min} measured at the PD while adjusting the PC through all its possible states. Then DOP is expressed as

$$DOP = \frac{I_{max} - I_{min}}{I_{max} + I_{min}} \quad \text{Eq. 1.1}$$

PS maintains its output DOP less than 5% within the operating temperature range at center operating wavelength, and within the operating wavelength range at 25°C. But simultaneous deviation of both parameters (temperature and wavelength) may increase output DOP over 5% even thought both parameters are in the specified operating ranges.

(2) Modulation frequency for each birefringence modulator is fine-tuned for optimum operation at factory.

(3) The frequency difference decides the measurement bandwidth limit. (Refer to 3. Theory, *Measurement Bandwidth Limitation*). It is typically 170kHz.

(4) Can be customized within 1530~1560nm. Other wavelengths such as 980nm, 1300nm, 1480nm and 1600nm are also available.

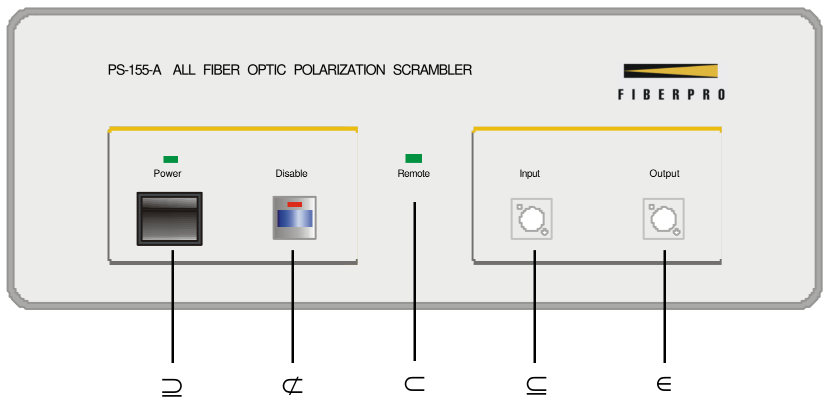
(5) Users can specify other types of connectors at the time of order.

2.0 OPERATION

Getting started

FIBERPRO's PS series are designed to give users plug-and-play operation. All you have to do is to make correct connectorizations and turn on the power. The double-stage birefringence modulator inside a PS is driven by well-adjusted electronics to achieve optimum performance regardless of the input SOP.

FRONT PANEL



⊇ **[Power]** switch / Indicator

- When the power switch is turned on, an LED indicator becomes lit on and the PS starts operating unless the [Disable] switch is turned on or the PS is disabled by the TTL external control.

⊄ **[Disable]** switch / Indicator

- Turning on this switch disables polarization scrambling.

⊂ **[Remote]** Indicator

- This LED is lit on when PS is under external control via RS-232 interface.

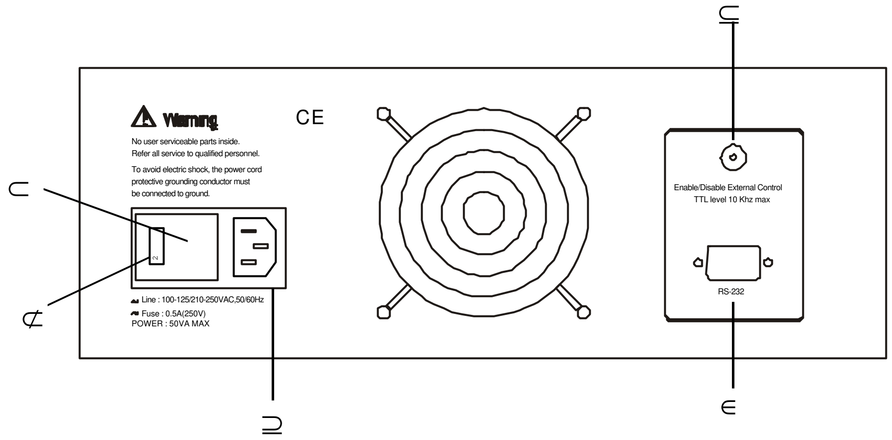
⊆ **[Input]** optical connector

- The input termination is FC/PC type unless specified otherwise.

∈ **[Output]** optical connector

- The output termination is FC/PC type unless specified otherwise.

REAR PANEL



⊇ **Power Entry Module** The power entry module is for the AC line voltage input. It blocks off high frequency noise entering the instrument. Before you plug the power cord into a socket outlet, check the voltage selector switch whether it is at correct position.

⊄ **Voltage Selector Switch** This switch is to select an input AC voltage. Setting at 115V is for operation between 100 and 125VAC. Setting at 230V is for operation between 210 and 250VAC

⊂ **Fuse Holder** To open the fuse holder, use a (-) screw driver.

⊆ **External Control : TTL** This BNC connector is to give external enable/disable control by TTL signal. High level signal into this connector disables PS. Maximum switching rate is 10kHz.

∈ **External Control : RS-232** RS-232 interface is provided (9-pin male D connector). Refer to Chapter 2. Operation, *Remote Control via RS-232 Interface*.

CAUTION

MAKE SURE TO USE CORRECT OPTICAL CONNECTOR TYPE. MATING AN APC-TYPE CONNECTOR WITH A PC TYPE CONNECTOR MAY CAUSE DAMAGE TO THE CONNECTOR FERRULES AND THE ADAPTER.

MAKE SURE THE END-FACES OF THE EXTERNAL CONNECTORS CLEAN, OR THE INNER CONNECTORS MAY BE CONTAMINATED, WHICH INCREASES INSERTION LOSS AND MAY CAUSE HIGH BACK REFLECTION.

Where in my system should PS be placed?

Basically, PS should be placed just before the device or the system under consideration in the whole optical path. It might be an EDFA chain, a fiber optic device or a measurement system. Refer to chapter 4. APPLICATIONS for detailed description.

Measurement Bandwidth

For polarization-independent measurements, the detection bandwidth should be limited within 10kHz. Refer to chapter 3. THEORY, *Measurement Bandwidth Limitation* for detailed description.

Remote Control via RS-232 Interface

RS-232 was originally designed for interface between DTE (Data Terminal Equipment) and DCE (Data Communications Equipment) by serial binary data interchange. Since most personal computers are now equipped with RS-232, a user can easily interface PS- -A with personal computer for remote control. Communication conditions of PS- -A must be set as follows

Baud rate	9600 bps
Data bit	8 bit
Stop bit	1 bit
Parity	None

Table 2.1 Communication conditions of PS- -A.

The lines needed for 9-pin serial communication are seven lines, that is, Received Data (RxD), Transmitted Data (TxD), Data Terminal Ready (DTR), Signal Ground (GND), Data Set Ready (DSR), Request To Send (RTS), and Clear To Send (CTS). RS-232 wiring from a Personal Computer Serial Port into a PS Serial Interface Device is shown in Fig 2.1.

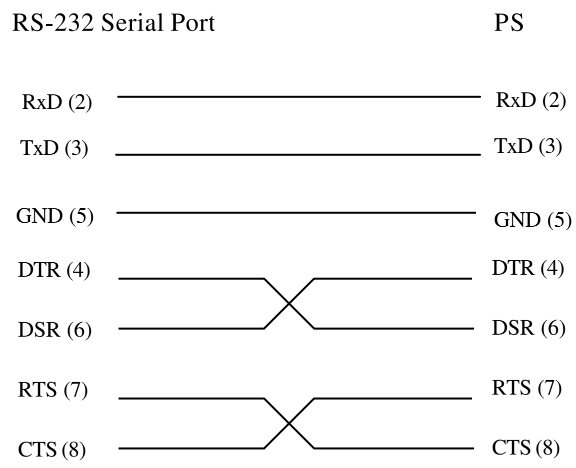


Figure 2.1. Wiring from a PC Serial Port into the PS

The command set for RS-232 interface is given in Table 2.2. If the commands are correctly transmitted to the PS, the PS replies "OK" in ASCII code to PC Serial Port. But when a wrong command is transmitted, the PS replies "ERR". **Note that the RS-232 commands must be transmitted and received in capital words followed by Carriage Return (CR).**

Command	Function
RMT	Login for remote control
ENB	Turn on the polarization scrambler
DSB	Turn off the polarization scrambler
LOC	Logout for remote control

Table 2.2. The PS command set for RS-232 interface

An example in C language for the PS remote control is shown below.

```
#include <bios.h>
#include <conio.h>

/* Value for selecting COM1 port */
#define COM1 0
#define DELAY_TIME 5

/* Communication conditions for RS-232 Serial Interface */
/* 0xe0 : Baud rate 9600 bps */
/* 0x03 : 8 bits Data bit */
/* 0x00 : No parity bit */
/* 0x00 : 1 bit Stop bit */
#define SETTINGS (0xe0 | 0x03 | 0x00 | 0x00)

/* Function for transmitting a command to PS */
/* cmd_kind : Pointer of command */
/* num_str : Length of command string */
void Send_Cmd (char *cmd_kind, int num_str);

char rmt[3]="RMT";
```

```
char dsb[3]="DSB";
char enb[3]="ENB";
char loc[3]="LOC";

main()
{
        /* Set up communication condition */
        bioscom(0, SETTINGS, COM1);

        Send_Cmd(rmt,3);
        delay(DELAY_TIME);
        Send_Cmd(dsb,3);
        delay(DELAY_TIME);
        Send_Cmd(enb,3);
        delay(DELAY_TIME);
        Send_Cmd(loc,3);
}

void Send_Cmd (char *cmd_kind,int num_str)
{
        int register in, i=0;
        for (i;i<num_str;i++)
                {
                /* Send one character among command string to PS */
                bioscom(1,cmd_kind[i],COM1);
                }
        in=0x0D;            /* Hexadecimal value for ASCII code CR */
        bioscom(1,in,COM1);        /* Send CR to PS */
}
```

3.0 THEORY

Introduction

In many optical fiber communication systems and sensors, optical signal of polarized light may be degraded by the presence of polarization dependence of the constituents. Polarization of light gives rise to erroneous results when it is used in characterizing fiber-optic components having PDL, even if it is small. In any of these cases, polarization scrambling is the most promising solution.

Polarization Scrambler randomizes the output SOP of light in order to lower the DOP of light effectively in time average. Here, randomization means the modulation of SOP on the Poincare sphere. However, PS does not generate a truly random trajectory but generates a predetermined trajectory depending on the input SOP. The important thing is that the trajectory on the Poincare sphere should be integrated in time to yield zero DOP regardless of the input SOP.

In this chapter it is assumed that the users have understanding of vector representation of the electromagnetic field, Jones vectors and matrices, Stokes parameters and Poincare sphere. This chapter deals with the concept of polarization scrambling, the methods of realizing it, polarization modulation speed and DOP, and double stage polarization modulation for input polarization independent operation.

Depolarizing Quasimonochromatic Light

Electric field vector of lightwave traveling through a medium along a certain direction, say z-axis, can be decomposed into two orthogonal directions, x- and y-axes. The state of polarization can be described in terms of amplitude of each electric field component and the phase difference between them. Since a quasimonochromatic light maintains its sinusoidal amplitude with constant phase only for coherence time t_c or coherence length l_c, it can be depolarized by introducing optical path difference that is longer than the coherence length between the two polarization components.

This depolarizing method seems to be the simplest way to get an unpolarized light in principle. However it fails to be practical in many applications where the spectral linewidth of the light source is too narrow. For example, in order to depolarize a conventional DFB LD that has 0.01nm FWHM, we may give phase delay between the two polarization components by transmitting the light through a high birefringence fiber. In this case, the length of the fiber would be as long as 620meters for a PMF having 4mm-polarization mode beat length. Moreover, this method gives rise to very large PMD of 800ps, which makes it impractical in most communication applications.

Polarization scrambling is the right solution for depolarizing any kinds of light sources regardless of their spectral linewidths. Polarization scrambling can be understood as polarization modulation. DOP of light can be made zero by modulating the SOP at a speed much faster than the detection bandwidth or the time constant of the system under consideration.

SOP of light is modulated via modulation of birefringence of the medium through which the light passes. Therefore polarization scramblers are classified into several types depending on the types of birefringence modulators. FIBERPRO's PS series is based on all-single mode fiber technology to give very low insertion loss and practically no return loss, PDL and PMD. The birefringence modulator composed of a single mode fiber and an acousto-optic transducer is driven by a sinusoidal RF signal of 700~1,000 kHz typically. **The Standard model of FIBERPRO's PS series has a double-stage birefringence modulator to achieve input polarization-independent operation.**

Mathematical Description of Polarization Scrambler

Electric field vector of a quasimonochromatic light travelling along z-axis is decomposed into two mutually orthogonal directions, say, x- and y-axis, thus expressed as

$$E_x = a_x \exp[i\varphi_x(t)],$$
$$E_y = a_y \exp[i\varphi_y(t)] \quad \text{Eq. 3.1}$$

where the phase difference δ is given by

$$\delta = \varphi_x(t) - \varphi_y(t) \quad \text{Eq. 3.2}$$

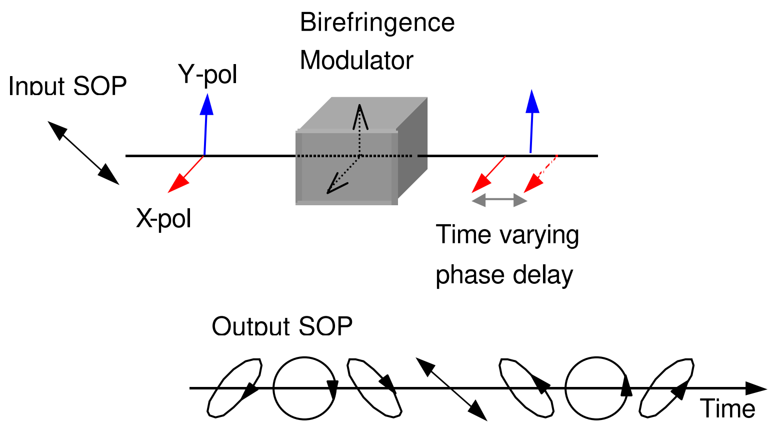


Fig. 3.1 Conceptual view of polarization scrambling.

The key fact of polarization scrambling is modulating the phase difference δ in a proper way to make DOP zero in time average. Fig. 3.1 shows the concept of polarization scrambling.

In terms of Stokes parameters defined as

$$\begin{aligned} S_0 &= \langle a_x^2 \rangle + \langle a_y^2 \rangle, \\ S_1 &= \langle a_x^2 \rangle - \langle a_y^2 \rangle, \\ S_2 &= 2 \langle a_x a_y \cos\delta \rangle, \\ S_3 &= 2 \langle a_x a_y \sin\delta \rangle, \end{aligned} \qquad \text{Eq. 3.3}$$

the effective DOP is given by

$$P = \frac{I_{pol}}{I_{tot}} = \frac{\sqrt{S_1^{\ 2} + S_2^{\ 2} + S_3^{\ 2}}}{S_0}. \qquad \text{Eq. 3.4}$$

In Eq. 3.3 < > notates time average of the parameter inside. In order to make the effective DOP equal to zero, the last three Stokes parameters should be made equal to zero.

$$S_1 = S_2 = S_3 = 0. \qquad \text{Eq. 3.5}$$

It is straightforward to derive the optimum operating condition for the polarization scrambler from Eq. 3.3 and Eq. 3.5 as will be described below.

The birefringence modulators are driven by sinusoidal signals. It follows that the time-varying phase delay $\Delta\phi$ between the two polarization modes of a birefringence modulator takes the form,

$$\Delta\phi = \phi_0 + \phi_m \sin(\omega t + \alpha), \qquad \text{Eq. 3.6}$$

where ϕ_0 is the constant phase delay due to the modulator geometry-induced birefringence and ϕ_m is the amplitude of the birefringence modulation. ω and α are the angular frequency

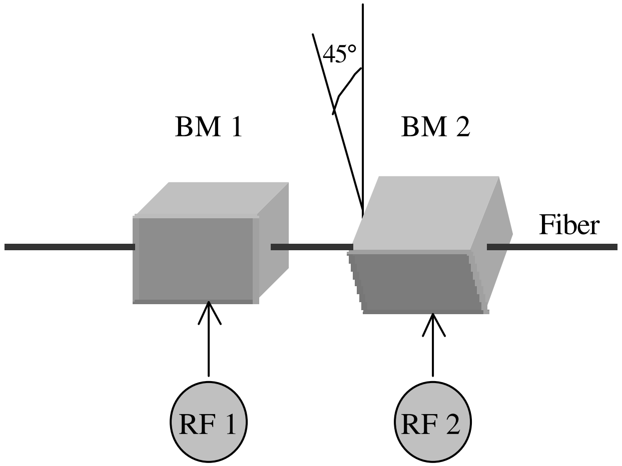


Fig. 3.2 Schematic diagram of PS series polarization scrambler. The birefringence axis of the second modulator is rotated 45° with respect to the axis of the first one.

and phase of applied RF signal, respectively.

Let us take the Jones matrices of each birefringence modulator in Fig. 3.2 as $M_1(\Delta\phi_1)$ and $M_2(\Delta\phi_2)$, respectively. Then the Jones vector of the output SOP, E_{out} can be expressed as successive multiplication of the Jones vector of the input SOP, E_{in} with M_1 and M_2.

$$E_{out} = M_2 M_1 E_{in} \qquad \text{Eq. 3.7}$$

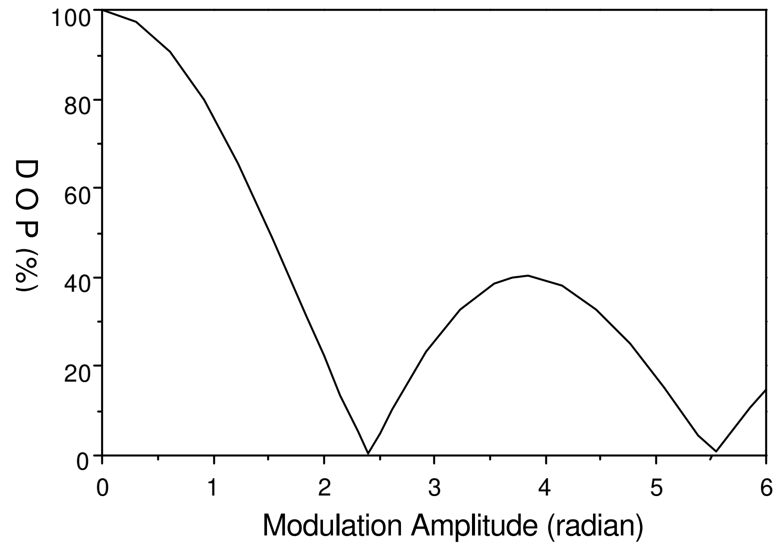


Fig. 3.3 DOP as a function of modulation amplitude of a birefringence modulator.

If we put the components of E_{out} into Eq. 3.3 and use Eq.3.5, then after a little algebra we get the expression for zero DOP condition.

$$J_0(\phi_{m1}) = J_0(\phi_{m2}) = 0 \qquad \text{Eq. 3.8}$$

where J_0 is the 0^{th} order Bessel function of the first kind. To satisfy Eq. 3.8 the birefringence modulation amplitudes, ϕ_{m1} and ϕ_{m2} should be one of the roots of J_0. PS has the modulation amplitude at 2.405. Plotted in Fig. 3.3 is DOP as a function of modulation amplitude for a birefringence modulator.

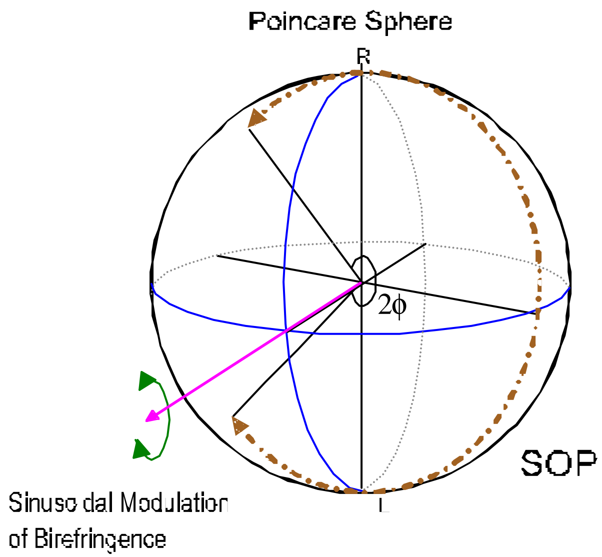


Fig. 3.4 Trace of SOP on Poincare sphere by a single-stage birefringence modulator

It is worthwhile to speculate as to the trace of SOP on the Poincare sphere. First, let us assume we have only one birefringence modulator. If we put a linearly polarized light into the modulator with its polarization direction at 45° with respect to the birefringence axis of the modulator, the trace would be a simple curve on the sphere as depicted in Fig. 3.4. It represents the rotation of the SOP around the birefringence axis of the modulator. The trace does not complete a great circle because the modulation

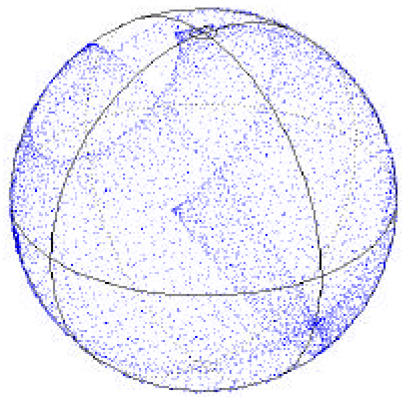


Fig. 3.5 Trace of SOP on the Poincare sphere by a double stage birefringence modulator. Plotted for 200μsec.

amplitude is 2.405 to get zero DOP.

Although the PS has a double-stage birefringence modulator, polarization scrambling occurs only at the second stage-modulator in the case where the input polarization is linear and aligned to the birefringence axis of the first modulator. The light passes the first stage-modulator without any change of SOP.

Shown in fig. 3.5 is the trace of SOP when the light is incident on the first-stage modulator of the double-stage birefringence modulator with its two polarization components projected equally onto the fast- and slow-axis of the modulator. This trace has been plotted for 200μsec. The output SOP moves pseudo-randomly on the Poincare sphere but it still does not cover the whole surface.

In most applications including PDG suppression of long-haul transmission systems, polarization independent measurement systems, and fiber interferometric sensor systems, the important factor is the DOP itself, not whether the SOP covers the whole surface of the Poincare sphere or not. FIBERPRO also provides triple-stage modulator type Polarization Scramblers for such applications that require full coverage of the Poincare sphere.

Measurement Bandwidth Limitation

You must consider how the detector bandwidth should be limited in order to get sufficiently low effective DOP for your systems when using a PS. The required limit of bandwidth is determined by the two frequencies, f_1 and f_2 of the RF signals applied to the double-stage birefringence modulator. If we put a **polarizer** at the

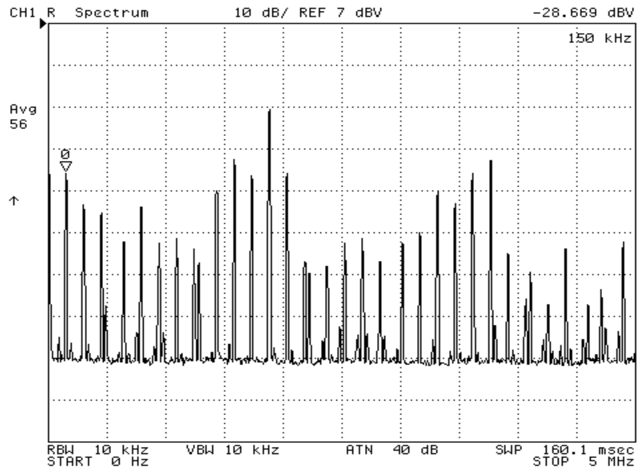


Fig. 3.6 RF spectrum of the optical output of a PS measured through a **polarizer**. f_1=940kHz. f_2=790kHz. The first prominent peak corresponds to f_1-f_2=150kHz.

output of a PS and observe the optical output with a fast detector to get frequency distribution, the detected signal is shown to be the sum of the harmonics of f_1, f_2 and the beating terms between them (Fig. 3.6). If the light is to be seen as unpolarized, it is required that the detector bandwidth be much lower than $|f_1-f_2|$ which is the difference of the two driving frequencies. As seen in Fig. 3.6, there is no prominent frequency component below it.

Fig. 3.7 shows the output DOP as a function of the detector cutoff

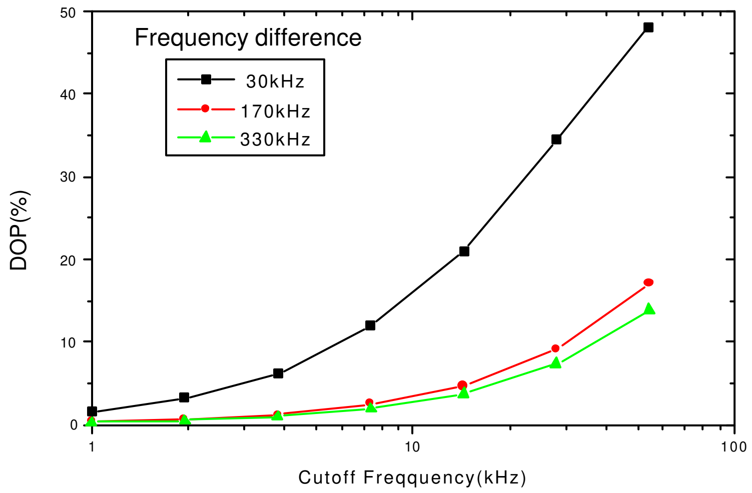


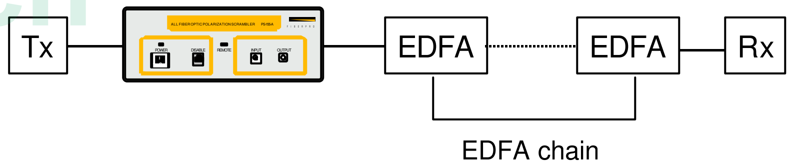
Fig. 3.7 DOP as a function of cutoff frequency of low pass filter at the photodetector. Curves are drawn for different settings of frequency difference between the two modulation frequencies.

frequency for several cases of different driving frequencies. Standard Polarization Scramblers are designed to have frequency difference about 170kHz, which corresponds to the middle curve with solid circle symbols. **The curve indicates that the detector cutoff frequency should be less than 10kHz to achieve DOP less than 5%.**

4.0 APPLICATIONS

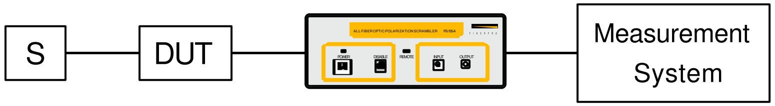
PDG Reduction

PS can remove Polarization Dependent Gain (PDG) of a long EDFA chain. An EDFA has PDG induced by Polarization Hole Burning (PHB) of which the time constant is approximately 10msec. If the light signal is polarization scrambled faster than the response of the EDFA, PDG gets suppressed and so does the degradation of SNR due to it.



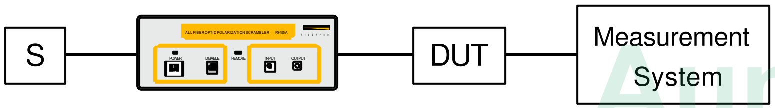
Removing PDL of DUT

PS can be used to depolarize optical source for polarization independent measurement. The measurement system can interrogate accurate value of the DUT characteristics such as insertion loss and filter profile, etc.



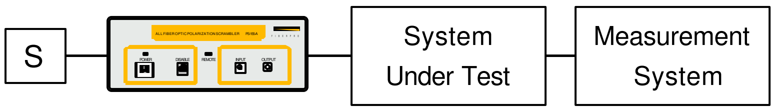
Removing PDL Induced Instrumental Error

Some measuring instruments have polarization dependence. This gives rise to errors in measurements. PS removes polarization dependence of the measuring instrument



Pseudo-random Polarization Generation

PS generates pseudo-random polarization states at high speed. This can be utilized in testing telecom systems under polarization variation.



FIBERPRO Limited Warranty

FIBERPRO warrants its products to be in conformance to mutually agreed upon written specifications and to be free from defects in material and workmanship. The warranty period of polarization scrambler is 1 year. The above warranty period shall begin on the date of shipment by FIBERPRO to Purchaser or, if Purchaser is an authorized reseller of such FIBERPRO products, from the date of shipment by the reseller to the reseller's original customer. FIBERPRO shall, at its option and cost, either repair or replace the products with new or reconditioned products and parts provided the products are returned by Purchaser along with dated and serialized proof of purchase to FIBERPRO or to an FIBERPRO authorized service facility, transportation and insurance prepaid, within the above warranty period and which are found by FIBERPRO to be defective within the terms of this warranty. Products repaired or replaced by FIBERPRO under this warranty will be returned by FIBERPRO to Purchaser, transportation and insurance prepaid. Replaced products and parts shall become the property of FIBERPRO. If any products returned by Purchaser to FIBERPRO for repair or replacement are found by FIBERPRO, after examination and testing, not to be defective, FIBERPRO shall so advise Purchaser and shall dispose of any such products in accordance with Purchaser's instructions and at Purchaser's cost, and Purchaser shall reimburse FIBERPRO for examination and testing expenses incurred at FIBERPRO's then current rates.

CONTINUED USE OR POSSESSION OF THE PRODUCTS AFTER EXPIRATION OF THE ABOVE WARRANTY PERIOD SHALL BE CONCLUSIVE EVIDENCE THAT THE WARRANTY IS FULFILLED TO THE FULL SATISFACTION OF PURCHASER.

The warranty set forth above shall not apply to failure or deficiency which has been caused by misuse, abnormal or unusually heavy use, neglect, alteration, improper installation, unauthorized repair or modification, improper testing, accident or causes external to the product such as but not limited to excessive heat or humidity, or improper installation. Such warranty shall also not apply to expendable components such as but not limited to fuse, power cord, adapters, and screws. FIBERPRO makes NO WARRANTY as to any products, which are supplied by it "AS IS" or as to any experimental or developmental products, or as to products not manufactured by FIBERPRO. FIBERPRO's warranty as set forth above shall not be enlarged, diminished or affected by, and no liability shall arise out of, FIBERPRO's rendering of technical advice in connection with Purchaser's order. The warranty set forth above is not assignable by Purchaser.

Purchaser's sole remedy under the above warranty shall be repair or replacement as provided above. FIBERPRO's sole and exclusive maximum liability for any claim by Purchaser or anyone claiming through or on behalf of Purchaser arising out of Purchaser's order or the above warranty shall not in any event exceed the actual amount paid by Purchaser to FIBERPRO for the product. In no event shall FIBERPRO be liable for any indirect, incidental, collateral, exemplary, consequential or special damages or losses arising out of Purchaser's order of products delivered under it or out of the above warranty, including without limitation loss of use, profits, or goodwill. Some countries do not allow the exclusion of limitation of incidental or consequential damages, so the above limitation or exclusion may not apply to Purchaser. EXCEPT AS STATED ABOVE IN THIS PARAGRAPH, THE FOREGOING WARRANTIES ARE IN LIEU OF ALL OTHER CONDITIONS OR WARRANTIES, EXPRESS, IMPLIED OR STATUTORY, INCLUDING, WITHOUT LIMITATION, AN IMPLIED CONDITION OR WARRANTY OF MERCHANTABILILTY OR FITNESS FOR A PARTICULAR PURPOSE AND OF ANY OTHER WARRANTY OBLIGATION ON THE PART OF FIBERPRO.