PMD-1000

PMDPro™ Polarization Optimized PMD Source

Operation Manual

Version 2.1

November 16, 2015

General Photonics Corp.   Ph: (909) 590-5473
5228 Edison Ave.   Fax: (909) 902-5536
Chino, CA 91710 USA   www.generalphotonics.com

SAFETY CONSIDERATIONS

The following safety precautions must be observed during operation, service and repair of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instrument. General Photonics Corp. assumes no liability for customers' failure to comply with these requirements.

- **Before operation, the user should inspect the instrument and review the manual carefully.**

- The instrument's rear panel includes a chassis ground terminal for electrical safety.

- Make sure that the instrument is in a secured work environment (in terms of temperature, humidity, electrical power, hazard due to fire or shock, etc.) for proper operation.

- Standard laser safety procedures should be followed during operation.

Table of Contents:

Section 1. Specifications:

Physical Features:

Dimensions	2U, 19 inch ¾ rack width
	3.5" (H) × 14" (W) × 14" (L)
Connector Type	FC/PC, FC/APC, SC/PC, or SC/APC
Operating Temperature	10 °C to 50 °C
Storage Temperature	−20 °C to 60°C

Optical Characteristics (Typical):

Operating Wavelength Range	C band or L band
Insertion Loss	5.0 dB @1550 nm (90 ps version)
	5.5 dB @1550 nm (180 ps version)
Input Power Range	−10 to 10 dBm
Return Loss	50 dB
DGD Range	0 to 91 ps or
	0.36 to 182.4 ps

DGD Resolution

	90 ps range	180 ps range
Discrete mode	0.357 ps	0.714 ps
Quasi-continuous mode	0.1 ps	0.2 ps

2nd-order PMD Range	2000 ps^2 (90-ps range)
	8100 ps^2 (180-ps range)
PMD Variation Time	1 ms (minimum)
SOP Alignment Accuracy	±2° at 23±5°C.
SOP Tracking Speed	10π/s
DOP Accuracy	±2% at 23±5°C.
PDL	0.45 dB typical (90 ps version)
	0.5 dB typical (180 ps version)
Wavelength Dependent Loss	0.6 dB (across C-band)
Transient Loss	0.6 dB (typical)

Electrical Characteristics:

Power Supply	100-240 VAC, 50-60 Hz
Communication Interfaces	USB, Ethernet, RS-232, and GPIB
Response Time	1 ms (typical)
Front Panel Display	2 × 20 character LCD

Section 2. Overview:

General Photonics' PMDPro™ is a breakthrough PMD source that can deterministically generate precise 1st-order PMD up to 180 ps and 2nd-order PMD up to 8100 ps^2. It combines this basic functionality with a rapid switching time (~1 ms) and polarization optimization capability to enable various applications related to high bit-rate optical fiber communication links. PMDPro simplifies and expedites all PMD related systems testing.
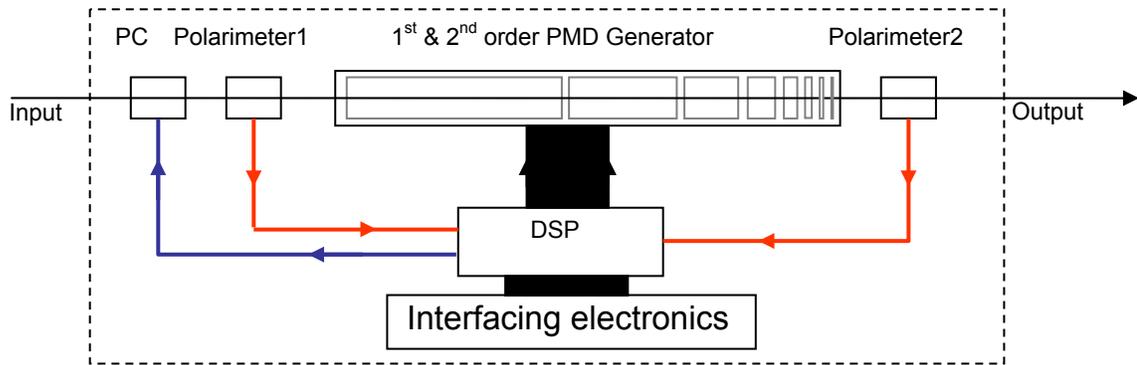
Figure 1 System diagram of polarization optimized PMD source

The PMDPro contains an automatic polarization controller and two polarimeters that continuously monitor the state of polarization (SOP) and degree of polarization (DOP) before and after the PMD generating elements. The polarization controller can be operated using feedback from the input polarimeter to automatically align and maintain the input SOP such that there is an equal power split between polarization components aligned to the principal axes of the DGD element to obtain the worst-case first order PMD effect. Alternatively, the controller can automatically adjust and maintain the input SOP using the feedback from the output polarimeter to either minimize or maximize the output DOP for each PMD setting.

Minimizing the output DOP enables testing of the worst-case total PMD effect, while maximizing the output DOP allows the PMDPro to act as a PMD compensator, allowing the user to determine the optimum PMD values for PMD compensation. The PMDPro can also perform PMD emulation by generating statistical distributions of first and second order PMD representing those of a real fiber link. In addition, the integrated polarization controller and polarimeters enable variable rate scrambling and deterministic polarization control functions, including trace generation and polarization stabilization at any SOP.

Basic functions can be controlled either manually from the front panel keypad or remotely via RS-232, USB, Ethernet, or GPIB interfaces. The control program also enables several advanced functions.

The structure, features, and functions of the PMDPro are described in more detail in sections 3 and 4. Section 5 includes application examples, and section 6 describes basic troubleshooting.

Section 3. Feature Description:

3.1 Optical Features:

The PMDPro system has two bulkhead adapters on the front panel to accommodate the optical input and output. The adapters are universal connector interfaces (UCI), which feature a male-type adapter top piece that can be removed for direct access to the ferrule end for routine cleaning and maintenance without removing the entire adapter from the panel. This feature helps avoid high insertion loss, high return loss and measurement instability caused by dirty or contaminated connectors. In addition, the PMDPro's universal interchangeable adapter allows the end user to switch to ST, SC, or FC connectors without opening the instrument panel. Although the PMDPro is shipped with a standard (typically FC/PC or FC/APC) fiber adapter, other interchangeable inserts are available. For additional information on different input fiber adapter inserts, please contact General Photonics.

External fiber connectors should be cleaned using industry standard cleaning methods before connection to the PMDPro. If this procedure is followed before each connection, the instrument's internal connector ferrules should not need regular cleaning. However, high insertion loss or measurement instability that does not improve after cleaning the external connectors may indicate that the instrument's internal connector ferrules require cleaning.

Each connector ferrule is contained in a universal connector interface consisting of a front piece that connects to the external fiber connector, and a base piece that is mounted on the front panel of the instrument, as shown in Figure 2. To clean a connector ferrule, first, make sure no external connector is connected to the universal connector interface. Then, using a Phillips screwdriver, remove the two small screws connecting the front and back parts of the adapter, and carefully pull the front flange straight out. (Note: never remove the adapter base from the front panel). The ferrule end should now be exposed. Clean the ferrule using standard cleaning procedures (compressed air or a fresh lint-free tissue and alcohol), taking care to avoid scratching the ferrule surface. Finally, replace the front flange (position it so that the key notch faces up, and the small alignment pin lines up with the hole in the base piece, before pushing it in) and the screws. For frequent measurements, we recommend that the user prepare a patch cord fiber to avoid wear on the internal connector.
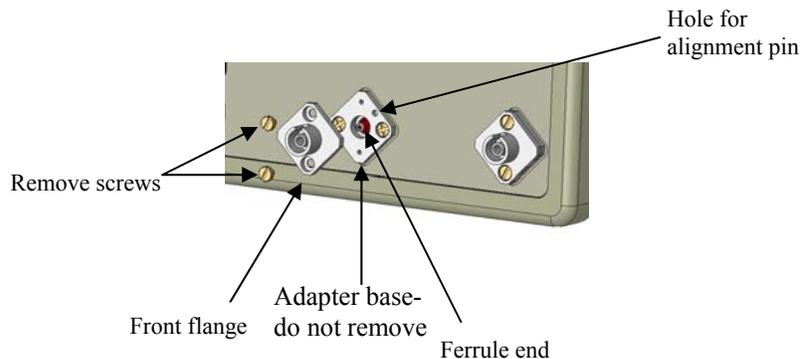
Figure 2 Diagram of universal connector interface

Input power should be between –10 and +10 dBm.

3.2 Electrical Features:

The PMDPro system uses a power supply that accepts 100-240 VAC, 50-60 Hz line voltages. Due to high voltage, the following safety precautions must be exercised during operation.

- The ground pin on the power supply cord must be connected to earth ground of the wall receptacle.
- Never touch the boards inside the package without proper insulation.
- The PMDPro is not user serviceable. It should be serviced only by factory-authorized personnel.

The front panel of the PMDPro is shown in Figure 3. The power switch (Power), liquid crystal display (LCD), push button control pads, and input/output optical connectors are mounted on the front panel. The AC power plug, fuse, chassis ground connector, RS-232, USB, Ethernet, and GPIB interface connectors, and two fans are mounted on the rear panel, as shown in Figure 4.

The PMDPro includes RS-232, USB, Ethernet, and GPIB interfaces for external computer operation of the system and data readout. RS-232 and USB cables are provided for connecting the PMDPro to a personal computer. A LabView™ (National Instruments, www.ni.com) control program compatible with all of the control interfaces is provided. Control commands and control program installation and operation instructions are located in Section 4.3.
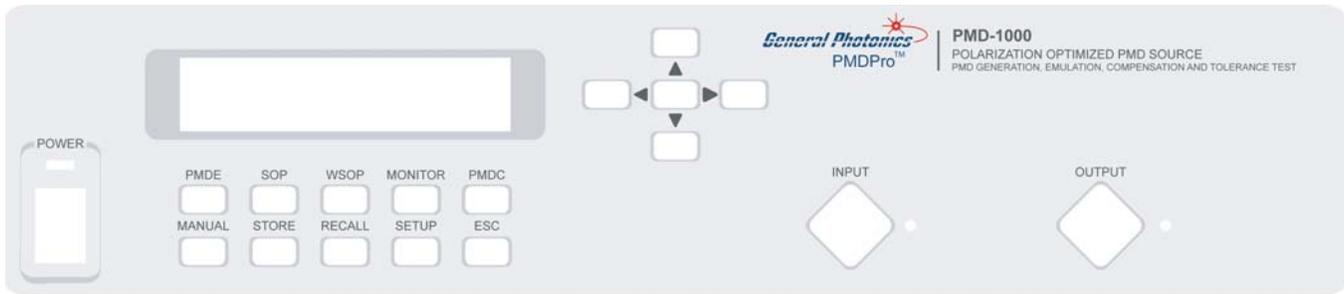
Figure 3 Front panel layout

Front panel description:

LCD display: displays data and operation mode information
Power: power on/off switch
Input: universal connector interface adapter for optical fiber input
Output: universal connector interface adapter for optical fiber output
Keypad: control button descriptions:

PMDE: DGD/PMD setting, scan, and emulation functions
SOP: Polarization control, waveform, and scrambling functions
WSOP Automatic input polarization alignment for worst-case PMD effect
MONITOR: Displays SOP and DOP readings from input and output polarimeters, as well as output power and PMD information
PMDC: DGD and PMD compensation functions
MANUAL: SOP control via direct, real-time setting of individual polarization controller channel voltages
STORE: Allows user to store sequences of PMD values for scans, or to store individual PMDC measurement results
RECALL: Allows user to recall stored PMD sequences or PMDC measurement results.
SETUP: Allows user to set basic system parameters: operation wavelength (ITU channel), GPIB address.
ESC: Steps back to screen one level up from currently displayed screen.
ENTER (center key in arrow keypad): Enters parameters set with arrow keys

▲
◄ ►: Arrow keys used to set measurement/control parameters.
▼
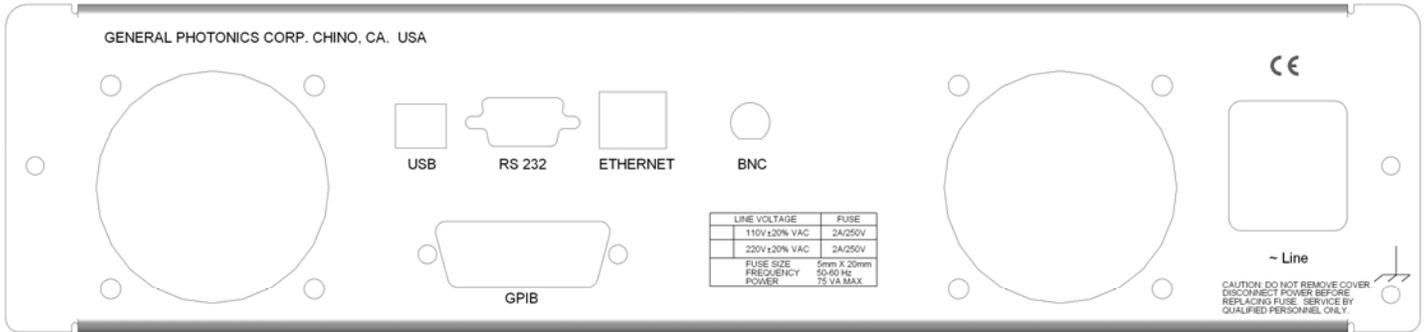
Figure 4 rear panel layout

Rear panel description:

USB: USB interface port
RS-232: serial communication port
Ethernet: Ethernet interface port
BNC: not used in PMD-1000
GPIB: GPIB interface port
Line: external AC supply input connector, 100-240VAC
$\perp$: chassis ground connector

Section 4. Operation Instructions:

Warning:
- **Never look into the light source fiber connector when the light source is turned on. THE OUTPUT LIGHT FROM A HIGH POWER LASER IS HARMFUL TO HUMAN EYES. Please follow industry standard procedures when operating a high power laser source.**

- **Avoid water condensation or liquid spills during PMDPro storage and operation.**

- **Check optical power level of the input optical beam. For accurate measurements, make sure the optical power level at the input connector is below 10 dBm (10 mW).**

4.1 Unpacking

Inspect PMDPro for any physical damage due to shipping and transportation. Contact carrier if any damage is found. Check the packing list to see if any parts or accessories are missing.

Avoid high-vibration environments when using the PMDPro.

4.2 Front Panel Operation

The conceptual structure and operational principles of the PMDPro are described in section 2. This section describes operational procedures and control sequences for control of the PMDPro's basic functions from the front panel.

Setup procedure is described below:

1. Make sure local AC voltage matches the AC voltage requirement of the PMDPro. If not, do not proceed. Contact General Photonics immediately. The PMDPro power supply accepts 100-240 VAC, 50-60 Hz line voltages.

2. Connect power cord and plug it into the wall receptacle. Make sure the ground pin of the power cord is connected to earth ground.

3. Make sure the input optical power is at an appropriate level, then connect input and output fibers to the PMDPro. It is important to clean the fiber connectors using industry standard procedures and to make sure that the connections are good. If using a high power optical source, if possible, turn off optical power source before connector cleaning.

4. Power on the PMDPro and the optical source.

When the PMDPro is first powered on, the LCD will briefly flash the following initialization screen, which shows the model number and firmware version.

```
GENERAL PHOTONICS
PMD-Pro VER 2.0
```

4.2.1 MONITOR:

After the initialization is finished, the PMDPro goes into monitor mode. The LCD displays:

```
DOP: xx.xx%      s1: x.xx
 s2: x.xx     s3: x.xx      I
```

This screen displays the SOP (Stokes parameters) and DOP information of the light as measured by the input (I) polarimeter. The up and down arrow keys can be used to toggle through two more display screens:

```
DOP: xx.xx%      s1: x.xx
 s2: x.xx     s3: x.xx      O
```

The second screen displays the SOP (Stokes parameters) and DOP information of the light as measured by the output (O) polarimeter.

```
P: xxx uW        x.xx dBm
  x.xx ps        x.xxps2
```

The third display screen shows the power level at the output polarimeter in mW/µW and dBm and the DGD and SOPMD values currently being generated by the PMDPro, in ps and ps^2, respectively.

If no light is detected, the PMDPro will display a "Power Low" message instead of the information described above.

Pressing the MONITOR button from any other operation or setup mode will stop any active polarization control or DGD scanning and return the display to this set of display screens. The polarization controller and PMD element will be left in their most recently set states.

Most of the function keys under the LCD display are used to access function menus to set up the various functions of the PMDPro. The menus and screen sequences are as follows.

4.2.2 SETUP:

Pressing the SETUP key accesses a setup menu that allows the user to configure the GPIB address (range 1~30) and operating wavelength (87 ITU grid channels for the C-band model), to query the IP address, and to clear the PMD sequence memory banks.

When the SETUP key is pressed, the LCD displays 6 menu options on 3 screens:

```
  1.  ITU FREQ CHANNEL
  2.  GPIB ADDRESS         ↓
```

```
  3.  GET DYNAMIC IP * ↑
  4.  GET STATIC IP       ↓
```

Note: the * next to the dynamic or static IP line indicates the PMDPro's current Ethernet communication mode. In this example, the PMDPro is set for dynamic IP addressing.

```
  5.  SET STATIC IP        ↑
  6.  INIT PMDE MEM-BANK
```

Use the up and down arrow keys to move between menu options and the ENTER key (the center key in the arrow keypad) to select the desired option.

1. ITU FREQ CHANNEL:
   Sets the operation wavelength. Use the left and right arrow keys to move the cursor and the up and down arrow keys to increment the digits to select the desired ITU channel number (range 1-87 for C-band model). The corresponding frequency and wavelength are displayed.

```
  Ch: C037      (193.40THz)
  λ: 1550.12 nm
```

   Once the value is set, pressing the ENTER key executes the setting and returns the display to the SETUP menu.

2. GPIB ADDRESS:
   This option sets the GPIB address for the PMDPro. When this option is selected, the screen displays:

```
  GPIB ADDRESS: 05
  (Range: 01 to 30)
```

Use the left and right arrow keys to move the cursor and the up and down arrow keys to increment the digits. The range of available addresses is 1 to 30, and the default value is 5. Once the value is set, pressing the ENTER key executes the setting and returns the display to the SETUP menu.

3. GET DYNAMIC IP:
    Sets the PMDPro for dynamic IP addressing and requests a dynamic IP address from the server.

    If the instrument is able to establish communication with the DHCP server and successfully retrieve a dynamic IP address, the dynamic IP address will be displayed on-screen.

    > GETTING DYNAMIC IP • •
    > (Please Wait)

    ↓

    > IP: 191.168.0.65
    > * Dynamic Mode Set
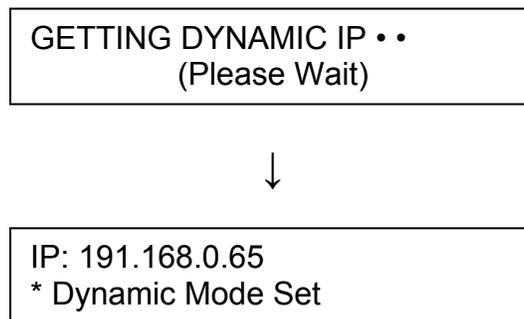
    If the request is unsuccessful, the address displayed will be the currently stored static IP address. If no static IP address has been stored by the user, the address displayed will be 0.0.0.0.

4. GET STATIC IP:
    Sets the PMDPro for static IP addressing and recalls the static IP address stored in memory.

    > GETTING STATIC IP • •
    > (Please Wait)

    ↓

    > FIX: 191.168.0.111
    > * Static Mode Set
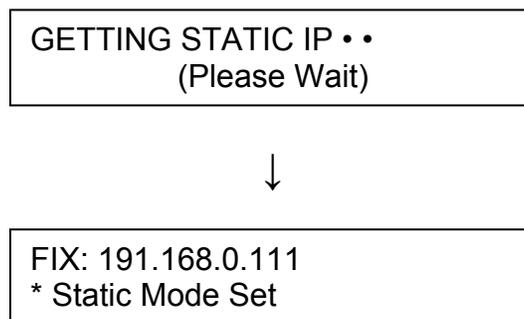
    See section 4.3.6 for instructions on hardware setup for Ethernet connection.

5. SET STATIC IP:
    This menu option is a placeholder for a function that is planned for future versions of this instrument. The static IP address and other parameters can be set using a LabView program (see Ethernet setup section for details).

6. INIT PMDE MEM-BANK
   Clears stored values from the selected PMD sequence memory bank and restores it to its default configuration. When this option is selected, the following screen is displayed:

```
INIT PMDE MEM-BANK: A
(SELECT BNK TO INIT)
```

The cursor will blink on the memory bank index position (A, in the current example). Use the left and right arrows to select the desired memory bank, and press ENTER to clear it. The instrument will ask the user to confirm the request to clear the memory bank:

```
INIT PMDE MEM-BANK: A
INIT BANK: A? [n] [y]
```

After the user confirms the data deletion, the screen will display:

```
PLEASE WAIT…
```

When the reinitialization of the data bank is complete, the machine will beep and the screen will return to the initialization confirmation screen:

```
INIT PMDE MEM-BANK: A
INIT BANK: A? [n] [y]
```

Use the ESC key to return to the Setup menu or one of the function keys to access a different menu.

4.2.3 PMDE:

The PMDPro has two operation modes for generating PMD values.

The discrete mode uses digital switching to generate PMD values according to the lookup table (included on the cd). 6561 DGD/SOPMD pairs can be accessed this way. Some of the SOPMD values in this set are wavelength dependent and some are wavelength independent. The wavelength dependence of any particular value in this set can be viewed using the PMD CALC function in the control program.

The quasi-continuous PMD generation mode allows full coverage of the PMD space. All PMD values generated in this mode are wavelength independent over the operation wavelength range of the PMDPro.

Figure 5 shows the PMD states covered by the PMDPro's discrete and continuous PMD generation modes.

(a)   (b)

(c)   (d)
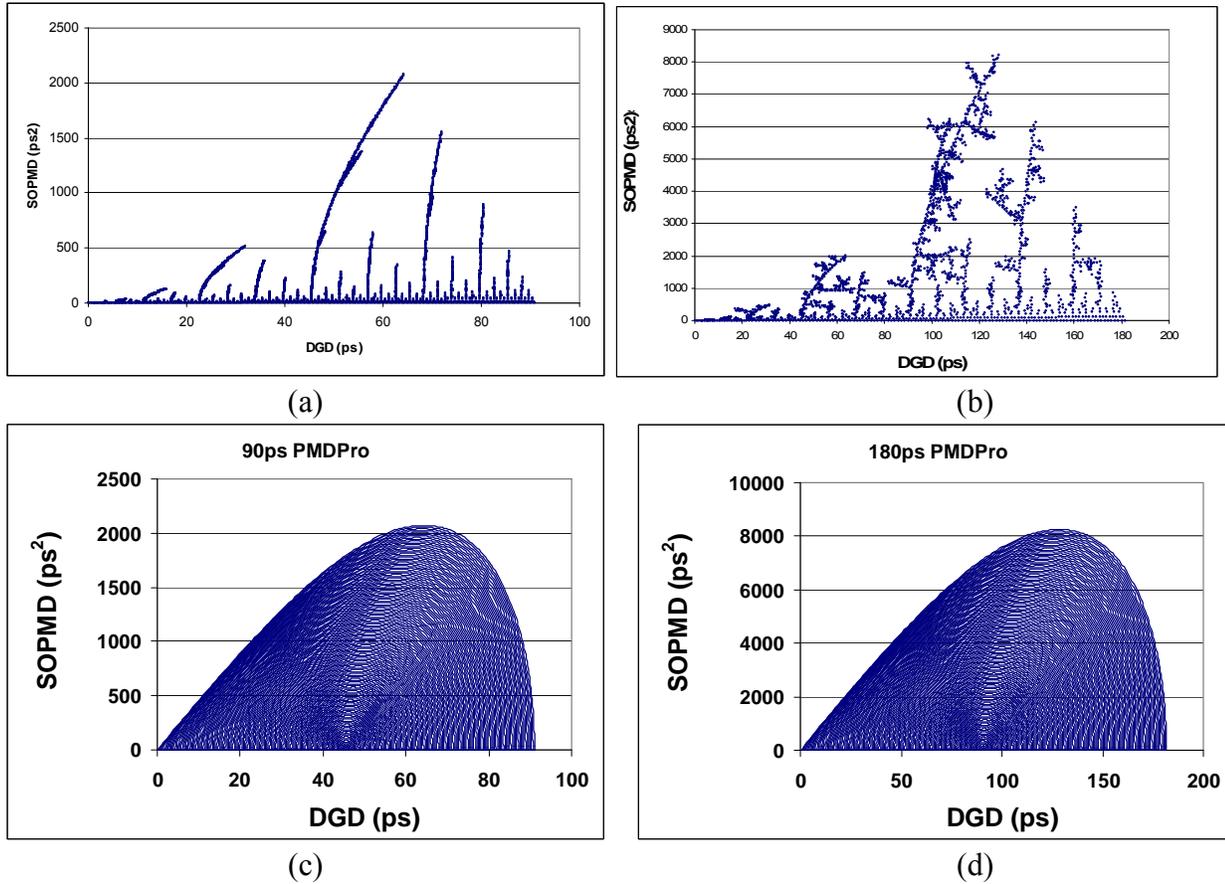
Figure 5 DGD/SOPMD coverage plots
a) 90 ps version, discrete mode
b) 180 ps version, discrete mode
c) 90 ps version, quasi-continuous mode
d) 180 ps version, quasi-continuous mode

Pressing the PMDE key on the front panel accesses the PMDPro's DGD/PMD generation functions, including generation of a single DGD/SOPMD pair, scanning through DGD or PMD states in the lookup table, generating a continuous PMD trace, scanning through a user-generated sequence of states, or generation of a Maxwellian distribution of DGD values.

When the PMDE key is pressed, the LCD displays 6 menu options on 3 screens:

```
1.  SET DISCRETE PMD ↓
2.  SET CONTINUOUS PMD
```

```
3.  SCAN DISCRETE PMD ↑
4.  PMD TRACE SCAN      ↓
```

```
5.  DGD-PMD EMULATION ↑
6.  SCAN PMD-MEM BANK
```

Use the up and down arrow keys to move between menu options and the ENTER key (the center key in the arrow keypad) to select the desired option.

1. SET DISCRETE PMD:
    Set a single PMD value (first and second order PMD combination) using the lookup table. When this option is selected, the LCD displays the following screen.

```
SET PMD  ID#:      _ _ _ 0
0.00 ps             0.0 ps2
```

Use the left and right arrow keys to move the cursor and the up and down arrow keys to increment the digits to select the index number (ID#) corresponding to the desired PMD value. There are 6561 PMD values (index numbers 0 to 6560). PMD values are grouped in the following order: states with DGD only, states with wavelength independent SOPMD, states with wavelength dependent SOPMD. The PMD corresponding to the selected index is displayed in the bottom line of the screen. The value on the left side is the DGD and the value on the right is the SOPMD.
The PMD setting is changed in real time as the index is incremented.

To observe the effect of the generated PMD on the input signal, press the MONITOR button. The display returns to the series of three screens showing, respectively, the SOP and DOP observed by the input polarimeter (before the PMD generation element), the SOP and DOP observed by the output polarimeter (after the PMD generation element) and the output power level and current DGD and SOPMD value. Use the up and down arrow buttons to move between the monitor screens.

2. SET CONTINUOUS PMD
In this mode, the user inputs the desired output DGD (in units of ps) and SOPMD (in units of ps^2). The PMDPro then calculates and displays the closest achievable match to the DGD and SOPMD values input by the user. At this point, the user can either choose to execute the setting or modify the requested values and recalculate.

When this option is selected, the LCD displays the PMD selection screen:

```
DGD:          _ 0.00 < 91.04
SOPMD:      _ _ _  0.0 < 0.0
```

For both DGD and SOPMD, the number to the left of the "<" symbol is the value set by the user. The number on the right is the maximum available value. The maximum available DGD value is determined by whether the PMDPro is a 90 ps or 180 ps unit. The maximum available SOPMD value is determined by the DGD value the user selects. As the user changes the requested DGD value, the maximum available SOPMD value will change accordingly.
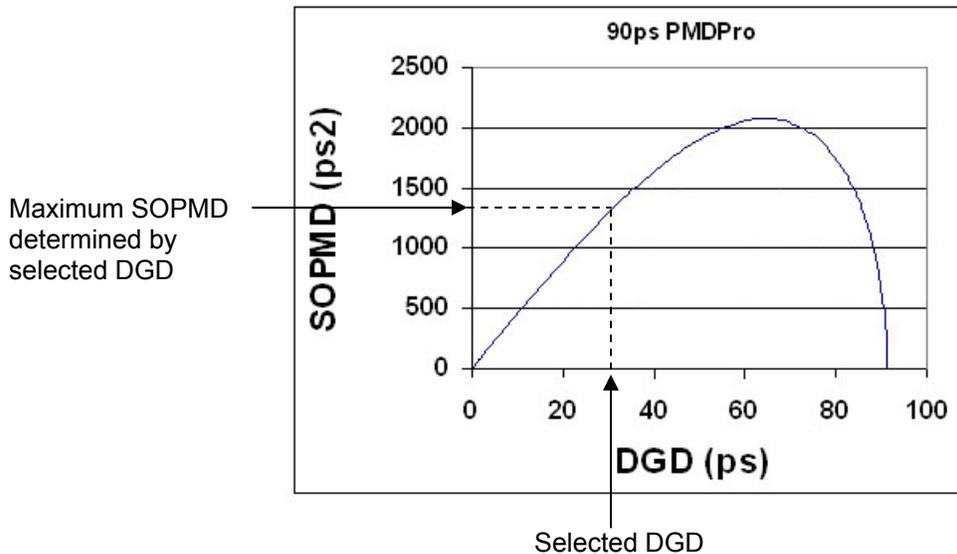
Figure 6 DGD/SOPMD range determinants for continuous control

Use the left and right arrow keys to move the cursor and the up and down arrow keys to increment the digits to set the DGD and SOPMD values to be matched. Note that the left and right arrow keys will scroll through all modifiable cursor positions. For example, pressing the right arrow key from the rightmost digit of the DGD setting line will move the cursor to the leftmost position of the SOPMD setting line

When the DGD and SOPMD values are set, press the ENTER key to calculate the closest available matches to the requested values. If the requested SOPMD is out of range, the PMDPro will flash an "SOPMD out of range" error message before returning to the PMD selection screen. If the selected values are within range, the LCD will display

```
DGD:          31.04 C 31.10
SOPMD:      _ 530.0 C 530.0
```

where the number to the right of the "C" on each line is now the calculated match to the requested value. At this point, the PMDPro has not yet changed the output DGD or SOPMD values; it has only displayed the results of the match calculation.

If the user is satisfied with the matched values, he can press the ENTER key again to execute the setting and change the output DGD and SOPMD to the calculated values. The LCD will display:

```
DGD:          31.04 E 31.10
SOPMD:      _ 530.0 E 530.0
```

where the "E" indicates that the calculated values have been enabled. From either the calculation or execution screens, the left arrow key can be used to return to the setting mode (the "C" or "E" will change back to the "<" symbol) and change the requested DGD and SOPMD values.

To observe the effect of the generated PMD on the input signal, press the MONITOR button. The display returns to the series of three screens showing, respectively, the SOP and DOP observed by the input polarimeter (before the PMD generation element), the SOP and DOP observed by the output polarimeter (after the PMD generation element) and the output power level and current DGD and SOPMD value. Use the up and down arrow buttons to move between the monitor screens.

3. SCAN DISCRETE PMD:
   Discrete mode DGD or PMD scan. This mode allows the user to set up a scan through either a selected subset of the DGD values in the lookup table or through all of the DGD/SOPMD pairs in the lookup table in order of index number. The setup screens for this option are as follows:

```
a. START (Scan PMD) ↓
b. MODE: Discrete PMD
```

```
c. INTERVAL: _ _100ms ↑
d. CYCLES: _ _ 10
```

```
e. RNG: _5.0, 60.0 ps
   (set: min and max) ↑
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

a. START:
    This option starts the scan. Use the other options to perform the scan setup, then return to option a) to begin the scan. When the scan is running, the screen displays:

```
DGD  ID# 000        CY: 0000
DGD: 0.00 ps        ID# 000
```

For a DGD only scan, or

```
PMD  ID# 0000       CY: 0000
0.00 ps             0.0 ps2
```

For a discrete PMD scan.

During the scan, the screen displays the current ID#, DGD and, if applicable, SOPMD values, and the number of completed cycles.

b. MODE:
    There are two scan options: "Discrete PMD" and "DGD Only". Use the up and down arrows to toggle between them, and ENTER to select the displayed option. "Discrete PMD" scans through all 6561 PMD states in the lookup table from lowest index number to highest index number. "DGD Only" scans through a selected subset of the 256 DGD states with SOPMD = 0, in order of increasing DGD. If "DGD Only" is selected, option a) becomes "START (Scan DGD)", and option e) is enabled.

c. INTERVAL:
    This option allows the user to set the dwell time, in ms, at each point in the scan. The time range is 1-60,000 ms. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the dwell time to the displayed value.

d. CYCLES:
    This option sets the number of times to run the scan. The cycle range is 1-9999. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the number of cycles to the displayed value.

e. RNG:
   This option appears only if "DGD Only" is selected for option b). It allows the user to set the lower and upper DGD limits for the scan.
   Range: 0.0 to 91.0 for 90 ps PMDPro.
              0.4 to 182.4 for 180 ps PMDPro.

4. PMD TRACE SCAN:
   Continuous mode PMD scan: Unlike the discrete mode scan, which generates a series of discontinuous PMD states according to the lookup table, the continuous mode scan varies the PMD continuously, with a user-controllable variation rate. This function is therefore ideal for PMD tracking speed tests.

   The DGD/SOPMD combinations available in quasi-continuous mode are points on one of the characteristic SOPMD vs. DGD curves.
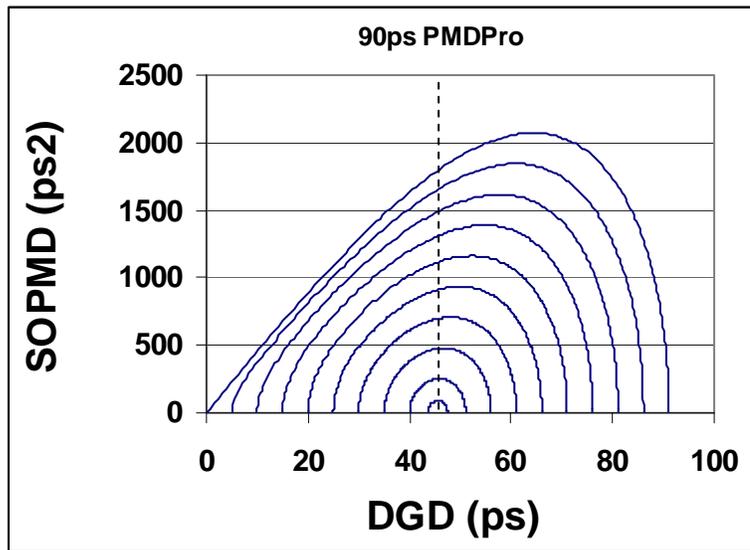
Figure 7 Characteristic SOPMD vs. DGD curves

In the PMD Trace scan function, the PMDPro traces out a demi-arc of a characteristic curve. Each demi-arc is half of a characteristic curve, with one endpoint on the DGD axis, as illustrated in Figure 7. The user selects a particular demi-arc to be traced by specifying a DGD value. The PMDPro then matches the specified value to the demi-arc with the DGD axis endpoint closest to that value.

The PMDPro can also step through a series of points along a demi-arc with a constant, user-controllable DGD step size. This is the step trace function. The transient between consecutive points in a step trace follows the characteristic curve, so that there are no discontinuous jumps during travel along a particular arc.

When the PMD Trace scan function is selected, the following screen is displayed:

```
A. CONTINUOUS TRACE
B. STEP TRACE
```

A. CONTINUOUS TRACE:

In continuous trace mode, the PMDPro varies the PMD along the selected curve using the minimum DGD step size of 0.1 ps. The user can select the DGD variation rate, in ps/s. The setup screens for continuous trace mode are as follows:

```
a.  START (con TRACE) ↓
b.  Rng: _0.00, 64.4 ps
```

```
c.  STEP DIRECTION: UP ↑
d.  CYCLES: _ _10 Count ↓
```

```
e.  MODE: BI-DIREC       ↑
f.  CON RATE: _ _1.0 ps/s
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

a. START:

This option starts the scan. Use the other options to perform the scan setup, then return to option a) to begin the scan.

While the scan is running, the screen displays:

```
CYC: _ _ _1/10      DIR: ←
63.6 ps             2002.7ps2
```

CYC: number of completed cycles/ total number of cycles to run.
DIR: scan direction.
        →←: bidirectional
        →:   unidirectional, increasing DGD
        ←:   unidirectional, decreasing DGD
The bottom line displays the current DGD and SOPMD values.

b. Rng:
This option selects the demi-arc to be traced by specifying the DGD range. Two DGD values are shown on this line. The first DGD value listed is the endpoint on the DGD axis. Use the left and right arrow keys to select the digit to be changed, and the up and down arrow keys to increment the active digit. The range for this value is 0.00 to 91.04 ps for a 90-ps PMDPro and 0.36 to 182.4 ps for a 180-ps PMDPro. As the DGD axis endpoint is changed, the other endpoint is adjusted accordingly. Note that the second endpoint is not on the DGD axis; while only its DGD value is displayed on this screen, it does have a nonzero SOPMD. Use the ENTER key to select the displayed DGD range.

c. STEP DIRECTION:
This option determines the beginning point and direction of the scan.
UP: scan begins at the lower DGD endpoint and proceeds in the direction of increasing DGD
DN: scan begins at the higher DGD endpoint and proceeds in the direction of decreasing DGD.
Use the up and down arrows to toggle the direction and the ENTER key to select the displayed setting.

d. CYCLES:
This option sets the number of times to run the scan. The cycle number range is 1-9999. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the number of cycles to the displayed value.

e. MODE:
This option determines whether one cycle is defined as a single direction or round-trip scan.
BI-Direc: Round-trip scan. The scan begins at the beginning point specified in option c), proceeds to the endpoint, then scans back to the beginning point.
UNI-Direc: Single-trip scan. The scan begins at the beginning point specified in option c), scans to the endpoint, and stops. The PMDPro then jumps back to the beginning point to begin the next cycle.
Use the up and down arrows to toggle between unidirectional and bidirectional, and the ENTER key to select the displayed setting

f. CON RATE:
Set the DGD variation rate, in ps/s, for the scan. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The variation rate range is 0.1 to 100 ps/s. The ENTER key selects the displayed value.

B. STEP TRACE:
In step trace mode, the PMDPro varies the PMD along the selected curve using a constant, user-selected step size and dwell time per point. The setup screens for step trace mode are as follows:

```
a.  START (stp TRACE) ↓
b.  Rng: _0.00, 64.4 ps
```

```
c.  STEP DIRECTION: UP ↑
d.  CYCLES: _ _10 Count ↓
```

```
e.  MODE: BI-DIREC      ↑
f.  STEP SIZE:  _ _0.4 ps ↓
```

```
g.  DWELL:      _ _50 ms ↑
(STEP TRACE ONLY)
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

Options a-e are the same as for continuous trace mode.

f. STEP SIZE:
Set the DGD step size between points, in ps. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The minimum step size is 0.1 ps. The maximum step size is determined by the range selected in option b). The ENTER key selects the displayed value.

g. DWELL time:
Set the dwell time at each point, in ms. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The dwell time range is 1 to 9999 ms. The ENTER key selects the displayed value.

5. DGD-PMD Emulation:
This is the statistical PMD emulation function. The PMDPro generates a Maxwellian distribution of DGD values with a user-selected number of points and average DGD. The SOPMD can either be zero (first-order PMD emulation only) or can be a statistical distribution corresponding to the generated DGD.

When this option is selected, the following screen is displayed:

```
┌─────────────────────────────────┐
│   A.  DGD ONLY EMULATION        │
│   B.  PMD EMULATION             │
└─────────────────────────────────┘
```

Select the desired option and press ENTER.

A. DGD ONLY EMULATION:

The setup screens for first-order PMD emulation are as follows:

```
┌─────────────────────────────────┐
│   a.  START (DGD Emula)   ↓      │
│   b.  AVERAGE DGD: 10.0ps        │
└─────────────────────────────────┘
```

```
┌─────────────────────────────────┐
│   c.  SAMPLE NUM: _ _1000 ↑      │
│   d.  CYCLE NUM: _ _ _10    ↓    │
└─────────────────────────────────┘
```

```
┌─────────────────────────────────┐
│   e.  INTERVAL: _2000 ms    ↑    │
│   (Rng: 1 ms to 60000 ms)        │
└─────────────────────────────────┘
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

a. START:

This option starts the emulation. Use the other options to perform the setup, then return to option a) to begin generating DGD values.

During the emulation, the screen displays:

```
┌─────────────────────────────────┐
│   CURRENT DGD: 37.49 ps          │
│   CY#:  0       SAM# 80          │
└─────────────────────────────────┘
```

CURRENT DGD: current DGD value, in ps.
CY#:   number of completed cycles.
SAM#: current sample number.

b. AVERAGE DGD:

This option specifies the average DGD value for the Maxwellian distribution. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The range for average DGD is 0.0 to 45.4 ps for the 90-ps PMDPro or 0 to 91.2 ps for the 180 ps PMDPro. The ENTER key selects the displayed value.

c. SAMPLE NUM:

This option specifies the number of samples in the distribution. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The range is 1 to 999999. The ENTER key selects the displayed value.

d. CYCLE NUM:
This option sets the number of times to run the emulation. The cycle range is 1-99999. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the number of cycles to the displayed value.

e. INTERVAL:
This option sets the dwell time per sample, in ms. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The range is 1 to 60000 ms. The ENTER key selects the displayed value.

B. PMD EMULATION
The setup screens for first and second order PMD emulation are as follows:

```
a.  START (PMD Emula)   ↓
b.  AVERAGE PMD: 10.0ps
```

```
c.  SAMPLE NUM: _1000   ↑
d.  CYCLE NUM: _ _ _10   ↓
```

```
e.  INTERVAL: _2000 ms   ↑
    (Rng: 1 ms to 9999 ms)
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

a. START:
This option starts the emulation. Use the other options to perform the setup, then return to option a) to begin generating PMD values.

During the emulation, the screen displays:

```
9.72 ps        436.75 ps2
CY#:  0        SAM# 80
```

Top line: current DGD and SOPMD
CY#:   number of completed cycles.
SAM#:current sample number.

b. AVERAGE PMD:
This option specifies the average DGD value for the Maxwellian distribution. Use the left and right arrows to move between digits and the up and down

arrows to increment the selected digit. The range for average DGD is 0.0 to 30.0 ps for the 90-ps PMDPro and 0.0 to 60.0 for the 180 ps PMDPro. The ENTER key selects the displayed value.

c. SAMPLE NUM:
This option specifies the number of samples in the distribution. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The range is 1 to 9999. The ENTER key selects the displayed value.

d. CYCLE NUM:
This option sets the number of times to run the emulation. The cycle range is 1-99999. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the number of cycles to the displayed value.

e. INTERVAL:
This option sets the dwell time per sample, in ms. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The range is 1 to 9999 ms. The ENTER key selects the displayed value.

6. SCAN PMD MEM BANK:
Scan through a user generated sequence of PMD values. There are 5 memory banks (labeled A-E), each with 100 storage locations; therefore, up to 5 sequences of PMD values can be stored and used for this scan. See the STORE menu section for instructions on storing sequences of PMD values. The PMDPro will scan through the memory locations in the selected bank in order, starting at the selected beginning point and ending at the selected end point.
The setup screens for a memory bank scan are as follows:

```
a.  START (SCN BNK)   ↓
b.  SCAN PMD-MEM BNK: A
```

```
c.  BGN A:00      ID#0039   ↑
d.  END A:99      (Contin)  ↓
```

```
e.  INTERVAL: _ 1000 ms ↑
f.  CYCLES: _ _10
```

Use the up and down arrows to move between scan setup options and the ENTER key to access the setup screen for the selected option.

a. START:
This option starts the scan. Use the other options to perform the setup, then return to option a) to begin the scan.

During the scan, if a discrete mode PMD value is stored at the current location, the screen displays:

```
PMD ID#: 0039      CY: 0000
13.92 ps           0.0 ps2
```

PMD ID#: Index number for current DGD/SOPMD pair
CY: number of completed cycles.
The bottom line displays the current DGD and SOPMD.

If a continuous value is stored at the current location, the scan monitor screen displays:

```
PMD (Contin)       CY: 0000
23.1 ps            300.0 ps2
```

Again, the bottom line displays the current DGD and SOPMD.

b. SCAN PMD-MEM BNK: X:
This option specifies the memory bank to be used for the scan. Use the up and down arrows to cycle through the bank labels (A-E), and the ENTER key to select the displayed bank.

c. BGN:
This option specifies the beginning memory location for the scan. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. There are 100 memory locations in each bank, labeled 00 to 99. As the memory location is changed, the right side of the screen displays either the ID# corresponding to the PMD stored there (for a discrete mode value) or (Contin) for a continuous mode PMD value. The ENTER key selects the displayed location.

d. END:
This option specifies the ending memory location for the scan. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. There are 100 memory locations in each bank, labeled 00 to 99. As the memory location is changed, the right side of the screen displays either the ID# corresponding to the PMD stored there (for a discrete mode value) or (Contin) for a continuous mode PMD value. The ENTER key selects the displayed location.

e. INTERVAL:
This option sets the dwell time per point, in ms. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. Note that a particular memory bank can store discrete mode PMD states, continuous mode PMD states, or a mixture of the two. If the memory bank contains only discrete mode values or only continuous mode values, the dwell time range is 1 to 60,000 ms. If the memory bank contains both discrete and continuous mode PMD values, the minimum dwell time is 100 ms. The ENTER key selects the displayed value.

f. CYCLES:
This option sets the number of times to run the scan. The cycle range is 1-9999. Use the left and right arrows to move between digits and the up and down arrows to increment the selected digit. The ENTER key sets the number of cycles to the displayed value.

4.2.4 SOP:

Pressing the SOP key accesses the PMDPro's deterministic polarization control and scrambling functions, including generation and stabilization of a single SOP, specified via Stokes parameters; continuous or random scrambling; or generation of specified traces.

If the PMDPro's PMD generator is set for a static PMD value (i.e. not scanning), that PMD setting will be unchanged during any polarization control accessed through the SOP menu.

For deterministic polarization control, the input polarimeter is used to generate the feedback signal to control the polarization controller, so the generated SOP is the SOP of the light before it enters the PMD element.

When the SOP key is pressed, the LCD displays 5 menu options on 3 screens:
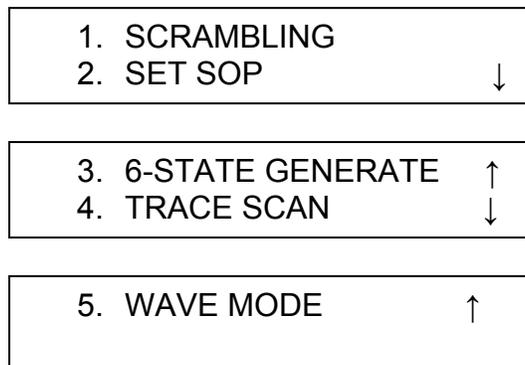
```
┌─────────────────────────────┐
│  1.  SCRAMBLING             │
│  2.  SET SOP            ↓   │
└─────────────────────────────┘
```

```
┌─────────────────────────────┐
│  3.  6-STATE GENERATE   ↑   │
│  4.  TRACE SCAN         ↓   │
└─────────────────────────────┘
```

```
┌─────────────────────────────┐
│  5.  WAVE MODE          ↑   │
│                             │
└─────────────────────────────┘
```

Use the up and down arrow keys to move between menu options and the ENTER key (the center key in the arrow keypad) to select the desired option.

1. SCRAMBLING:
This option enables the random or continuous (triangle wave based) scrambling functions of the PMDPro. Selecting this option brings up the following screen:

```
A.  RANDOM SCRAMBLE
B.  TRIANGLE SCRAMBLE
```

Selecting RANDOM SCRAMBLE brings up the following screen:

```
RAN SCRM  FR: 0500Hz
2.73ps        1.4ps2
```

Selecting TRIANGLE SCRAMBLE brings up the following screen:

```
TRI SCRM   FR: 100.00Hz
10.71ps            0.0 ps2
```

For either scrambling mode, the top line shows the selected scrambling mode and frequency, and the bottom line shows the current DGD and SOPMD.

Select the desired scrambling frequency. Use the left and right arrows to move between digits and the up and down arrows to increment the values. The scrambling frequency range is 1-6000 Hz for random scrambling and 0.01-500 Hz for triangle scrambling. When the desired frequency is set, press the ENTER button. The PMDPro will begin scrambling. The screen display remains the same, but the cursor will move to the bottom right corner of the screen. During scrambling, pressing the left arrow key will stop the scrambling and move the cursor to frequency selection so that the scrambling frequency can be changed.

2. SET SOP:
This option generates and maintains a user-set state of polarization (SOP) against fluctuations in input polarization state. The desired polarization state is set via Stokes parameters. When this option is selected, the LCD displays the following screen:

```
S1: +1.00        S2: +0.00
S3: +0.00        SIGN: +
```

Use the left and right arrow keys to move to the first Stokes parameter to be set. Set the value for the first parameter and then press ENTER. The cursor will advance to the next Stokes parameter. Use the arrow keys to set the desired value

for the second Stokes parameter. Press ENTER. If the first two values set are incompatible with a valid SOP, the screen will display an error message. Otherwise, the cursor will advance to the SIGN position. Use the up and down arrow keys to set the desired sign (+ or −) for the third Stokes parameter and press ENTER. The PMDPro will calculate and display the third Stokes parameter using the values input for the first two Stokes parameters, and will execute the SOP setting. The cursor will move to the bottom right corner of the screen while the PMDPro is maintaining the selected SOP. To select a new SOP, use the left and right arrow keys to move the cursor back to the Stokes parameter setting positions.

3. 6-STATE GENERATE:
   This is a shortcut function that allows the user to simply select one of 6 SOP states commonly used for measurements (the 6 Poincaré sphere pole points), rather than having to enter the Stokes parameters from the SET SOP screen. When this option is selected, the LCD displays the following screen:

   ```
   a.  START (SOP 6-Sta)
   b.  STATE Angle: 0°
   ```

   a. START:
      Selecting option a) implements the SOP setting selected in option b). The PMDPro will generate and maintain the selected SOP.

      The 6-state generation operation screen is shown below:

      ```
      SOP 6-STATE…0°
      0.00 ps       0.0 ps2
      ```

      The top line shows the SOP setting (0° linear, in the example above).
      The bottom line displays the current DGD and SOPMD.

   b. STATE Angle:
      This option specifies the SOP to be generated. Use the up and down arrows to cycle through the 6 options:
      0°:   linear horizontal polarization
      +45°: linear polarization oriented at +45°
      90°:   linear vertical
      −45°: linear polarization oriented at −45°
      RHC: right hand circular
      LHC: left hand circular.
      The ENTER key selects the displayed option.

4. TRACE SCAN:
In this function, the PMDPro's polarization controller traces out a great circle on the Poincaré sphere about the selected axis. The setup screens for SOP trace scanning are as follows:

```
a.  START (SOP Scan)
b.  TRACE Angle:        0° ↓
```

```
c.  SPEED: _ _ _100 ms   ↑
d.  STEP:           _1.0°
```

a. START:
Selecting option a) begins the trace scan. Set up the scan parameters using the other options, then return to option a) to begin scanning.

The trace scan operation screen is shown below:

```
TRACE SCAN…0°
0.00 ps        0.0 ps2
```

The top line shows the trace axis (0°, in the example above).
The bottom line displays the current DGD and SOPMD.

The trace function will continue until the user selects another option.

b. TRACE Angle:
This option allows the user to select the axis about which the great circle will be drawn. The axis is a radius of the sphere oriented at a specified angle (given in sphere coordinates) from the S1 axis.
   0°:   The rotation axis is the S1 axis
   +45°:   The rotation axis is in the S1-S2 plane, midway between the S1 and S2 axes
   90°:   The rotation axis is the S2 axis.
   −45°:   The rotation axis is in the S1-S2 plane, midway between the S1 and −S2 axes.
   S3=0:   The rotation axis is the S3 axis; i.e., the polarization state stays linear, with the inclination angle changing.
   SCAN: Traces one full circle about each axis in turn
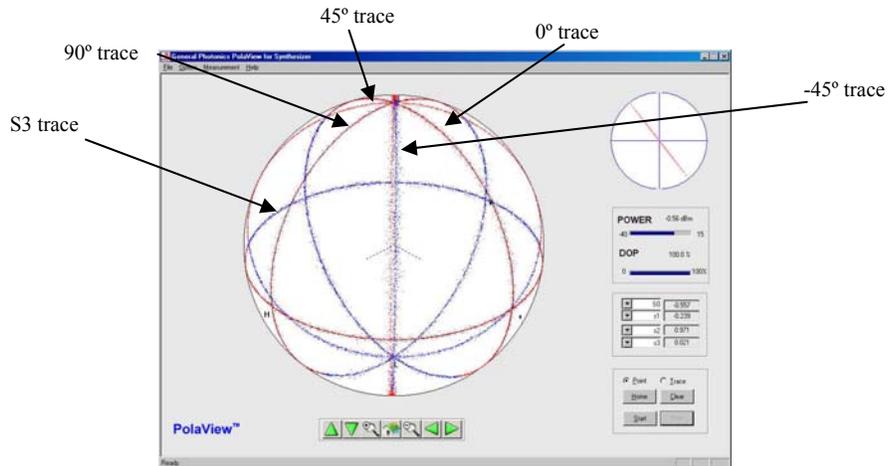
Figure 8 The 5 trace scans
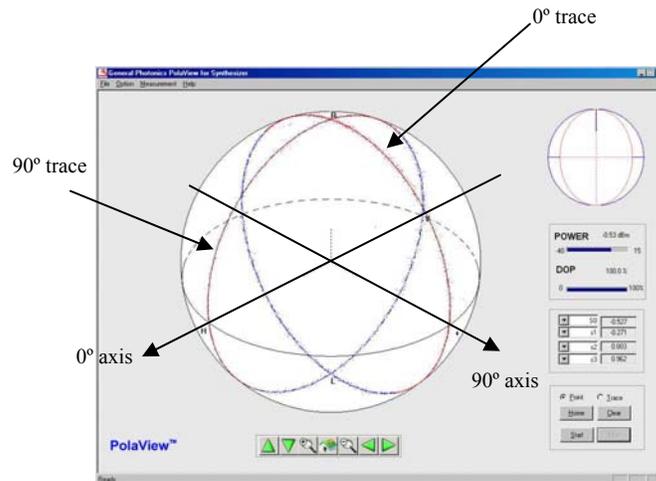
Figure 9 0º and 90º axes and corresponding traces

c. SPEED:
   This option sets the dwell time per step. Use the left and right arrow keys to move between digits and the up and down arrow keys to increment the active digit. The range is 1 to 60,000 ms.
   The ENTER key selects the displayed option.

d. STEP:
   This option sets the step size, in degrees. Use the left and right arrow keys to move between digits and the up and down arrow keys to increment the active digit. The range is 0.1 to 64.4°.
   The ENTER key selects the displayed option.

5. WAVE MODE:

This option allows the user to independently set periodic waveform control signals for 4 channels of the polarization controller. This gives the user the flexibility to switch back and forth between two SOPs (square wave on one channel), to set up a constant-rate SOP variation (triangle wave on one channel) or to use multiple channels to implement a more complicated variation pattern.

Applying a sine wave to one channel sweeps out a ring (or portion thereof, depending on the amplitude), sinusoidally in time, on the Poincaré sphere. Figure 10-13 show examples of this for each of the 4 channels individually. Figure 10 is the trace for a sine wave with amplitude 60V and frequency 5 Hz applied to channel 1. Figure 11 is the same sine wave applied to channel 2. Figure 12 and 13 show the trace for a sine wave with amplitude 30V and frequency 5 Hz applied to channels 3 and 4, respectively. Since V_π is about 30V, the first two traces sweep out close to a full ring, while the last two sweep out about half a ring.
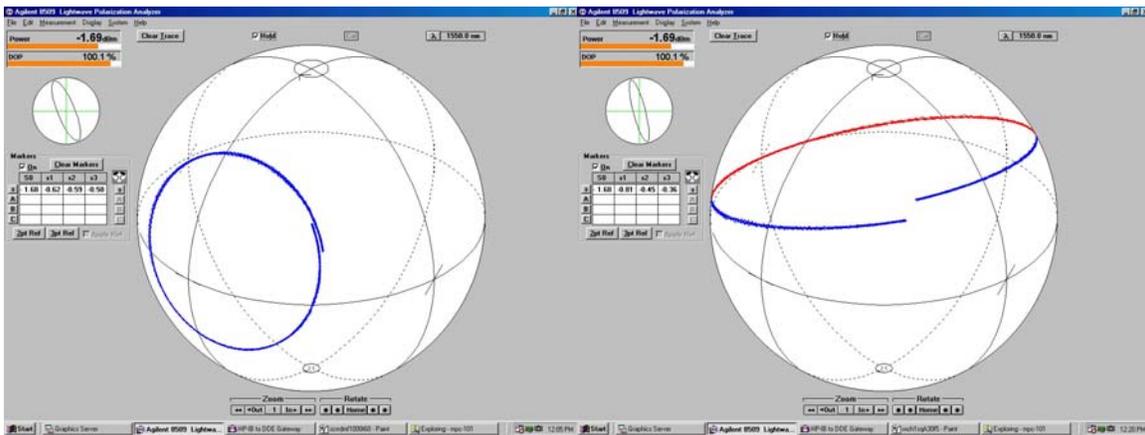
Figure 10 Sine wave with A=60V, f=5Hz on channel 1   **Figure 11 Sine wave with A=60V, f=5Hz on channel 2**
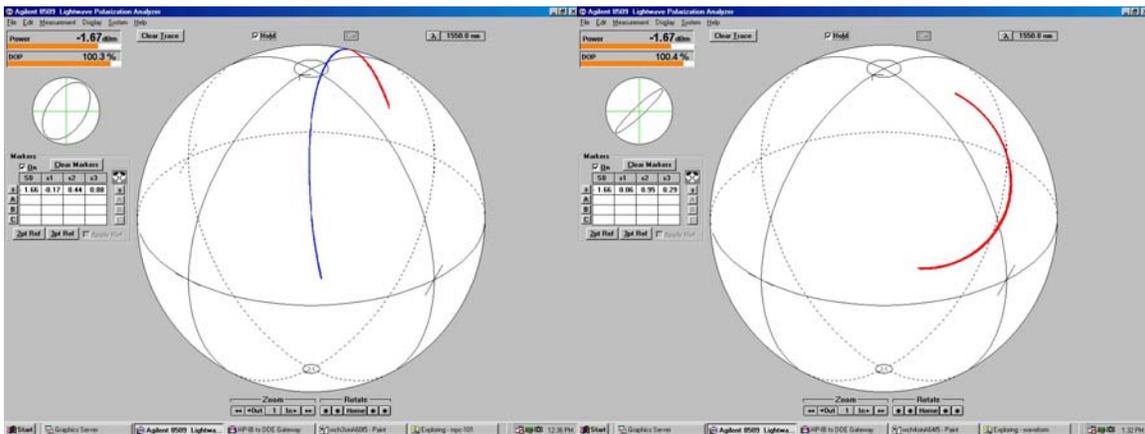
Figure 12 Sine wave with A=30V, f=5Hz on channel 3   **Figure 13 Sine wave with A=30V, f=5Hz on channel 4**

A triangle wave applied to a single channel also sweeps out a ring (or portion thereof, depending on the amplitude) on the Poincaré sphere, but the polarization change along that path occurs at a constant speed determined by the frequency. The final trace over several periods will look the same as that of a sine wave.

If a square wave is applied to a single channel, the polarization will switch periodically between two polarization states determined by the amplitude of the wave. The frequency determines how long the polarization stays in each state. Figure 14-17 show the traces for a square wave with amplitude 30V and frequency 5 Hz, applied to channels 1-4, respectively.
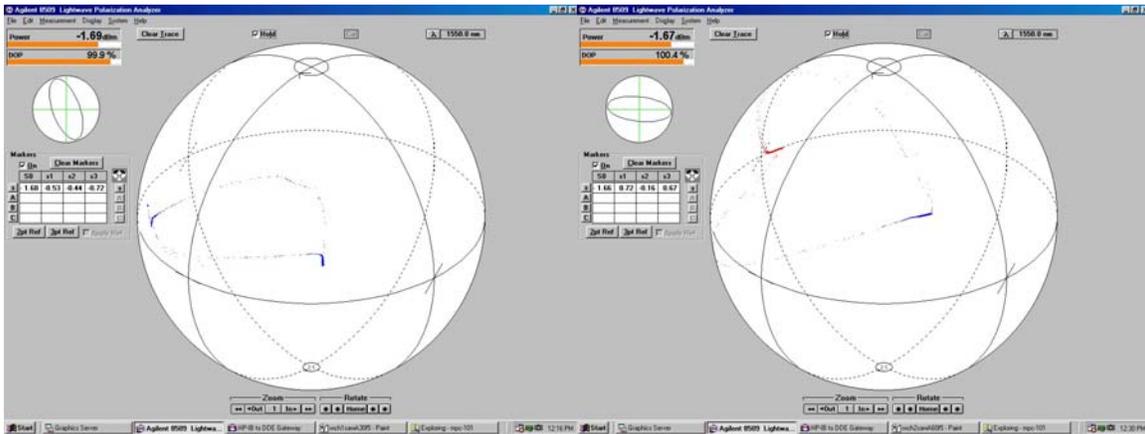
Figure 14 Square wave with A=30V, f=5Hz on channel 1   **Figure 15 Square wave with A=30V, f=5Hz on channel 2**
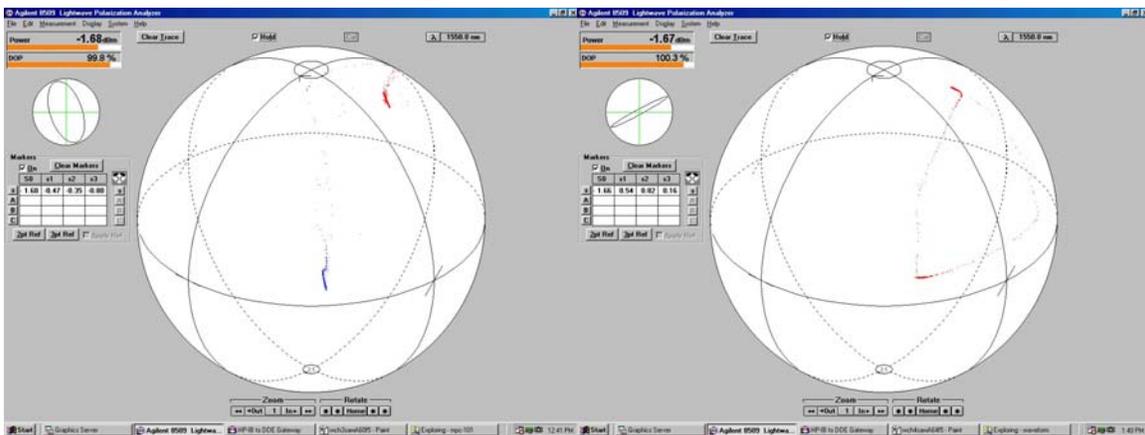
Figure 16 Square wave with A=30V, f=5Hz on channel 3   **Figure 17 Square wave with A=30V, f=5Hz on channel 4**

If periodic waveforms are simultaneously applied to more than one channel, their effects are superposed, and the polarization state periodically sweeps out a more complicated pattern on the Poincaré sphere. Certain frequency combinations will cover the entire sphere. This can be a basis for polarization scrambling. Figure 18-21 show some examples.
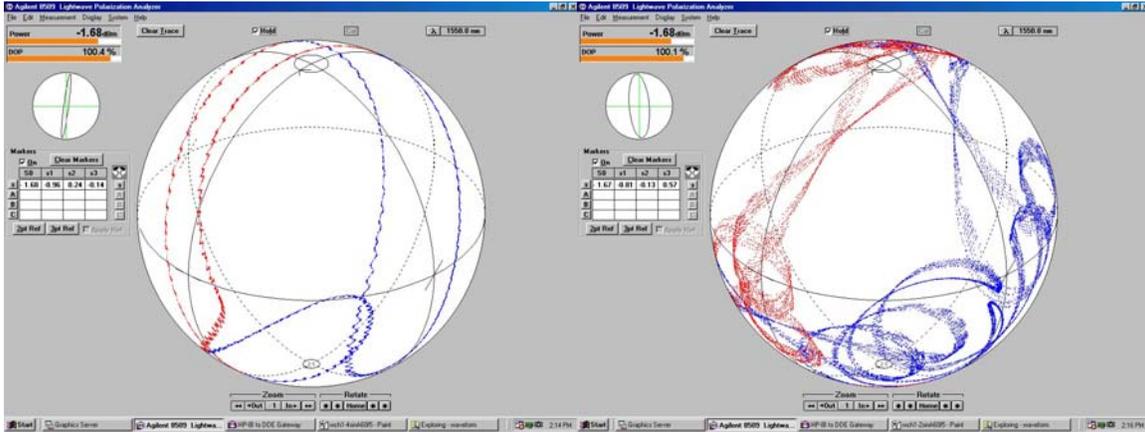
Figure 18 Sine wave with A=60V, f=5Hz on channel 1 Sine wave with A=60V, f=5Hz on channel 2

Figure 19 Sine wave with A=60V, f=5Hz on channel 1 Sine wave with A=60V, f=1Hz on channel 2
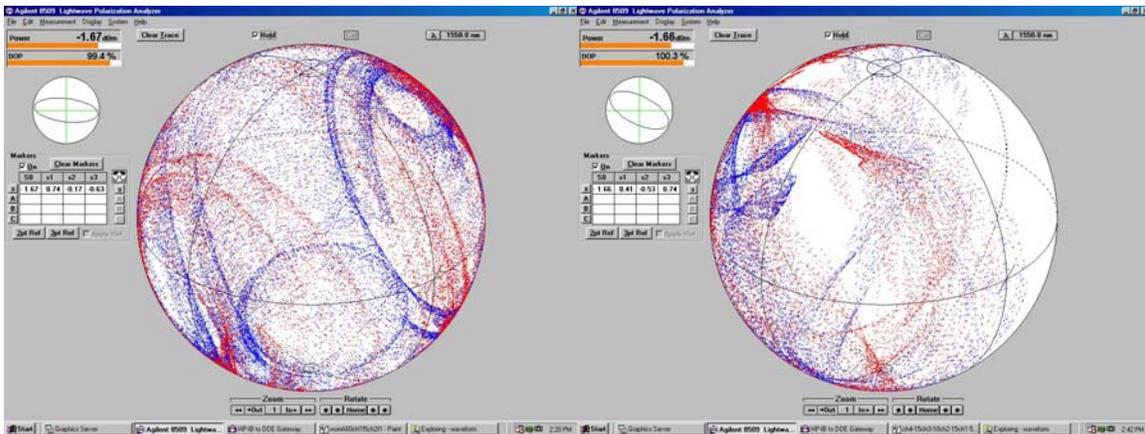
Figure 20 Sine wave with A=60V, f=5Hz on channel 1 Sine wave with A=60V, f=1Hz on channel 2 Sine wave with A=60V, f=3Hz on channel 3

Figure 21 Sine wave with A=60V, f=5Hz on channel 1 Saw wave with A=30V, f=3Hz on channel 2 Square wave with A=20V, f=2Hz on channel 3

The operation screen for the SOP waveform function is shown below:

```
CHANNEL: 4          Amp: _ _0.0V
F: _ _0.0 Hz         W: Sine
```

Use the left and right arrows to move the cursor and the up and down arrows to change settings or values at the current cursor position.

CHANNEL: Select polarization controller channel to be controlled. Use up and down arrows to scroll through CH 1-4.

Amp: Set amplitude for waveform for selected channel.
Range: 0.0-150V

F: Set frequency for waveform for selected channel.
Range: 0.0-120 Hz.

W: Select waveform type for selected channel.
Use up and down arrows to scroll through choices:
Sine, Triangle, Square.

When the waveform parameters are set up for all channels to be used, press the ENTER key to begin waveform generation. The cursor will move to the lower right of the screen during operation. Use the arrow keys to stop operation and return to waveform setup.

4.2.5 WSOP:

After a static PMD state has been set using the PMDE function (either from discrete or continuous mode), this function uses the PMDPro's polarization controller to adjust the input SOP to the PMD generation element to obtain the worst-case PMD effect based on either of two methods.

In the first case, the input polarimeter reading is used to control the polarization controller to align the input polarization state to achieve an equal power split between polarization components aligned to the slow and fast axes of the PMD element, as shown in the figure below.
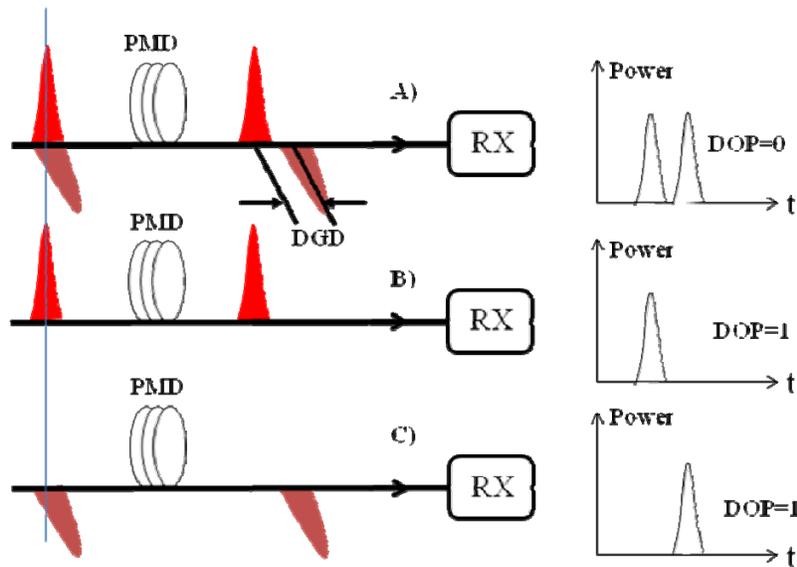
Figure 22 Effect of input polarization alignment on PMD effect caused by a DGD element
  a) Equal power split between fast and slow axes
  b) Input polarization aligned to fast axis- pulse is not distorted
  c) Input polarization aligned to slow axis- pulse is phase delayed but not distorted

In the second case, the output polarimeter reading is used to control the polarization controller to tune the input polarization state to minimize the DOP of the signal after it passes through the PMD element.

When WSOP is selected, the screen displays 2 options:

> 1. EQUAL POWER SPLIT
> 2. OUTPUT DOP TO MIN

1. EQUAL POWER SPLIT:
   This option can be used with a DGD-only (SOPMD = 0) discrete mode state (PMD ID#0-255). It aligns the polarization state of the signal at the input to the PMD element such that the power is split equally between polarization components aligned to the slow and fast axes of the PMD element.

   If the PMD setting is a continuous mode state or a lookup table state with an ID# >255, the following error message will be displayed when the equal power split option is selected:

> *Active in DGD only*
> Discrete: ID# 0 to 255

If the PMD setting is a lookup table state with index number between 0 and 255 when the equal power split option is selected, the PMDPro will immediately adjust the SOP to balance the power split between the fast and slow axes, and the following operation screen will be displayed:

```
EQU-POW-SPL     (DGD)
        43.20ps    0.0ps2
```

The lower line displays the current DGD setting on the left. The SOPMD, on the right, will always be 0.0 for this option.

2. OUTPUT DOP TO MIN:
   This option can be used with any discrete or continuous mode PMD setting. It tunes the polarization state at the input to the PMD element to the SOP that results in the maximum depolarization of the signal by the PMD element (i.e. minimum DOP measured at the output polarimeter). When this option is selected, the following operation screen is displayed:

```
DOP I: 100%      O: 30%
        19.90ps    300.0ps2
```

The top line shows the DOP measured by the input (I) and output (O) polarimeters and the bottom line shows the DGD and SOPMD of the currently selected PMD state. The polarization controller will actively optimize SOP as long as the PMDPro is in this mode.

4.2.6 PMDC:

Pressing the PMDC button accesses the PMDPro's PMD compensation functions. In this mode, the PMDPro uses its polarization controller and PMD generation element to find the optimum SOP and PMD value to compensate for any PMD in the input signal. This set of operations uses only the PMDPro's discrete PMD generation mode. Additional PMDC-based functions are available in the deluxe version of the control software. For the PMDC functions, the PMDPro tunes the SOP and DGD/PMD to maximize the DOP measured by the output polarimeter. The combinations of SOP and DGD or PMD that are available for the search depend on the function chosen by the user.

The DGD and PMD optimized compensation functions can also be used to measure the DGD or PMD in the system.

Data from any of the 4 PMD compensation modes can be stored using the STORE button (for more detail, see the STORE section).

When PMDC is selected the screen displays the following options:

```
┌─────────────────────────────────┐
│  1.  DGD OPTIMIZED Comp         │
│  2.  PMD OPTIMIZED Comp  ↓      │
└─────────────────────────────────┘
```

```
┌─────────────────────────────────┐
│  3.  DGD SELECTED Comp  ↑       │
│  4.  PMD SELECTED Comp          │
└─────────────────────────────────┘
```

Use the up and down arrow keys to move between menu options and the ENTER key (the center key in the arrow keypad) to select the desired option.

1. DGD OPTIMIZED COMP.:
    This function scans through all available DGD states (with SOPMD = 0) and optimizes the input SOP to find the DGD value that best compensates the PMD of the system under test. When this option is selected, the PMDPro immediately begins searching:

```
┌─────────────────────────────────┐
│  DGD Searching...               │
│  (PLEASE WAIT)                  │
└─────────────────────────────────┘
```

When the optimum DGD value is found, the screen displays:

```
┌─────────────────────────────────┐
│  DOP I: 32.1%      O: 96.5%     │
│  DGD: 17.85ps      ID#: 50      │
└─────────────────────────────────┘
```

The bottom line shows the DGD value and corresponding index number that provide the best compensation for the system PMD. This DGD value can also be considered a measurement of the amount of DGD in the system.

The top line displays the measured DOP at the input (I) and output (O) polarimeters. The output DOP indicates how well the system PMD is compensated. The polarization controller continues to actively optimize SOP as long as the PMDPro is in this mode.

2. PMD OPTIMIZED COMP.:
    This function scans through all 6561 PMD states in the lookup table, including states with zero SOPMD, wavelength independent SOPMD, and wavelength dependent SOPMD, and optimizes the input SOP to find the PMD value that best compensates the PMD of the system under test. When this option is selected, the PMDPro immediately begins searching:

```
┌─────────────────────────────────┐
│  PMD Searching...               │
│  (PLEASE WAIT)                  │
└─────────────────────────────────┘
```

When the optimum value is found, the screen displays:

```
┌────────────────────────────────────────┐
│  DOP I: 33.9%          O: 87.2%         │
│  41.95ps              22.4ps2           │
└────────────────────────────────────────┘
```

The bottom line shows the DGD and SOPMD values that provide the best compensation for the system PMD. This PMD value can also be considered a measurement of the PMD in the system.

The top line displays the measured DOP at the input (I) and output (O) polarimeters. The output DOP indicates how well the system PMD is compensated. The polarization controller continues to actively optimize SOP as long as the PMDPro is in this mode.

3. DGD SELECTED COMP.:
   This option scans the input SOP to the PMD element to search for the maximum possible output DOP value for any given user-selected DGD state. When this option is selected, the screen displays:

```
┌────────────────────────────────────────┐
│  DOP I: 33.6%          O: 91.5%         │
│  DGD: 7.14ps          ID#: 20           │
└────────────────────────────────────────┘
```

The top line displays the DOP measured at the input (I) and output (O) polarimeters when the DGD SELECTED COMP function was first selected. The bottom line displays the current DGD state (DGD value and corresponding index number). Use the arrow keys to select the desired DGD index. The DGD state updates in real time as the index is changed. When the desired DGD state is selected, press the ENTER key to begin polarization optimization at that state. The display format will remain the same, but the input and output DOP values in the first line will update with their real-time values.

Use the left arrow key to stop the SOP searching and return the cursor to the index selection position.

4. PMD SELECTED COMP.:
   This option scans the input SOP to the PMD element to search for the maximum possible output DOP value for any given user-selected PMD state. When this option is selected, the screen displays:

```
┌────────────────────────────────────────┐
│  MAX DOP: 92.7%   (088)                 │
│  31.42ps              0.0ps2            │
└────────────────────────────────────────┘
```

The DOP in the top line is the DOP measured at the output (O) polarimeter when the PMD SELECTED COMP function was first selected. The number at the top right of the screen is the currently selected PMD index. The bottom line displays

the current DGD and SOPMD corresponding to the index. Use the arrow keys to select the desired PMD index. The PMD state updates in real time as the index is changed. When the desired PMD state is selected, press the ENTER key to begin polarization optimization at that state. The display changes to the following screen:

```
DOP I: 33.6%      O: 91.5%
31.42ps           0.0ps2
```

The DOP measured at the input (I) and output (O) polarimeters will update in real time. Use the left arrow key to stop the SOP searching and return the display to the previous (index selection) screen.

4.2.7 Manual:

The manual polarization control function allows the user to tune the polarization state via direct control of the voltages applied to each of the 6 channels of the PMDPro's polarization controller. It can be used to quickly find a particular SOP or for fine adjustment to optimize a worst-case SOP for PMD tolerance testing. When the MANUAL key is pressed, the LCD displays the following set of screens:

```
V1: 75.0V         V2: 75.0V
V3: 75.0V         V4: 75.0V    ↓
```

```
V3: 75.0V         V4: 75.0V    ↑
V5: 75.0V         V6: 75.0V
```

When the cursor is on the channel selection position (cursor blinking on the 1 of V1, for example), the arrow keys can be used to move between channels. From a channel selection position, pressing ENTER will move the cursor to the voltage corresponding to the current channel position. Once on the voltage, use the arrow keys to set the voltage for that channel (left and right arrow to move between digits and up and down arrows to change the value of the selected digit). The voltage range for each channel is 0.0 to 150.0V, and V_π for each channel is about 30V. The channel voltages are updated in real time as the settings are changed so that the effects of the SOP change can be observed. Pressing ENTER when the cursor is on a voltage setting position will advance it to the next channel selection position.

4.2.8 STORE:

This mode allows the user to store either sequences of PMD values to be used for a sequential scan (see PMDE section) or PMD compensation data from any of the PMD compensation function modes.

When the STORE button is pressed, the LCD displays the following screen:

```
1.  PMDE Str Seq    BNK:A
2.  PMDC STORE   RESULT
```

1. PMD SEQUENCE:
   This option allows users to store up to 5 sequences of PMD values for use in the selected PMD scan function (see PMDE section for details on how to run a scan of a stored sequence). Each storage bank (A-E) can hold up to 100 values (index range 00-99). A PMD sequence stored in a bank can consist of discrete mode PMD values, continuous mode PMD values, or a combination of the two. Press the ENTER key to select this option. The cursor will move to the bank index (A-E). Use the arrow keys to select the desired storage bank and then press ENTER. The LCD displays the following screen:

```
A: _Dsc    ID#:0023        Lo: 00
  8.21ps             0.0 ps2
```

The letter at the top left of the screen indicates the selected storage bank (A, in this example). _Dsc indicates that a discrete mode value is to be stored. ID# is the PMD index number of the value to be stored (the DGD and SOPMD corresponding to the index are displayed in the bottom line of the screen) and Lo is the memory location index.

Use the left and right arrow keys to move the cursor position, and the up and down arrow keys to change the value at the current cursor position.

To store a discrete mode PMD value, move the cursor to the ID# position and use the arrow keys to set the desired PMD index. The corresponding DGD and SOPMD displayed in the bottom row will update as the index is changed. Then, move the cursor to the Lo position and use the arrow keys to set the desired memory location. Pressing ENTER from here will store the current PMD value in the currently selected memory location and increment the memory location by 1.

To store a continuous mode PMD value, move the cursor to the _Dsc position and press the up or down arrow key. The screen display will change to:

```
┌─────────────────────────────────────────┐
│  A: _Cts    (Calc)      Loc: 00          │
│  DGD: 8.21              SO: _ _0.0        │
└─────────────────────────────────────────┘
```

This is the calculation screen. To select a DGD/SOPMD pair to be matched and stored, use the left and right arrow keys to move the cursor to the DGD and SOPMD positions, and the up and down arrows to change the values. As soon as one of the values is changed, the screen changes to edit mode:

```
┌─────────────────────────────────────────┐
│  A: _Cts    (Edit)      Loc: 00          │
│  DGD: 29.90             SO: _300.0        │
└─────────────────────────────────────────┘
```

After editing the DGD and SOPMD values, press the ENTER key. The PMDPro returns to the calculation screen and shows the calculated values that most closely match the requested ones:

```
┌─────────────────────────────────────────┐
│  A: _Cts    (Calc)      Loc: 00          │
│  DGD: 30.07             SO: _270.0        │
└─────────────────────────────────────────┘
```

If the calculated values are acceptable, move the cursor to the Loc position, set the desired memory location, and press ENTER. The PMDPro will store the current set of DGD/SOPMD values to the selected memory location and increment the memory location by 1.

2. PMDC RESULT:
   This option allows the user to store PMD compensation data from any of the PMDPro's PMD compensation functions. After obtaining the PMDC result, press the STORE button and select the PMDC STORE RESULT option. The top line of the screen will display the DOP measured by the input (I) and output (O) polarimeters at the end of the last PMD compensation run. The bottom line will display the PMD index number (ID#) used for the PMD compensation and the current memory location (MEM-Lo).

```
┌─────────────────────────────────────────┐
│  DOP I: 37.2%          O: 98.4%          │
│  S       ID# 18        MEM-Lo: 0         │
└─────────────────────────────────────────┘
```

Use the arrow keys to select the desired memory location index (range 0-99) and press ENTER to store the data at that location. After the data is stored, the display will return to the PMDC mode selection screen.

4.2.9 RECALL:

This mode allows the user to recall previously stored sequences of PMD values or PMD compensation data. The screen interfaces are almost identical to those of the STORE function.

When the RECALL button is pressed, the LCD displays the following screen:

```
1. PMDE Rcl Seq    Bnk:A
2. PMDC RECALL RESULT
```

1. PMD SEQUENCE:
    This option allows users to see the contents of any of the 5 PMD sequence storage banks. With the cursor on option 1, press the ENTER key to select it. The cursor will move to the bank index (A-E) location. Use the arrow keys to select the desired storage bank and then press ENTER. The LCD displays the following screen if a discrete mode PMD value is stored at the current memory location:

```
A: Disc          ID#:0039  Lo: 00
         3.57ps          0.0ps2
```

    The letter in the upper left corner indicates the selected storage bank (A, in this example). Lo is the memory location index. ID# is the PMD index number of the value stored at that location (the DGD and SOPMD corresponding to the index are displayed in the bottom line of the screen).

    The arrow keys can be used to change the memory location index to look at the contents of other locations. If the value stored at a particular location is a continuous mode PMD value, the display changes to:

```
A: Cons         Recall    Loc: 05
DGD: 19.90      SO: _ 300.0
```

    Again, the stored DGD and SOPMD values are displayed in the bottom row.

2. PMDC RESULT:
    This option allows the user to recall previously stored PMD compensation data and apply the stored DGD or PMD value to a new selected DGD or PMD compensation run. When the PMDC RESULT option is selected from the RECALL options menu, the LCD displays the following screen:

```
┌─────────────────────────────────────────┐
│ DOP I: 37.2%        O: 98.4%             │
│ R       ID# 18      MEM-Lo: 0           │
└─────────────────────────────────────────┘
```

This is the PMDC data stored at memory location (MEM-Lo) 18. The top line of the screen shows the stored DOP measured by the input (I) and output (O) polarimeters, and the bottom line shows the PMD index number (ID#) used for the PMD compensation.

To look at data stored in a different memory location, use the arrow keys to select the desired memory location index (range 0-99). The DOP values and PMD index will change in real time to the values stored at the selected memory location.

Pressing ENTER from a recalled PMDC result screen will begin a new selected DGD or PMD compensation run using the PMD or DGD value from the recalled data set.

4.3 Remote Control Operation

General Photonics provides a control program for the PMDPro which allows access to several advanced functions as well as the basic functions accessible from the front panel. The following sections describe the system requirements, setup, and control program interface.

4.3.1 System Requirements

- Operating system: Windows XP or later
- 2 GB memory recommended

4.3.2 Installation

Run the file "setup.exe". This will start the installation wizard. In addition to installing the control program and necessary drivers, this file will install shortcuts for the remote control program on the desktop and the start menu.

The first installation wizard interactive screen is shown below.
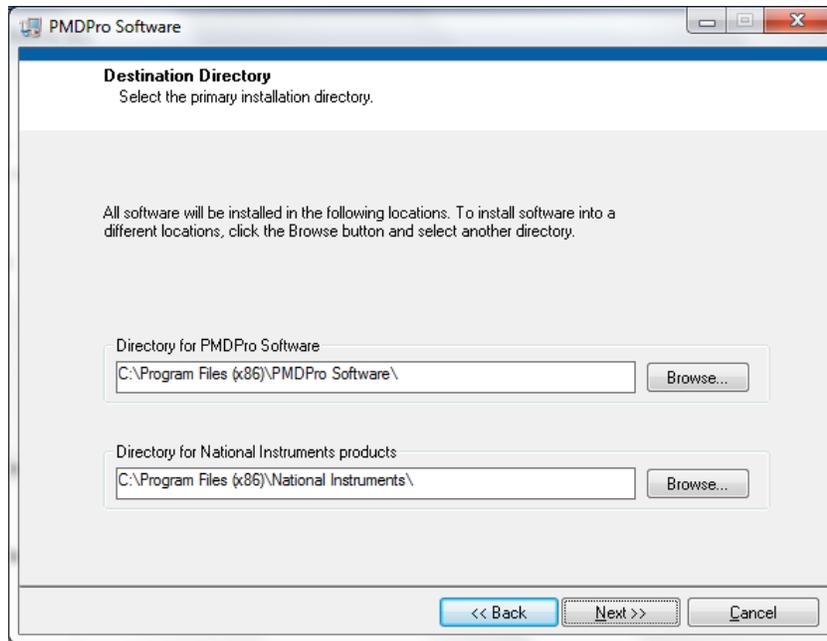
Specify the destination directories for program files and drivers. The default locations are the ones shown in the screenshot. Click "Next" to proceed.

A license agreement page will appear.
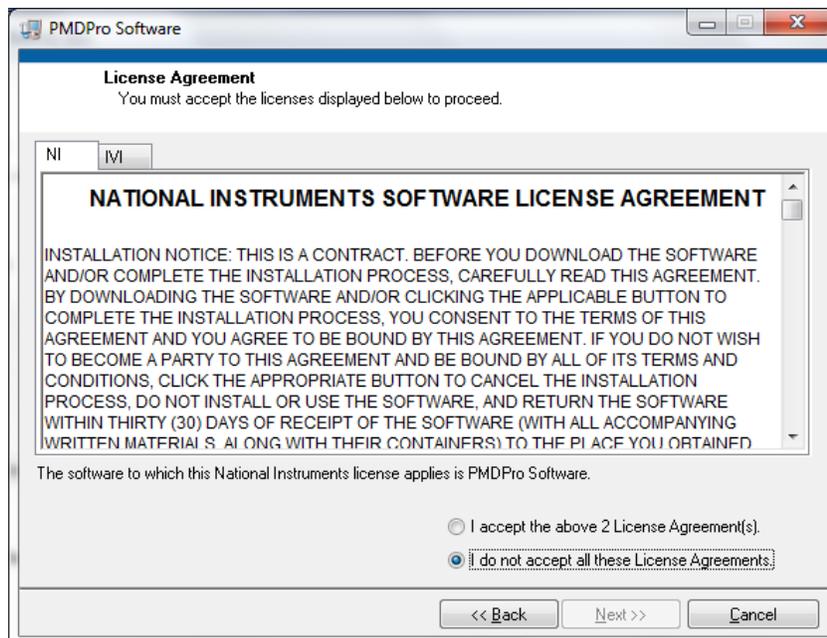
Accept the license terms and click "Next" to proceed.

A summary page lists the files to be installed or changed.
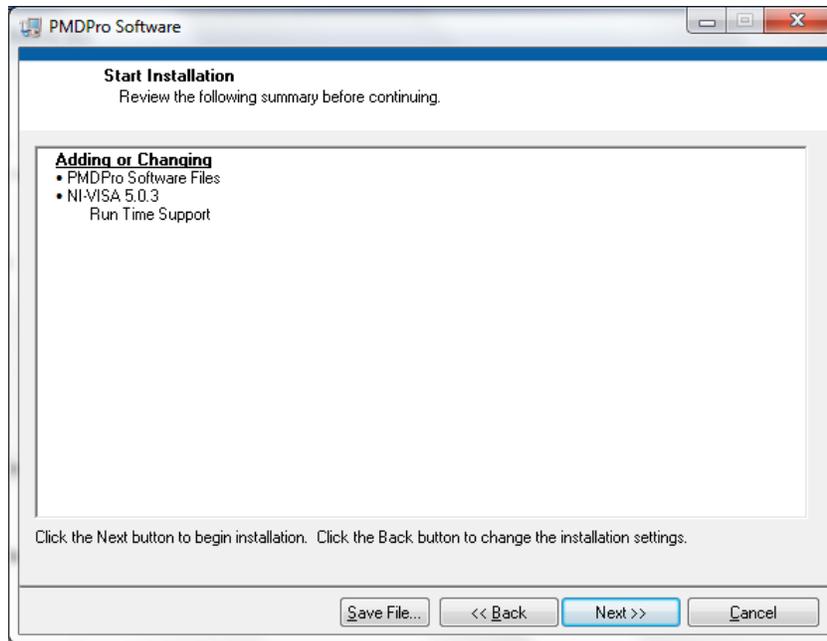
Click "Next" to begin installation. When all of the files are installed, an "installation complete" screen will be displayed.
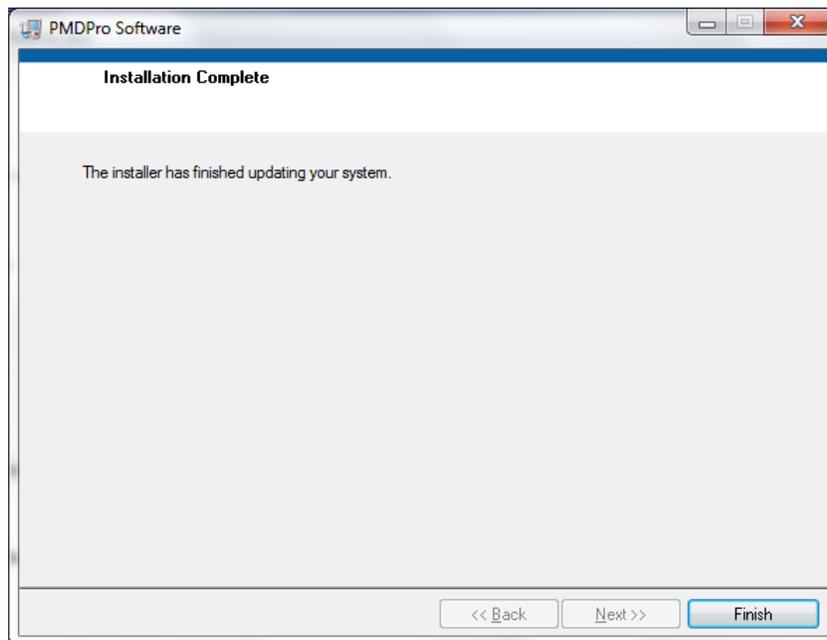
This completes the installation process. Click "Finish". The computer will need to be restarted before the program can be used.

Drivers installed:
- LabVIEW Run-Time Engine 2012 SP1 - (32-bit)
  Operating system: Windows 8; Windows 7; Windows Vista; Windows XP (SP3) 32-bit; Windows Server 2008 R2 64-bit; Windows Server 2003 R2 32-bit
- NI-VISA Run-Time Engine 5.3
  Operating system: Real-Time OS; Windows 7 64-bit; Windows 7 32-bit; Windows Vista 64-bit; Windows Vista 32-bit; Windows XP; Windows XP Embedded; Windows Server 2008 R2 64-bit; Windows Server 2003 R2 32-bit.
- FTDI USB Driver (requires additional steps- see USB Setup section). See Readme file for USB driver for version information.

4.3.3 RS-232 Connection

The RS-232 connector on the rear panel of the PMDPro is a DB9 male connector. Use a straight connection RS-232 cable (DB-9 female to female) to connect the PMDPro to the RS-232 port of a computer. To ensure proper communication, use a serial cable with direct pin-to-pin connected wires (see Figure 23) at both ends of the cable.
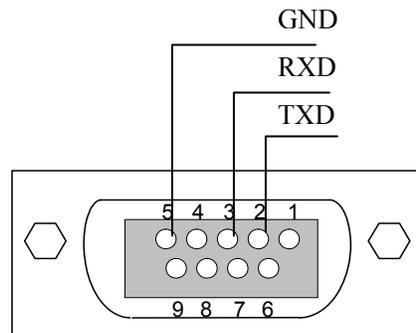
Figure 23 RS-232 connector on rear panel of PMDPro

RS-232 command notes:
1. RS-232 port uses asynchronous framing, 8 data bits, no parity bit, and 1 stop bit.
2. RS-232 baud rate: 28800 bps.

4.3.4 USB Connection

USB communication requires installation of an additional driver. After the control program is installed and the computer is restarted, connect the PMDPro to the computer with a USB cable and power on the PMDPro. This should initiate installation of the USB driver.

If asked to specify a driver location, select the "USB Driver" folder and make sure that "include subfolders" is checked.

4.3.5 GPIB Connection

To ensure proper communication, use a GPIB cable that is fully compatible with the IEEE 488.1 standard. All GPIB/IEEE 488 interface connections must be made before turning on the instruments.

The GPIB address can be changed either from the SETUP menu of the front panel controls or from the SETUP screen of the control program (if an interface other than GPIB is being used).

4.3.6 Ethernet Connection

The IP address from an ISP is assigned in one of two ways:

- Set to an IP which is only good for a limited time, and which is changed according to the policy set by the ISP's DHCP server. This is a *dynamic IP address*.
- Set to an IP address which can be unchanged for months or years at a time. This is a *static IP address*.

Ethernet Setup:

1. Connections:
   There are two connection configurations for Ethernet control:

   a) Static IP: the administrator assigns the instrument a fixed IP address. In this mode, the instrument can be directly connected to the control PC, as shown in Figure 24. For a direct connection, a cross-linked network cable must be used. Note: Static IP can also be used with the instrument connected to a router. In this case, a straight-linked network cable would be used.
   b) Dynamic IP: the DHCP server assigns the instrument an available address when requested. Connect the instrument with a DHCP server (router or exchange server), as shown in Figure 25. For this configuration, a standard straight-linked network cable must be used.
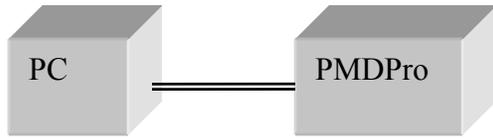
Figure 24 Direct connection: PMDPro to PC   Figure 25 Connect PMDPro with DHCP server
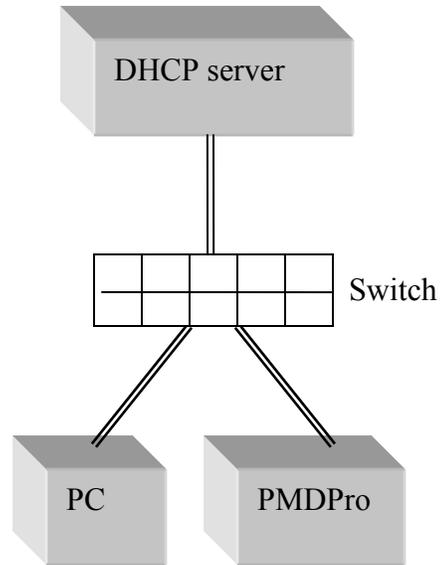
2. Request IP address:

    There are two ways to select the IP mode (dynamic or static) and request (dynamic) or query (static) the IP address.

    Front Panel:
    As described in section 4.2, the user can set the PMDPro for static or dynamic IP addressing and query the IP address from the front panel SETUP menu. Press the SETUP button on the front panel. GET DYNAMIC IP sets the PMDPro for dynamic IP addressing and requests a dynamic IP address from the server. GET STATIC IP sets the PMDPro for static IP addressing and requests the static IP address stored in memory.

    LabView Program:
    The GP_SET_ETHERNET program can also be used to obtain the dynamic IP address or the full set of static IP network settings.

3. Set IP address (static mode only):

    The LabVIEW program *(GP_SET_ETHERNET.vi or GP_SET_ETHERNET.exe)* must be used to set up the static Ethernet configuration. Static IP setup cannot be done from the front panel.

---

4. GP_SET_ETHERNET program:

   To run this program:
   a) Connect the PMDPro to the control computer with a straight wired RS-232 cable as described in section 4.3.3. This program is RS-232 only, and cannot be run from any other interface.
   b) Set the control computer's baud rate to 28800.
   c) Open the program GP_SET_ETHERNET.Select the correct serial (RS-232) port from the port configuration box at the top of the screen. The baud rate should be set to 28800. Once these two parameters are set, click the white arrow to run the program.

   The program has 3 tabs.

   The first tab, "GET IP CONFIG" is used to query the current IP configuration of the instrument. When the "Get IP Config" button at the left of the screen is clicked, the program will read back the instrument's current network parameters, as well as whether the instrument is currently set for static or dynamic IP addressing.
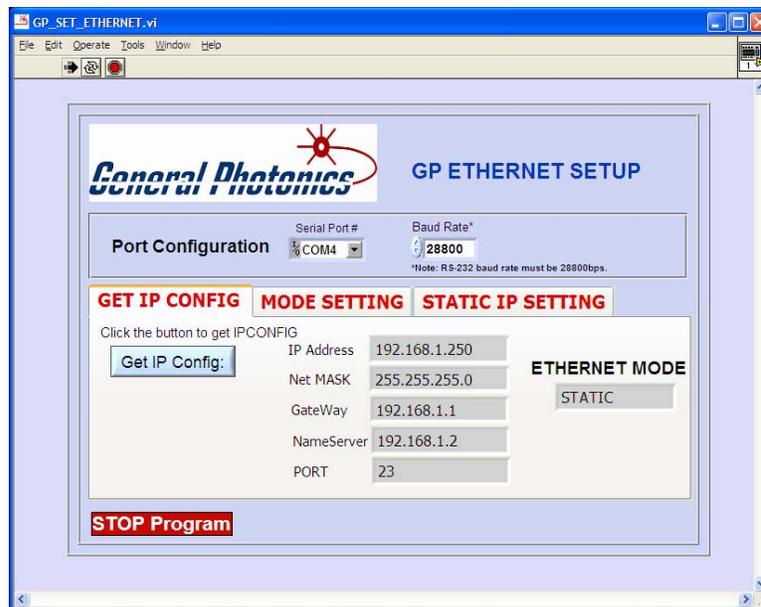
IP Config query screen- Static IP mode result
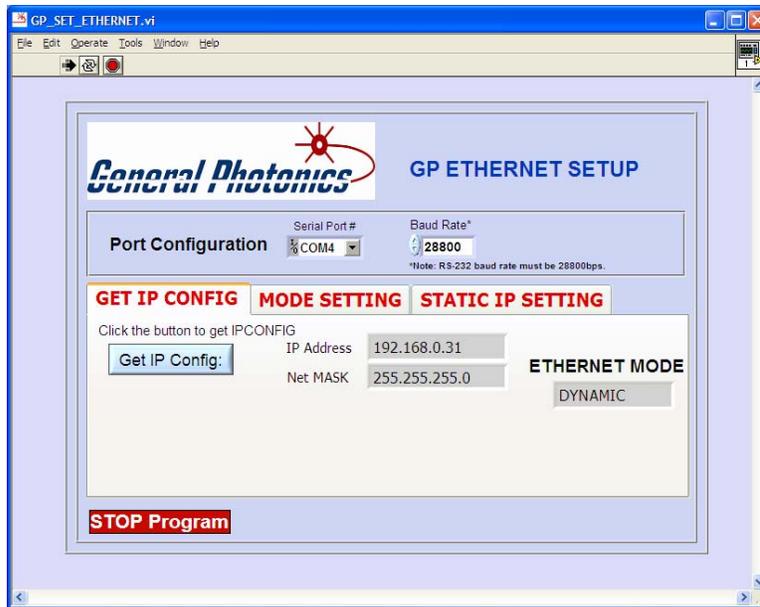
IP Config query screen- Dynamic IP mode result

The second tab, "MODE SETTING" allows the user to switch the instrument between static and dynamic IP addressing modes.
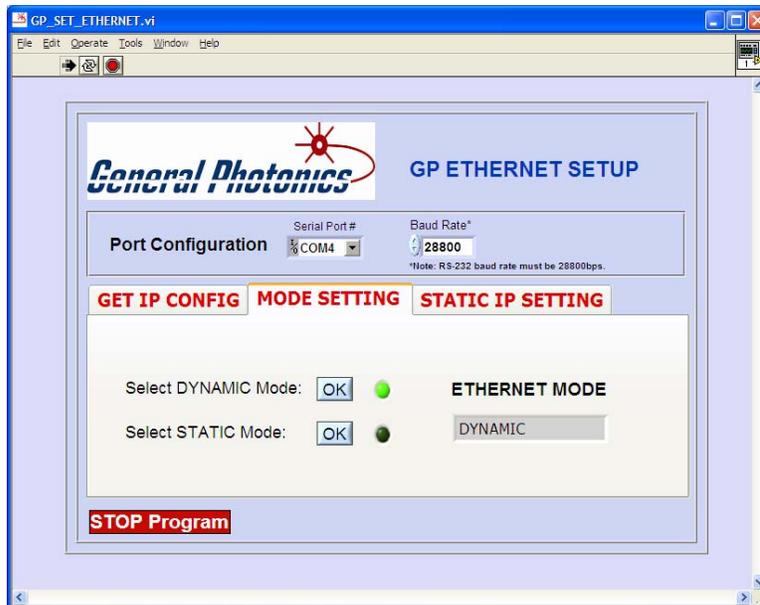
Ethernet mode selection screen- dynamic
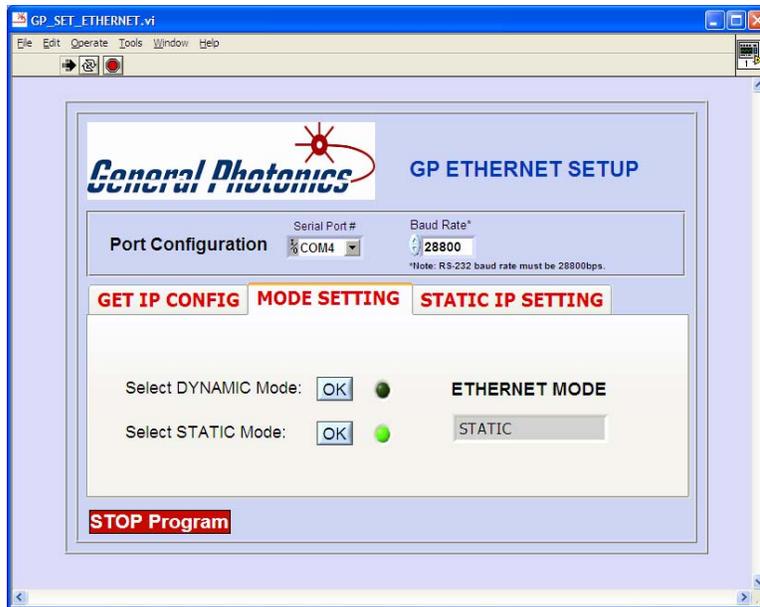
Ethernet mode selection screen- static

Clicking the "OK" button for dynamic mode puts the PMDPro into dynamic IP mode. The instrument will obtain the dynamic IP information from the server. When it is finished, the indicator for dynamic mode will turn green, and the Ethernet Mode status box will say "DYNAMIC".

Clicking the "OK" button for static mode puts the PMDPro into static IP mode. The instrument will recall the static IP settings from its memory. These can then be used for communication. When it is finished, the indicator for static mode will turn green, and the Ethernet Mode status box will say "STATIC".

The PMDPro writes its most recently saved static IP settings and its active mode to memory. If it is powered off while in static mode, when it is powered back on, it will be in static mode, and the most recently saved set of IP configuration information can be used for communication.

If the PMDPro is powered off while in dynamic IP mode, when it is powered back on, it will be in dynamic IP mode.

The third tab in the program, "STATIC IP SETTING", allows the user to set the static IP configuration information. Input the information into the corresponding boxes and click the "SET" button. As each value is written, its indicator turns green. When all of the information is successfully stored, the "Set OK" indicator will turn green.
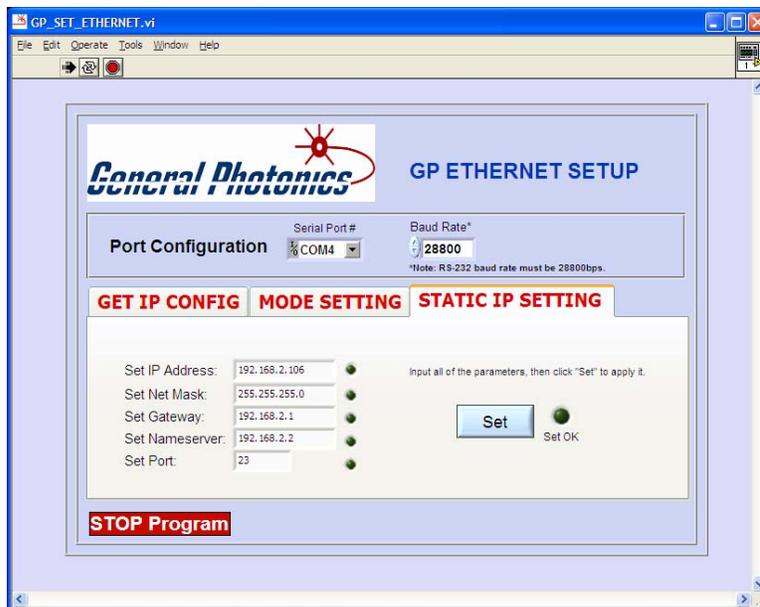
Static IP setup screen.

Notes on configuration:

The net mask and gateway should be the same as those for the control computer (see example below). The first 3 groups of numbers in the IP address should be the same as those for the control computer (192.168.2, for example). The last number can be any available number, but cannot be the same as the IP address of the control computer. If the last number of the computer's subnet mask is n, the available IP address range is n+1 to 254. For example, if n = 0, then the available IP addresses are 1 to 254. Then, if the computer's IP address is 17, the user can set the IP address for the PMDPro to any number in the range 1-254 except 17.

Notes:
- To connect the instrument directly to a PC, use a PC to PC cable. To connect the instrument to a LAN, use a standard network cable.
- For Ethernet control, the serial port is only used during Ethernet setup via the GP_SET_ETHERNET program.
- The remote control command format is the same for all communication protocols (RS-232, USB, Ethernet, GPIB).

4.3.7 Control Program Interface

Connect the PMDPro to the control computer using the desired remote control interface (RS-232, USB, Ethernet, or GPIB) and power on the instrument. When the control program is first started, it will ask if the control interface is Ethernet.

If the "yes" button is clicked, the user will be prompted to enter an IP address.

Enter the instrument's IP address and click OK. The user can set the PMDPro for static or dynamic IP addressing and query the IP address from the menu options accessible by pressing the SETUP button on the front panel.

If the "no" button is clicked, the program will auto-sense the control interface (USB, RS-232, or GPIB) and the port being used.

Always close the control program before turning off the instrument.

Monitor Screen

When the program is first started, if the communication between the computer and PMDPro is properly established, the screen shown below will be displayed. If the program does not detect the PMDPro, it will display a message to that effect.

Available communication ports will be displayed in a pull-down menu at the bottom left of the screen. Select "Refresh" if the correct port is not displayed. The connection port can be verified from the Device Manager on the control computer (Control Panel → System → Hardware → Device Manager (View Devices by Type) → Ports).
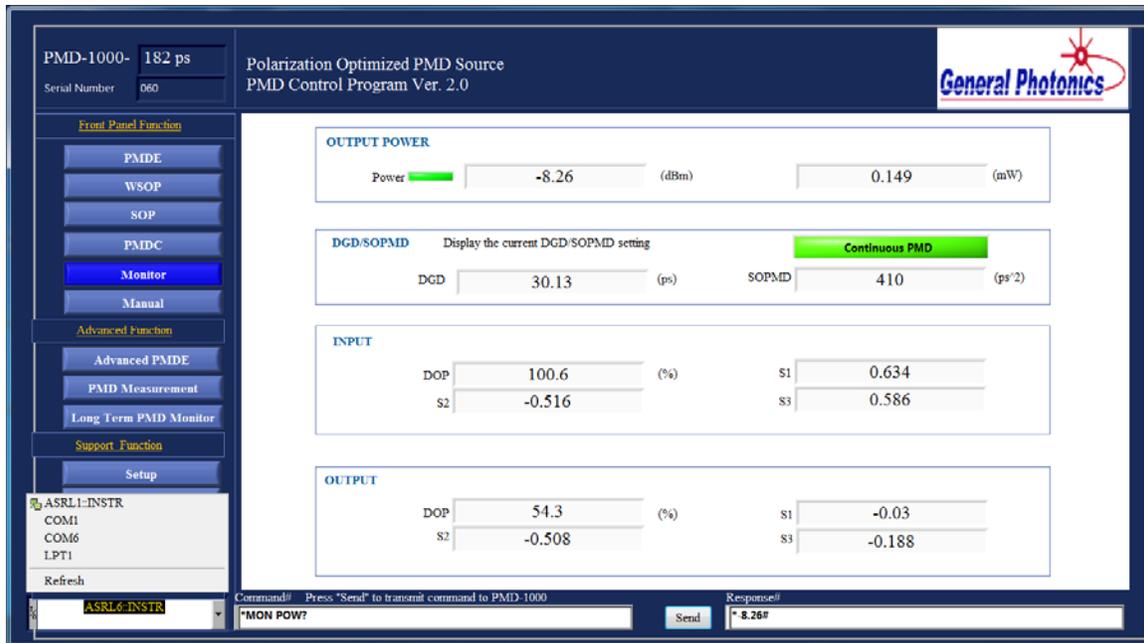
The program interface consists of a function selection panel on the left side of the screen and the main operation area, which occupies most of the screen.

The function selection panel contains 13 buttons corresponding to various operation modes. These buttons are divided into three groups. The top group ("Front Panel Function") includes most of the basic functions. The second group ("Advanced Function") includes more advanced functions using the quasi-continuous PMD generation function and 2D and 3D graphing capabilities. The third group ("Support Function") includes operation setup parameters, data storage and recall functions, and wavelength dependence simulations. When one of these buttons is clicked, the corresponding operation mode screen appears in the operation area. When the program is first started, the default operation mode is monitor mode. This screen can also be accessed by clicking the "MONITOR" button in the function selection panel.

The monitor screen has 4 sections.

The output power section displays the output power in dBm and mW.

The DGD/SOPMD section displays the DGD and SOPMD currently being generated by the PMD-1000, as well as an indicator showing whether the current state is a discrete (lookup table) or continuous PMD state.

The INPUT section displays the DOP and SOP (Stokes parameters) measured by the PMD-1000's input polarimeter.

The OUTPUT section displays the DOP and SOP (Stokes parameters) measured by the PMD-1000's output polarimeter, located after the PMD generating element.

Front Panel Functions:

PMDE

The PMDE operation screen includes the basic discrete mode PMD generation and scanning functions.

SET PMD:
This function is used to select a particular DGD/SOPMD state from the lookup table. When the user selects a PMD index number (ID#), the PMD-1000 generates the corresponding DGD/SOPMD pair and displays the DGD and SOPMD values in the corresponding boxes. Output values are updated in real time as the index number is changed.

DGD MAXWELLIAN DISTRIBUTION:
This is a first-order PMD emulation function. The PMD-1000 generates a Maxwellian statistical distribution of DGD values with the total number of samples (Sample Num) and average DGD, in ps, specified by the user. The range for average DGD is 30 ps for a 90 ps PMDPro and 60 ps for a 180 ps PMDPro. Cycle Num is the number of times the scan will be run. Scan Interval is the dwell time per point, in ms. Only DGD states (SOPMD=0) are used in the emulation.

SCAN DGD:
The PMD-1000 scans a series of DGD values (with SOPMD=0) in a user-defined range in order from lowest to highest. Set the desired dwell time per point (Scan Interval) and number of times to run the scan (Cycle #) by typing in the boxes or using the up and down arrows. Set the start and end DGD values for the scan, in ps, by typing in the boxes and then clicking outside the boxes. The program will match the closest lookup table

DGD values to the ones entered. Click "Start" to start the scan. During the scan, the current DGD value (in ps) is displayed in the box at the right of the screen.

SCAN PMD:
The PMD-1000 scans all DGD/SOPMD pairs in order of their index number (see lookup table for corresponding values). Set the desired dwell time per point (Scan Interval) and number of times to run the scan (Cycle #) and then click "Start" to start the scan. During the scan, the current PMD index number and the corresponding DGD and SOPMD values are displayed.

WSOP:

This function combines the PMDPro's discrete PMD generation function with its automatic polarization control function. The polarization controller is used to tune the input SOP to the PMD generation element to obtain the worst-case DGD or PMD effect for a given DGD and/or SOPMD value.
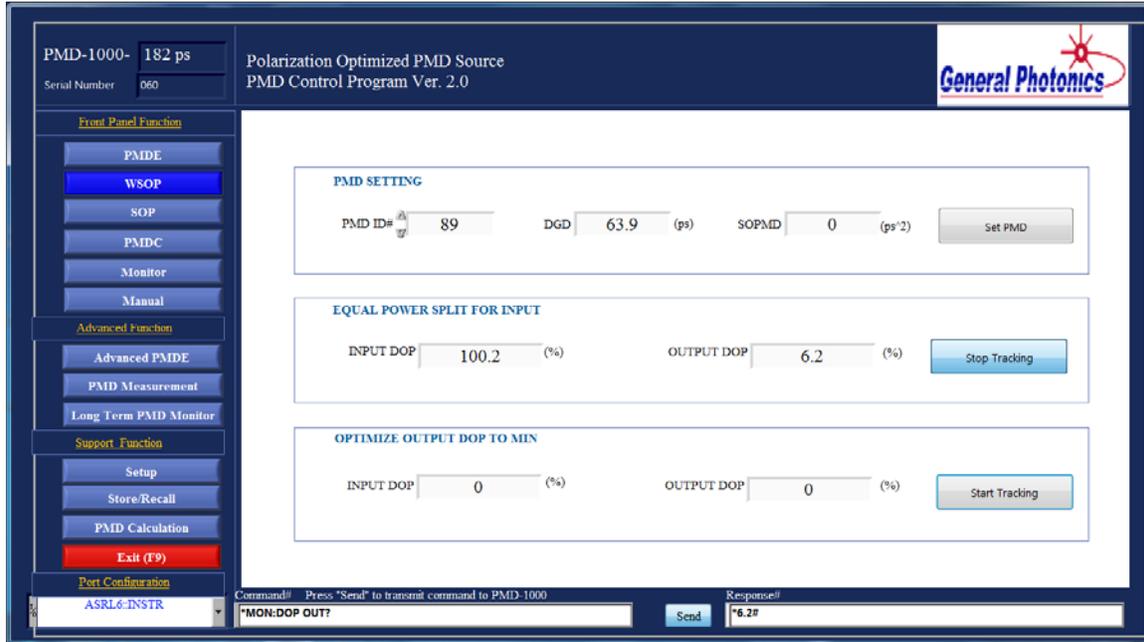
PMD SETTING:
First, select the desired DGD/SOPMD pair by setting the index number in the PMD ID# box. The corresponding DGD and SOPMD will be displayed in the adjacent boxes. Click "Set PMD" to execute the setting.

EQUAL POWER SPLIT:
In this function, the input polarimeter reading is used to control the polarization controller to align the input polarization state to obtain an equal power split between the polarization components aligned to the slow and fast axes of the PMD element. This function can be used only with DGD-only states (SOPMD = 0). These correspond to PMD index numbers 0-255. If a larger index number is selected, this function will be disabled (The "Start Tracking" button will be grayed out). Click the "Start Tracking" button to begin the SOP search. The DOP values measured by the input and output polarimeters are displayed in the corresponding boxes.

OPTIMIZE OUTPUT DOP TO MIN:
In this function, the output polarimeter reading is used to control the polarization controller to tune the input polarization state to minimize the DOP of the signal after it passes through the PMD element. This function can be used with any PMD value in the lookup table. Click the "Start Tracking" button in this section of the screen to begin the search. The DOP values measured by the input and output polarimeters are displayed in the corresponding boxes.

SOP:

The SOP operation screen includes the PMD-1000's polarization control and scrambling functions.
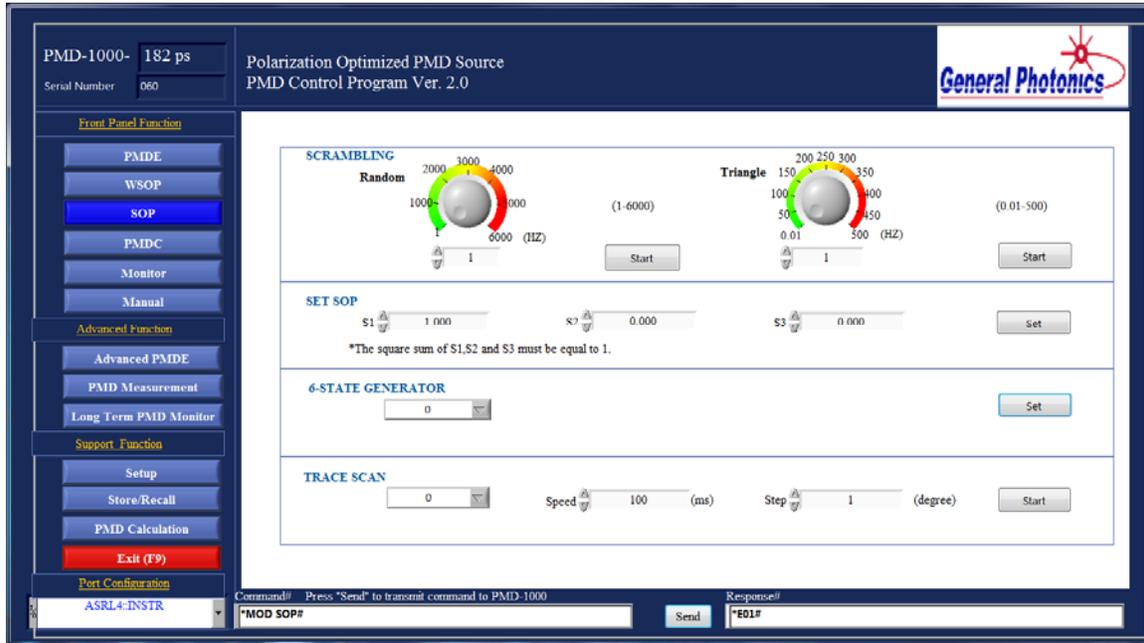
SCRAMBLING:
The PMD-1000 can perform either random scrambling, in which it generates random discontinuous points on the Poincaré sphere, or continuous scrambling, in which it uses an algorithm based on a set of triangle waves to generate a continuous trace on the Poincaré sphere. Select the frequency for the desired scrambling mode (random or triangle) and click the corresponding "Start" button to begin scrambling.
Frequency ranges:
  Random scrambling: 1-6000 Hz
  Triangle scrambling: 0.01-500 Hz

SET SOP:
Use this function to set and maintain a particular SOP. Set the Stokes parameters of the desired state, making sure that they fulfill the condition $S_1^2 + S_2^2 + S_3^2 = 1$, and then click the "Set" button to generate and maintain that state.

In most cases, as the user adjusts one Stokes parameter, the others will auto-adjust to satisfy the normalization condition. However, if the user sets a condition that does not satisfy the normalization condition, the program will display an error message:

S1*S1+S2*S2 should be less than 1

OK

6-STATE GENERATOR:

0
45
-45
90
RHC
LHC
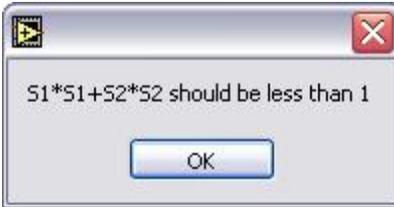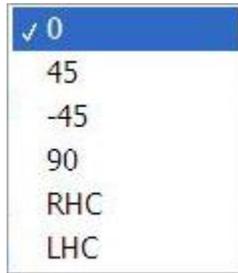
This function generates and maintains any of the Poincaré sphere pole points (0°. +45°, −45° or 90° linear states or right hand or left hand circular states). Select the desired state from the pull-down menu and click "Set".

TRACE SCAN:
This function traces out a great circle on the Poincaré sphere about the selected axis.

0
45
-45
90
S3=0
SCAN-ALL
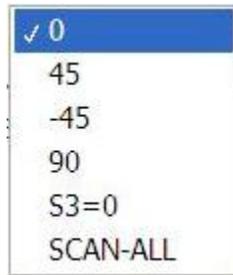
Select the desired axis from the pull-down menu and set the dwell time per point (Speed), in ms, and step size between points, in degrees. Then, click "Start" to begin generating the trace.

SCAN-ALL traces out one circle about each axis in turn.

PMDC:

This panel controls the PMD-1000's PMD compensation functions using discrete PMD generation mode. In all of these cases, the PMD-1000 uses its polarization controller and polarimeters to maximize the output DOP, but the DGD or PMD value used for compensation differs depending on the particular function selection.

1st ORDER PMD COMPENSATION:
Click the "Start" button in this box to begin. The PMD-1000 scans through all DGD states (with SOPMD = 0) in the lookup table and optimizes the SOP at each state to find the DGD value that best compensates the PMD at the input to the instrument. It displays the resulting DGD value, as well as the input and output DOP values.

1st & 2nd ORDER PMD COMPENSATION:
Click the "Start" button in this box to begin. The PMD-1000 scans through all DGD/SOPMD pairs in the lookup table and optimizes the SOP at each point to find the DGD/SOPMD pair that best compensates the PMD at the input to the instrument. It displays the resulting DGD and SOPMD values, as well as the input and output DOP values.

SELECTED 1st ORDER PMD COMPENSATION:
Select the desired DGD index number (PMD ID#) and click the "Start" button. The PMD-1000 optimizes the SOP to maximize the output DOP using the selected DGD value. It displays the selected DGD value, as well as the input and output DOP values.

SELECTED 1st & 2nd ORDER PMD COMPENSATION:
Select the desired PMD index number (PMD ID#) and click the "Start" button. The PMD-1000 optimizes the SOP to maximize the output DOP using the selected DGD/SOPMD values. It displays the selected DGD and SOPMD values, as well as the input and output DOP values.

MONITOR:

This screen was described at the beginning of the control program description. It can be used to monitor the status of the light signal, including the output optical power, the current output PMD setting and control mode of the PMD generator, and the SOP/DOP values at the input and output polarimeters.

MANUAL:

The PMD-1000 includes a 6-channel piezo-driven fiber-squeezer polarization controller. The manual operation mode allows the user to directly set the control voltages to each channel of the polarization controller, rather than using the polarimeter feedback to control the polarization controller.
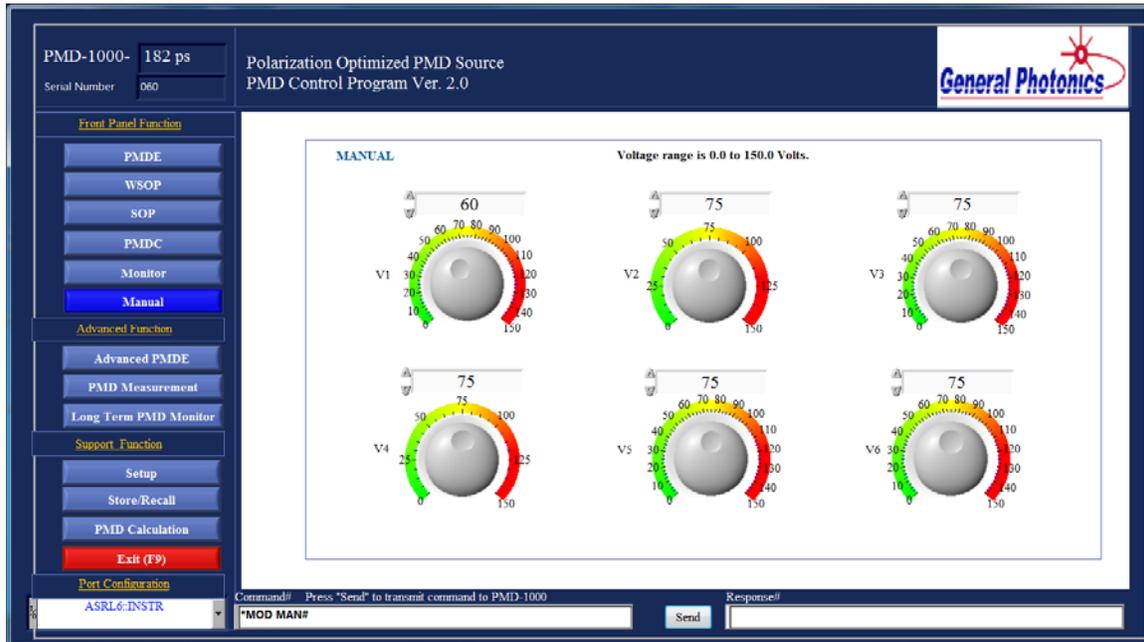
The voltage range for each channel is 0-150V. V_π for each channel is about 30V.

Advanced Functions:

This function set includes more advanced PMD generation and scan functions that make use of the PMDPro's quasi-continuous PMD generation capability.

It also includes PMD measurement and long-term monitoring functions.

ADVANCED PMDE:

This operation mode combines the PMD-1000's continuous PMD generation function with scan/emulation and polarization control functions.

There are four tabs within this section:

Continuous PMD + Polarization Control:

This is the control screen for the PMD-1000's deterministic quasi-continuous PMD generation function. This function allows the user to select any DGD/SOPMD combination within the area bounded by the curve.
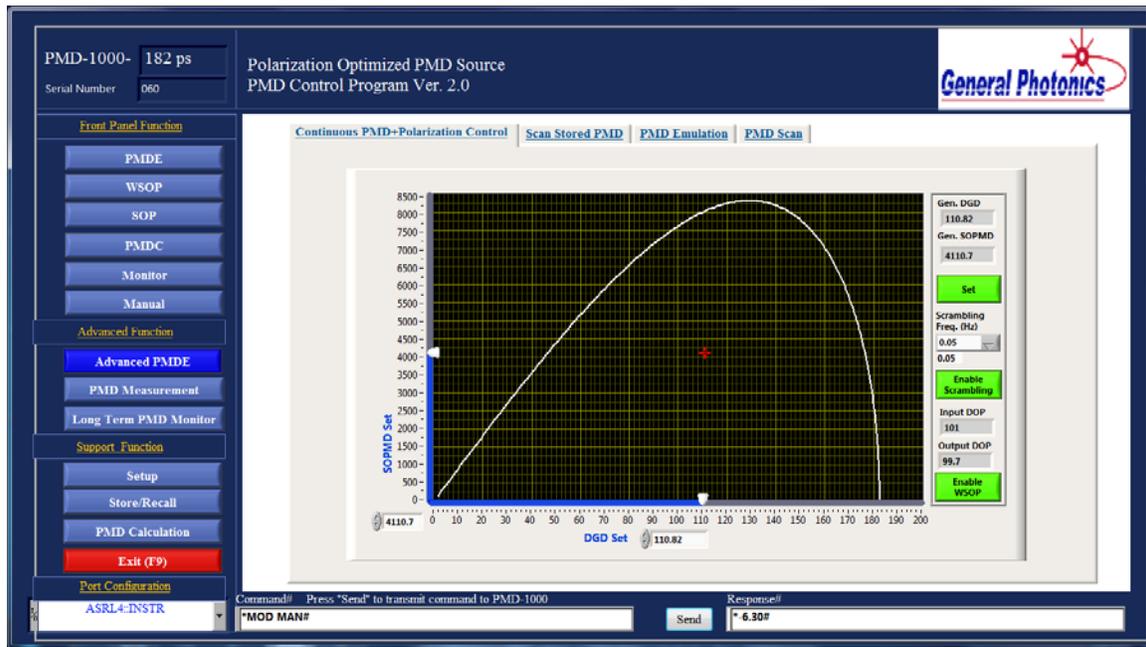
The user can select the desired DGD and SOPMD values by dragging the sliders on the plot axes, by selecting or typing values in the selection boxes for each axis, or by dragging the cursor (a red cross) to the desired point on the plot. Clicking the "Set" button causes the PMDPro to calculate and output the closest available matches to the DGD and SOPMD chosen. The indicator boxes at the top right of the screen display the calculated DGD and SOPMD values.

There are two methods to combine the PMD generation function with polarization control to ensure that the worst-case PMD effect is found.

1. To enable continuous polarization scrambling, set the desired scrambling frequency, either by selecting a value from the pull-down menu or by typing a value in the box directly under the pull-down menu and then clicking elsewhere on the screen. Click the "Enable Scrambling" button to begin polarization scrambling. This function is designed to facilitate PMD tolerance testing with polarization multiplexed signals.

2. To enable automatic SOP optimization for worst-case PMD effect by minimizing the output DOP, click the "Enable WSOP" button. This function is useful for PMD tolerance tests with single-polarization signals. The PMDPro monitors and displays the DOP values measured by the input and output polarimeters in the boxes above the "Enable WSOP" button.

Scan Stored PMD:

The PMD-1000 has 5 memory banks which can store up to 100 PMD settings each. The user can thus store up to 5 sequences of PMD values and then use this function to scan through them.
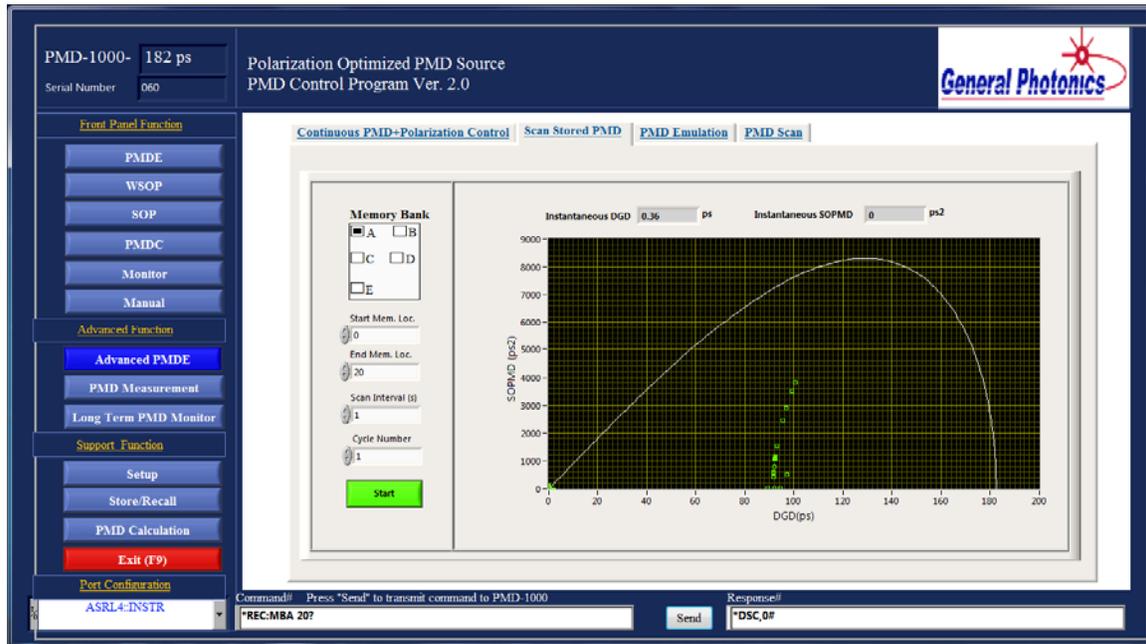
Select the desired memory bank (A-E), and the beginning and ending locations within that bank to be used for the scan. Set the desired dwell time per point (Scan Interval). If the selected memory bank contains only continuous PMD values or only discrete (lookup table) PMD values, the minimum dwell time is 0.001 s. If it contains a combination of continuous and discrete PMD values, the minimum dwell time is 0.5 s. If a dwell time < 0.5 s is selected for a mixed set of continuous and discrete values, the user will be

prompted to either run the scan with a dwell time of 0.5 s, or to exit the scan and return to parameter setup.
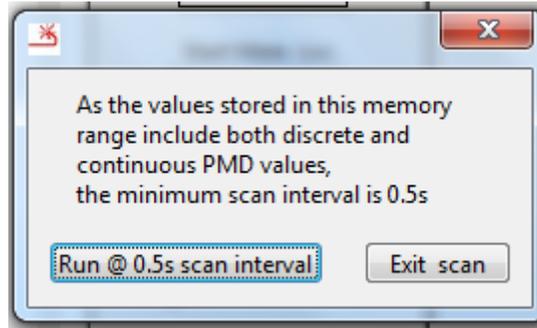
Note also that if the selected dwell time is <1 s, the scan will run, but the points will not be plotted on the display.

Select the number of times to run the scan (Cycle #) and then click "Start" to start the scan. For dwell time settings ≥ 1s, as the scan progresses, each point is plotted on the graph as it is generated, and its DGD and SOPMD values are displayed above the graph.

PMD Emulation:

This function performs statistical first-order or first and second order PMD emulation to simulate the PMD in real systems. For single-polarization signals, the SOP can also be automatically optimized for worst-case PMD effect at each PMD value.

Select "DGD only" (SOPMD = 0) or "PMD" (DGD + SOPMD emulation) from the pull-down menu at the top left of the operation area of the screen:

PMD Emulation- DGD only:

The "DGD only" PMD emulation function generates a Maxwellian distribution of DGD values with SOPMD =0.
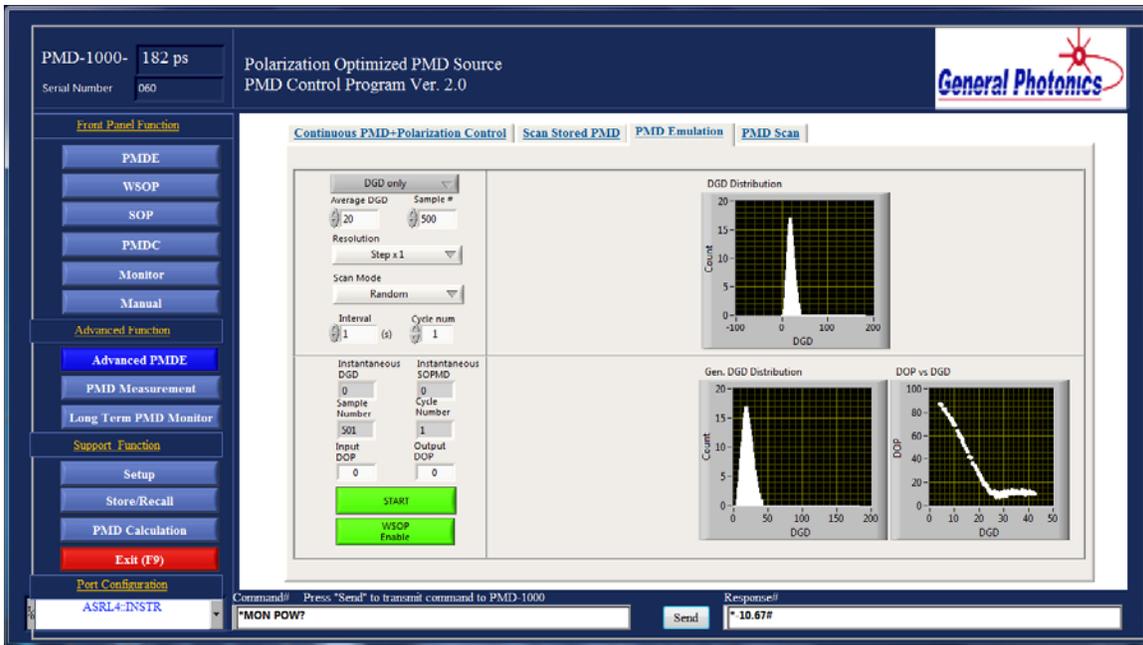
Selection parameters:

Average DGD: average DGD value (in ps) for the distribution.

Range: 0-30 ps for 90 ps PMDPro, 0-60 ps for 180 ps PMDPro.

Sample #: Total number of samples to be included in the distribution

Resolution: Minimum index number spacing between DGD values used in the scan.
For example, if the intrinsic DGD resolution of a 90 ps PMD-1000 is 0.357 ps, and the user chooses "step x2", then the DGD resolution used for the scan is 2 x 0.357 = 0.714 ps.
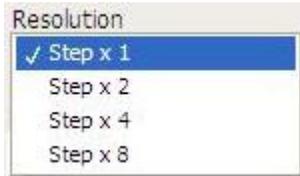
Scan Mode: Determines the order in which DGD values within the distribution will be generated.

Random: DGD values are generated in random order.

Sorted: DGD values are generated in increasing order from lowest to highest.

Interval: dwell time (in s) per sample. Minimum value is 0.001s. However, data will only be plotted for dwell times ≥ 1s.

Cycle Num: Number of times to run the scan.

The DGD distribution plot shows the calculated distribution of DGD values that corresponds to the selected parameters. This plot can be used to find a combination of average DGD and sample number that will yield a good distribution.

If the dwell time per point (scan interval) is ≥ 1 s, the program monitors the progress of the emulation. As each point is generated, the status block at the lower left of the screen

---

shows the DGD and SOPMD, sample number, number of completed cycles, and input and output DOP. The generated DGD distribution plot shows all points generated so far. When the emulation is complete, it will match the calculated DGD distribution plot above it. The DOP vs. DGD graph plots the output DOP vs. DGD for all generated points.

For dwell time values > 1 s, the WSOP function is also available. Click the "WSOP Enable" button at the bottom left of the screen before starting the emulation to enable automatic polarization optimization for the worst-case PMD effect at each DGD value. Please note that the WSOP function is only effective for single polarization signals.

For dwell time values <1 s, the WSOP and scan monitoring functions are disabled. The monitor plots are replaced by a progress bar:
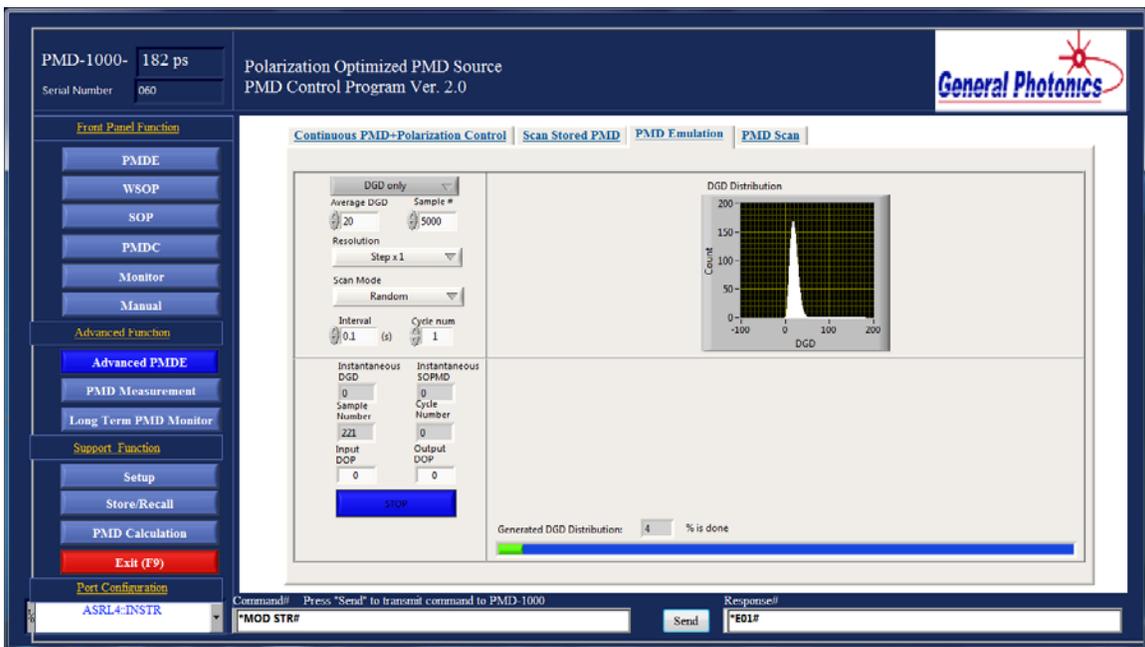
PMD Emulation- 1st and 2nd order:

The PMD emulation function generates a Maxwellian distribution of DGD values and a statistical distribution of SOPMD values corresponding to the generated DGD.
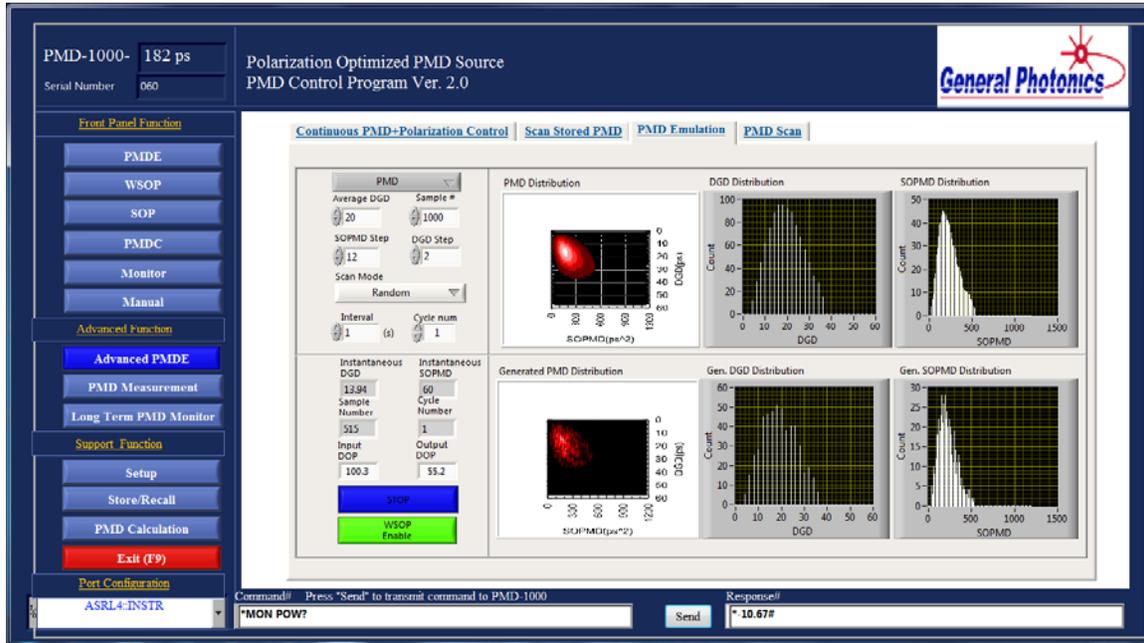
Selection parameters:
    Average DGD: average DGD value (in ps) for the distribution
            Range: 0-30 ps for 90 ps PMDPro, 0-60 ps for 180 ps PMDPro.
    Sample #: Total number of samples to be included in the distribution
    SOPMD Step: Minimum SOPMD step size, in ps^2, to be used in distribution
    DGD Step: Minimum DGD step size, in ps, to be used in distribution
    Scan Mode: Determines the order in which DGD values within the distribution will
            be generated.
            Random: DGD values are generated in random order.
            Sorted: DGD values are generated in order from lowest to highest.
    Interval: dwell time (in s) per sample. Minimum value is 0.001s. However, data will
            only be plotted for dwell times $\geq$ 1s.
    Cycle Num: Number of times to run the scan

The plots in the top row show the calculated distributions of values for the emulation.

The PMD distribution plot shows DGD vs. SOPMD, with the color indicating the frequency of occurrence of a particular set of values. This is a 3D plot that can be rotated or zoomed for viewing from different perspectives, as shown below.

To rotate a 3D graph, drag it with the mouse. To zoom in or out, hover the mouse over it and scroll up or down.
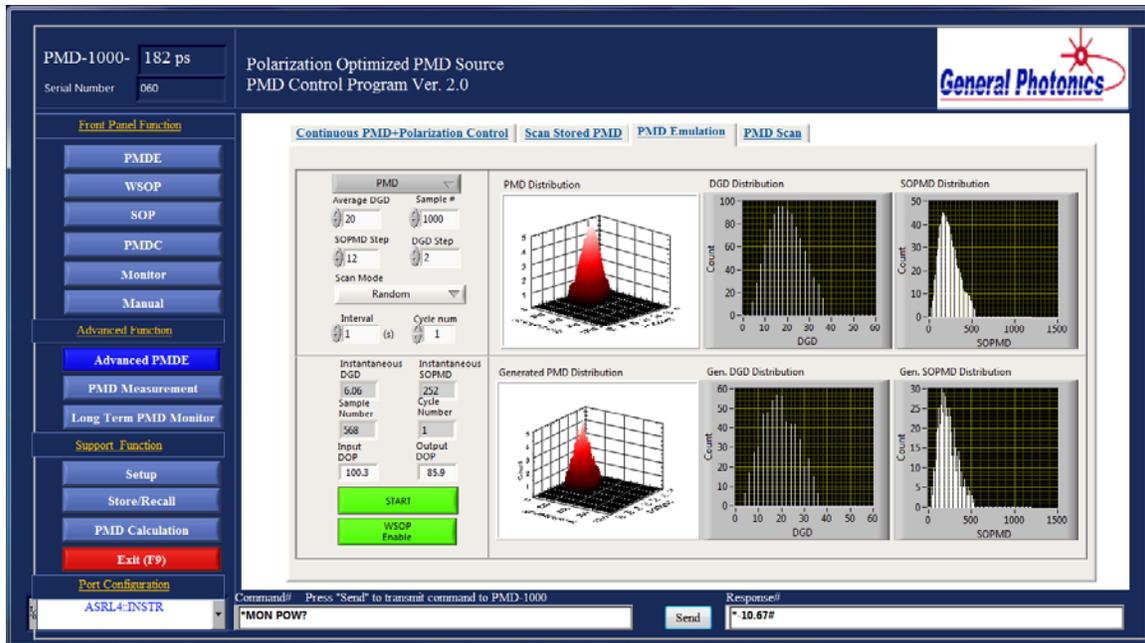
The DGD distribution plot shows the calculated distribution of DGD values that corresponds to the selected parameters. This plot can be used to find a combination of average DGD and sample number that will yield a good distribution.

The SOPMD distribution plot shows the calculated distribution of SOPMD values that corresponds to the selected parameters.

If the dwell time per point (scan interval) is ≥ 1 s, the program monitors the progress of the emulation. As each point is generated, the status block at the lower left of the screen shows the DGD and SOPMD, sample number, number of completed cycles, and input and output DOP. The generated PMD, DGD, and SOPMD distribution plots track the progress of the emulation. When the emulation is complete, the generated value plots will match the calculated value plots above them.

For dwell time values >1 s, the WSOP function is also available. Click the "WSOP Enable" button at the bottom left of the screen before starting the emulation to enable automatic polarization optimization for the worst-case PMD effect at each DGD value.

For dwell time values <1 s, the WSOP and scan monitoring functions are disabled. The monitor plots are replaced by a progress bar:
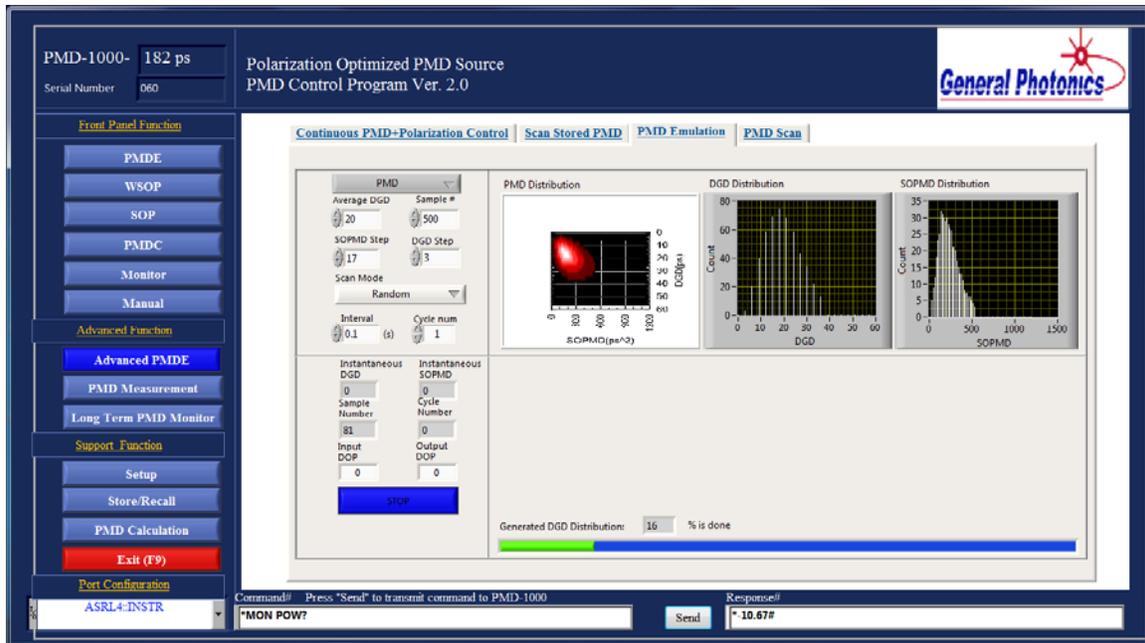
PMD Scan:

This function set uses the quasi-continuous PMD generation mode to generate two types of PMD scans. The PMD trace scan creates a continuous PMD variation at a user-selectable rate of change. The local PMD scans generate a series or grid of PMD values with user-selectable DGD and/or SOPMD boundaries and step sizes.

PMD Trace Scan:

This function generates continuous PMD traces along one of the characteristic curves in PMD space. Each trace is a demi-arc of a characteristic curve.

The user can select a series of traces to be generated. As each trace is configured, it is added to the trace list in the upper left corner of the screen and to the graph on the right side of the screen.

To add a trace to the list, go to the trace setting block in the middle left of the screen. Select a DGD value in the "Start DGD" box. This is the trace endpoint on the DGD axis (with SOPMD = 0). The DGD and SOPMD values corresponding to the other endpoint will automatically update as the start DGD is changed. Clicking the "Add Trace" button adds the trace to the trace list and the graph.

To delete a trace from the list, click on it in the trace list to highlight it, then click the "Delete Trace" button in the middle left section of the screen.
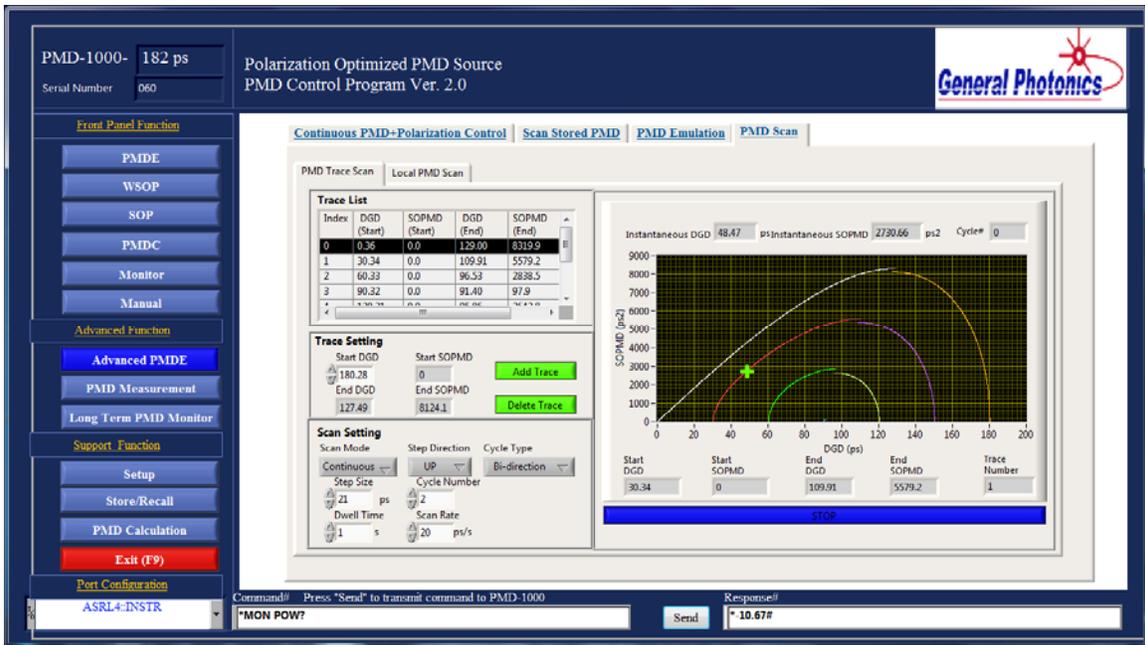
The "Scan Setting" block on the lower left of the screen is used to configure the operational parameters for the scan.
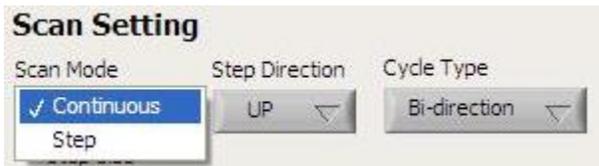
The scan mode pull-down menu allows the user to choose between a continuous or step scan. In a continuous scan, the PMDPro uses the smallest possible DGD step size (0.1 ps) to generate the trace, and the user can select the rate of change of DGD, in ps/s. In a step scan, the PMDPro generates a series of points placed along the trace, with user-selectable DGD step size and dwell time at each point. The transient between any two consecutive points on a trace still follows the trace, however, so either the continuous or step scan can be used for applications that require continuous PMD variation.

The step direction pull-down menu selects the direction of travel along the trace. If "UP" is selected, the PMDPro starts at the lower DGD limit point (whether designated as start or end point) and traverses the trace to the other limit point. If "DOWN" is selected, the PMDPro starts at the higher DGD limit point and traverses the trace to the lower DGD limit point.
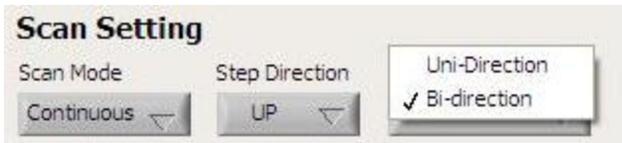
The cycle type pull-down menu allows the user to select between a one-way or round-trip scan.

Cycle number designates how many times to generate each trace before going on to the next trace on the list. In the example above, the scan is set for continuous, up, bidirectional, and 2 cycles, with the first trace's limit points set at (0.36 ps, 0.0 ps^2) and (129.00 ps, 8319.9 ps^2). The PMDPro will make 2 round trips along the first trace (yellow, in the example above), starting at point (0.36, 0), going along the trace to point (129.00, 8319.9) and back to point (0.36, 0). It will then make 2 round trips along the second trace (red, in the example above) starting and ending at point (30.34, 0), and so on.

If the scan mode is set to "continuous", the PMDPro traverses the trace at a constant rate of change of DGD. Set the scan rate (in ps/s) using the up and down arrows or by typing in the box. The range for scan rate is 0.1 to 100 ps/s.

If the scan mode is set to "step", the scan speed is determined by the step size and dwell time. The step size is the DGD difference, in ps, between consecutive points, and the dwell time is the time, in seconds, that the PMDPro stays on each point. The step size range is 0.1 to 64 ps, and the dwell time range is 0.001 to 9.999s.

Once the trace list and scan operation parameters are configured, click the "Start" button to begin. The monitor block on the right of the screen shows the progress of the scan. The cursor will move along the traces as the PMD changes. The indicator boxes above the graph monitor the progress of an individual trace segment. As the trace is generated, they show the instantaneous DGD and SOPMD values and the number of cycles completed for the current trace segment. The indicator boxes under the graph provide the definition information for the current trace segment: the DGD/SOPMD values for the start and end points and the trace number (index number indicating its order in the list).

Local PMD Scan:

This set of functions allows the user to scan through a selected DGD range with fixed SOPMD, a selected SOPMD range with fixed DGD, perform a 2-D DGD/SOPMD scan, or scan through a user-defined list (table) of DGD/SOPMD pairs. All of these functions can be performed with automatic worst-case SOP search enabled or disabled.
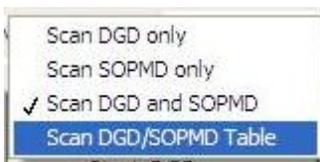
Select the desired scan function from the pull-down menu, as shown in the picture above.

To enable worst-case SOP optimization, click the "WSOP Enable" button at the bottom left of the screen before running a scan. To disable it, select "Disable WSOP". Please note that this function can only be used with single-polarization signals.

Scan DGD only:

This function scans through a user-defined DGD range with a fixed SOPMD value.
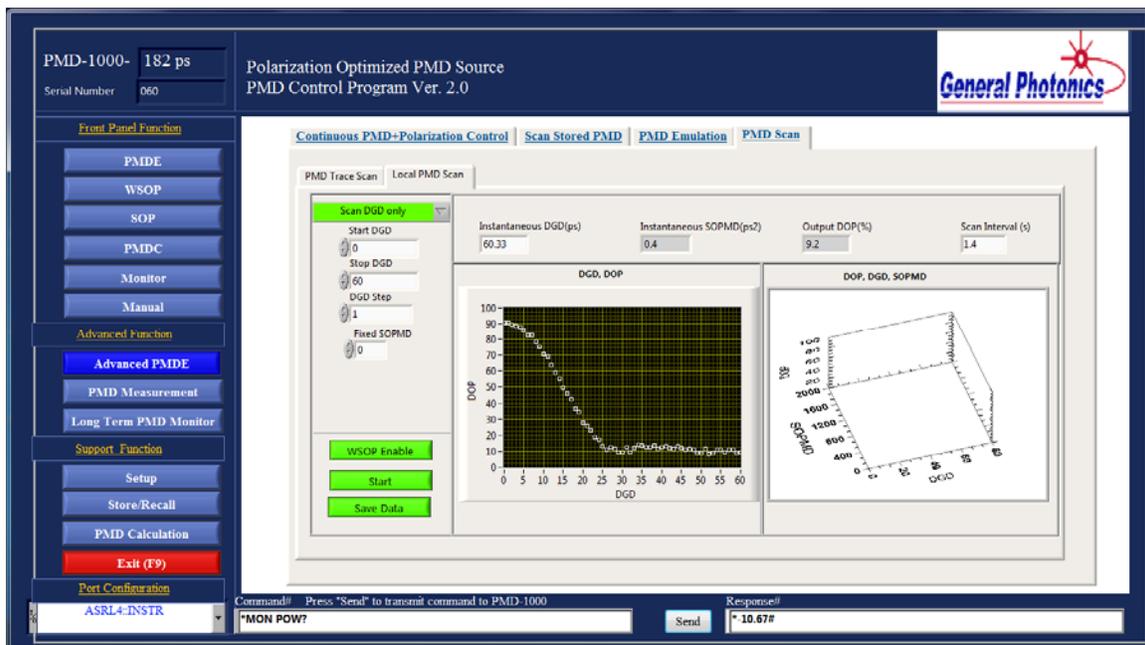
Selection parameters:
    Start DGD: DGD start value, in ps
    Stop DGD: DGD end value, in ps
    DGD step: step size in ps
    Fixed SOPMD: fixed SOPMD value, in ps^2
    Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

Note that the SOPMD value setting may limit the DGD scan range.

When the scan parameters are set, click "Start" to start the scan. As each point is generated, the DGD, SOPMD, and output DOP are displayed above the graph, and the output DOP vs. DGD is plotted in the graph on the left.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA".

The program will prompt for a filename and location:
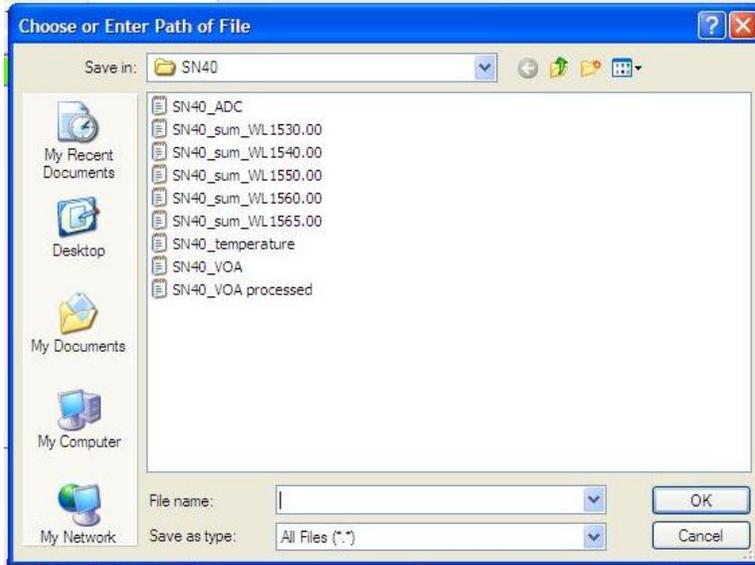
Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan SOPMD only:

This function scans through a user-defined SOPMD range with a fixed DGD value.
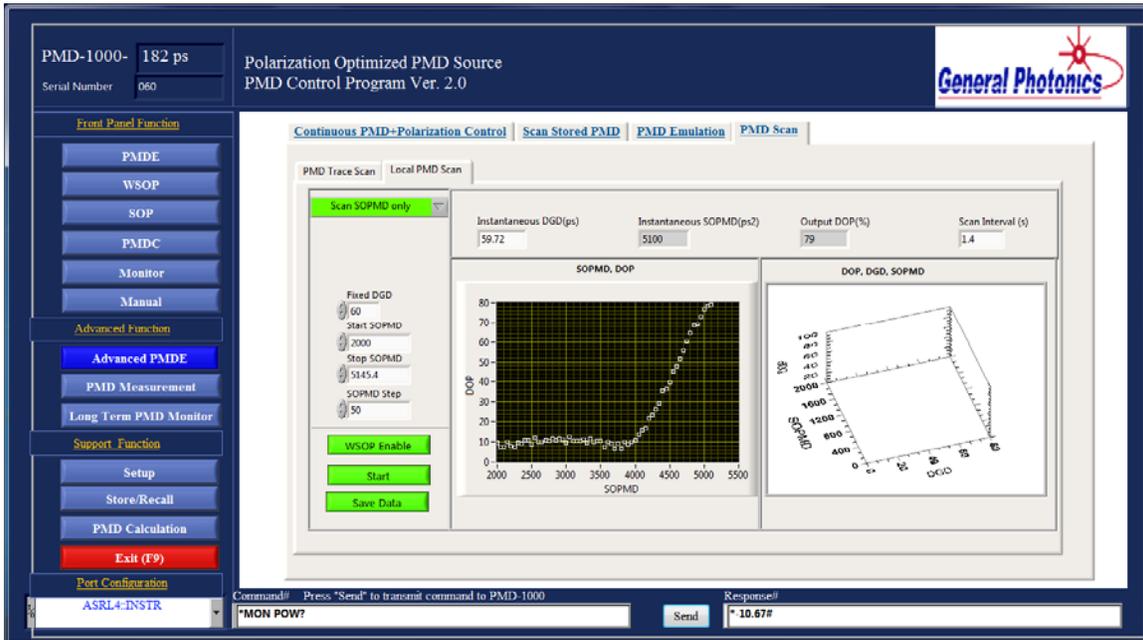
Selection parameters:
Fixed DGD: fixed DGD value, in ps
Start SOPMD: SOPMD start value, in ps^2
Stop SOPMD: SOPMD end value, in ps^2
SOPMD step: step size in ps^2
Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

When the scan parameters are set, click "Start" to start the scan. As each point is generated, the DGD, SOPMD, and output DOP are displayed above the graph, and the output DOP vs. SOPMD is plotted in the graph on the left.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan DGD and SOPMD:

This function performs a scan of a 2-D grid in PMD space. The user defines the grid by specifying the DGD and SOPMD limit points and step sizes.
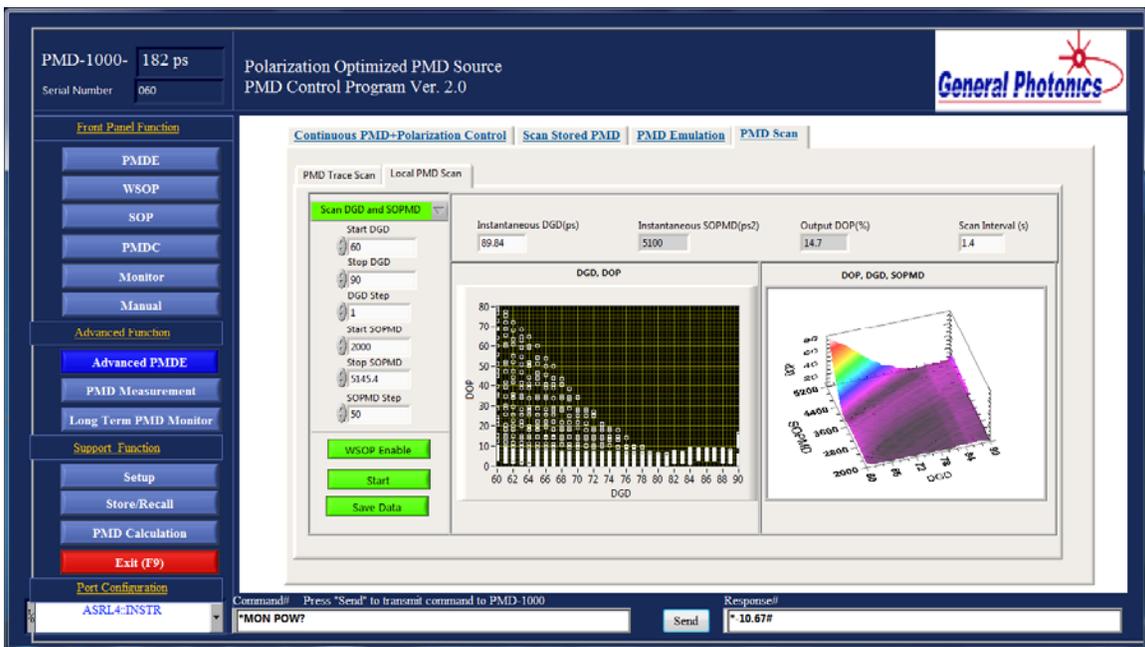
Selection parameters:
    Start DGD: DGD start value, in ps
    Stop DGD: DGD end value, in ps
    DGD step: DGD step size, in ps
    Start SOPMD: SOPMD start value, in ps^2
    Stop SOPMD: SOPMD end value, in ps^2
    SOPMD step: SOPMD step size, in ps^2
    Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

When the scan parameters are set, click "Start" to start the scan. As each point is generated, the DGD, SOPMD, and output DOP are displayed above the graphs, and the output DOP vs. DGD is plotted in the graph on the left.

The data is also plotted in a 3D graph on the right of the screen. The graph can be rotated or zoomed to view the data from different perspectives.

To rotate a 3D graph, drag it with the mouse. To zoom in or out, hover the mouse over it and scroll up or down.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan DGD/SOPMD table:

This function scans through a set of user defined DGD/SOPMD pairs.
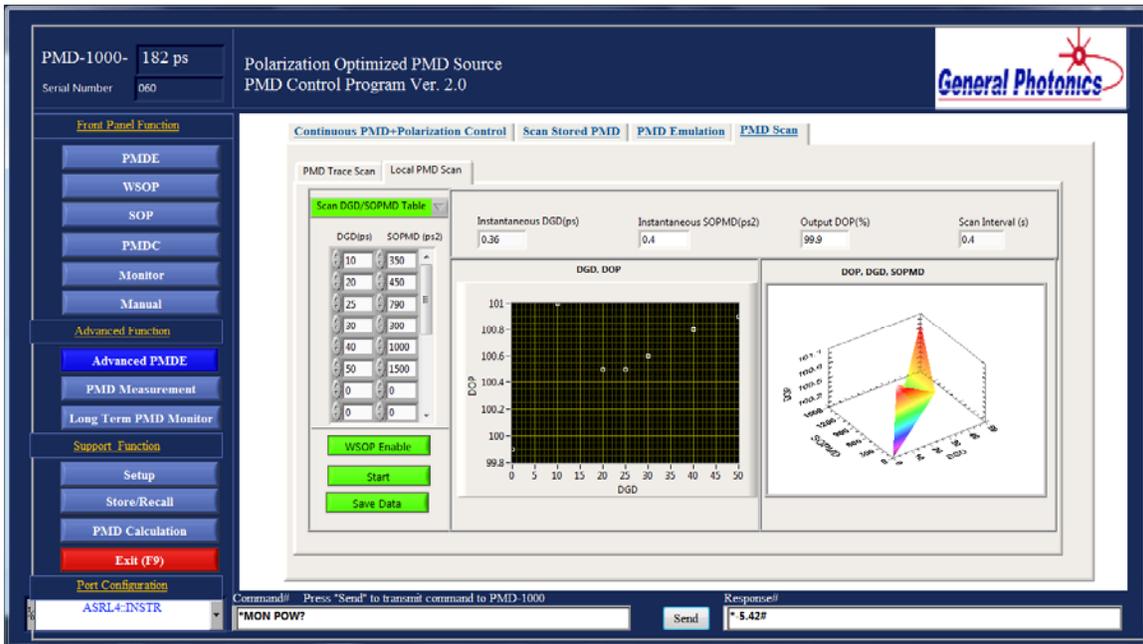
Enter the PMD values to be scanned in the table on the left of the screen. DGD values are in ps and SOPMD values in ps^2.

As in the other scan functions, the dwell time per point (Scan Interval, in s) should be set in the box above the graph. The minimum value is 0.4 s.

When all of the PMD values are entered into the table, click "Start" to start the scan. As each point is generated, the DGD, SOPMD, and output DOP are displayed above the graph, and the output DOP vs. DGD is plotted in the graph on the left. The graph on the right is a 3D graph of DOP vs. SOPMD and DGD. It can be rotated or zoomed for viewing from different perspectives.

To rotate a 3D graph, drag it with the mouse. To zoom in or out, hover the mouse over it and scroll up or down.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

PMD Measurement and Long-term Monitoring:

The functions contained in these two categories are designed to measure and/or monitor the PMD in a system.

PMD Measurement:

The functions in this set measure the PMD in the system under test using the PMDPro's PMD compensation function. They scan through a selected set of PMD values and optimize the SOP at each state in the scan to determine which PMD value in the set can best compensate the PMD in the system. That PMD value is the measured PMD for the system under test.

There are two tabs under this function set.

PMD Measurement:

This function uses the quasi-continuous PMD generation mode to scan through a selected set of PMD values and optimize the SOP at each state in the scan to maximize the output DOP. It allows the user to scan through a selected DGD range with fixed SOPMD or a selected SOPMD range with fixed DGD, to perform a 2-D DGD/SOPMD grid scan, or to scan through a table of user-set DGD/SOPMD pairs.

Select the desired scan function from the scan setting pull-down menu, as shown in the picture below.

Scan DGD only:

This function scans through a user-defined DGD range with a fixed SOPMD value.

Selection parameters:
  Start DGD: DGD start value, in ps
  Stop DGD: DGD end value, in ps
  DGD step: DGD step size, in ps
  Fixed SOPMD: fixed SOPMD value, in ps^2
  Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

When the scan parameters are set, click "Start" to start the scan. At each point in the scan, the DGD, SOPMD, and maximum output DOP for that point are displayed above the graphs, and the maximum output DOP vs. DGD is plotted in the graph on the left. The maximum output DOP for the scan and the corresponding DGD and SOPMD values are displayed below the graph.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan SOPMD only:

This function scans through a user-defined SOPMD range with a fixed DGD value.

Selection parameters:
    Fixed DGD: fixed DGD value, in ps
    Start SOPMD: SOPMD start value, in ps^2
    Stop SOPMD: SOPMD end value, in ps^2
    SOPMD step: SOPMD step size, in ps^2
    Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

When the scan parameters are set, click "Start" to start the scan. At each point in the scan, the DGD, SOPMD, and maximum output DOP for that point are displayed above the graphs, and the maximum output DOP vs. SOPMD is plotted in the graph on the left. The maximum output DOP for the scan and the corresponding DGD and SOPMD values are displayed below the graph.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA".
Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan DGD and SOPMD:

This function performs a 2-D DGD/SOPMD grid scan over a user-defined area.

Selection parameters:
Start DGD: DGD start value, in ps
Stop DGD: DGD end value, in ps
DGD step: DGD step size, in ps
Start SOPMD: SOPMD start value, in ps^2
Stop SOPMD: SOPMD end value, in ps^2
SOPMD step: SOPMD step size, in ps^2
Scan Interval (on top of graph): dwell time per point, in s. Minimum value: 0.4 s.

When the scan parameters are set, click "Start" to start the scan. At each point in the scan, the DGD, SOPMD, and maximum output DOP for that point are displayed above the graphs, and the maximum output DOP vs. DGD is plotted in the graph on the left. The maximum output DOP for the scan and the corresponding DGD and SOPMD values are displayed below the graph. The graph on the right is a 3D graph of DOP vs. SOPMD and DGD. It can be rotated or zoomed for viewing from different perspectives.

To rotate a 3D graph, drag it with the mouse. To zoom in or out, hover the mouse over it and scroll up or down.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

Scan DGD/SOPMD value in table:

This function scans through a set of user defined DGD/SOPMD pairs.
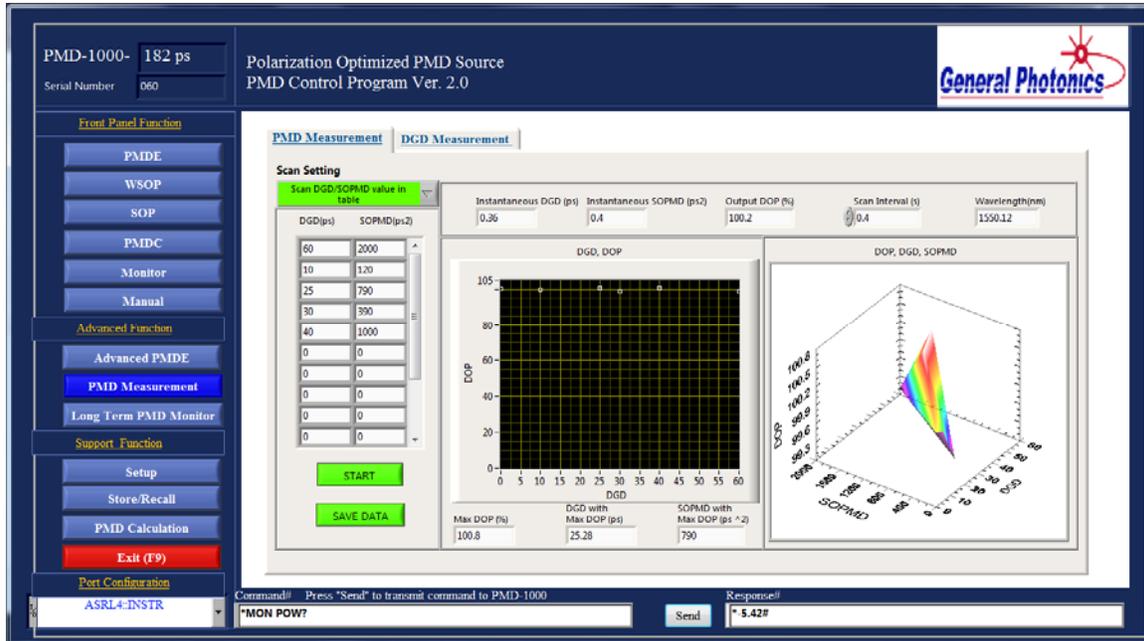
Enter the PMD values to be scanned in the table on the left of the screen. Each row designates one DGD/SOPMD pair. The DGD value, in ps, should be entered in the first column and the SOPMD value, in ps^2, in the second column.

As in the other scan functions, the dwell time per point (Scan Interval, in s) should be set in the box at the top of the graph. The minimum value is 0.4 s.

When all of the PMD values are entered into the table, click "Start" to start the scan. At each point in the scan, the DGD, SOPMD, and maximum output DOP for that point are displayed above the graphs, and the maximum output DOP vs. DGD is plotted in the graph on the left. The maximum output DOP for the scan and the corresponding DGD and SOPMD values are displayed below the graph. The graph on the right is a 3D graph of DOP vs. SOPMD and DGD. It can be rotated or zoomed for viewing from different perspectives.

To rotate a 3D graph, drag it with the mouse. To zoom in or out, hover the mouse over it and scroll up or down.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA". Data is saved as a text file with 3 columns: DGD, SOPMD, and DOP.

DGD Measurement:

This function scans through the DGD-only states in the lookup table (discrete mode) and optimizes the SOP at each state to maximize the output DOP.
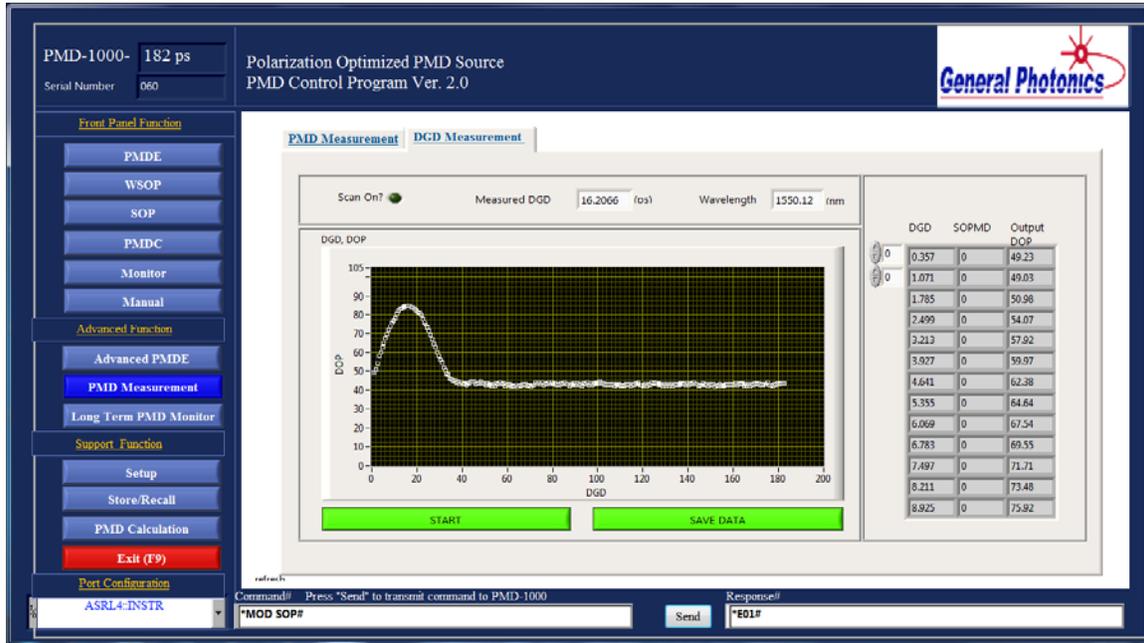
There are no selection parameters for this scan. Click "Start" to start the scan. While the scan is running, the "Scan on?" indicator will be green. When the scan is finished, the DGD and SOPMD values and the corresponding maximum output DOP are displayed in the table on the right of the screen, and the maximum output DOP vs. DGD is plotted in the graph. The DGD value with the highest output DOP is displayed in the "Measured DGD" box at the top of the screen.

The graph serves as a measurement of both the PMD in the system and of how much of an effect PMD compensation will have. The DGD value corresponding to the peak DOP in the plot is the DGD in the input signal to the PMD-1000. The height of the peak relative to the baseline DOP indicates the effect of PMD compensation.

After the scan is finished, the data can be saved to a file by clicking "SAVE DATA".
Data is saved as a text file with 2 columns: DGD and DOP.

Long Term PMD Monitor:

This function is designed for live monitoring of PMD in a system. The PMD effect in a system is a dynamic phenomenon. It changes over time with changes in input polarization or environmental conditions. Whereas the other PMDC functions provide a snapshot measurement of the PMD of the system at the time the measurement was taken, this function allows the user to monitor the PMD effect over an extended period to characterize the behavior of the actual system. It uses the lookup table DGD measurement function described in the previous section.
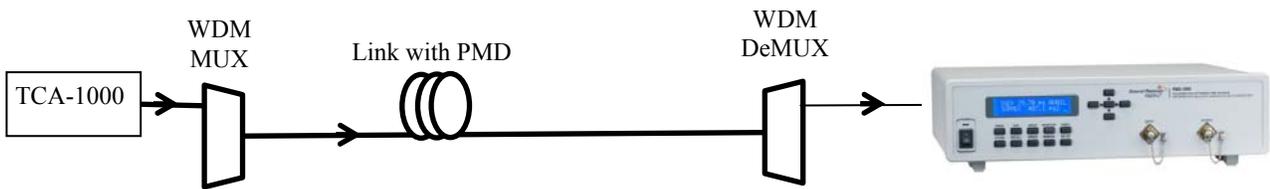
Figure 26 System setup using TCA-1000 as signal emulator

Figure 26 illustrates a system setup for PMD monitoring using General Photonics Tunable Channelized ASE Source (TCA-1000) in conjunction with the PMDPro. The TCA-1000 is used as the input to one frequency channel before multiplexing. After demultiplexing, that frequency channel is sent to the PMDPro, which performs DGD measurements at user-specified intervals.

Since the PMD effect varies with input polarization, it is possible to obtain spurious results if the input polarization happens to be aligned to the effective fast or slow axis of the device or link under test. To counter this possibility, the TCA-1000 can be instructed to periodically rotate its output polarization state by 45°.
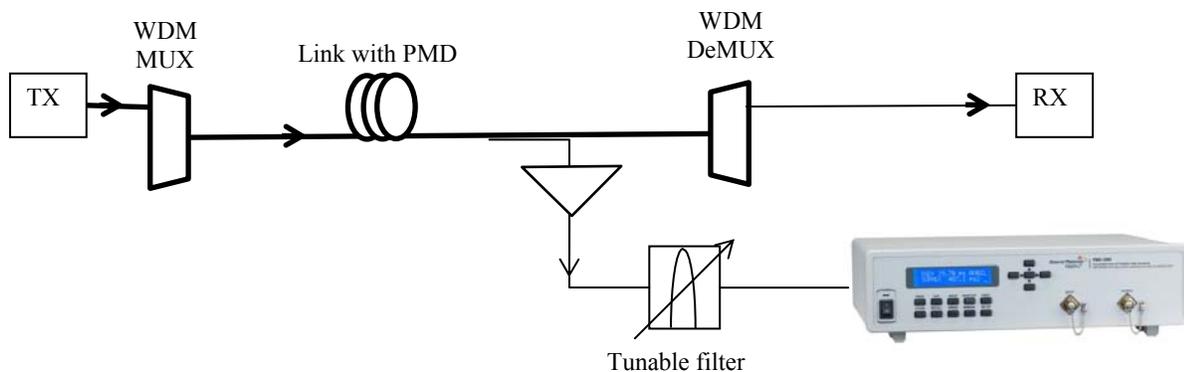
Figure 27 System setup for long-term monitoring of in-service link

Figure 27 illustrates a system setup for monitoring the PMD of an in-service link. The signal is tapped before the demultiplexer, sent through an EDFA, and then the frequency channel to be tested is separated out with a tunable filter and sent to the PMDPro.
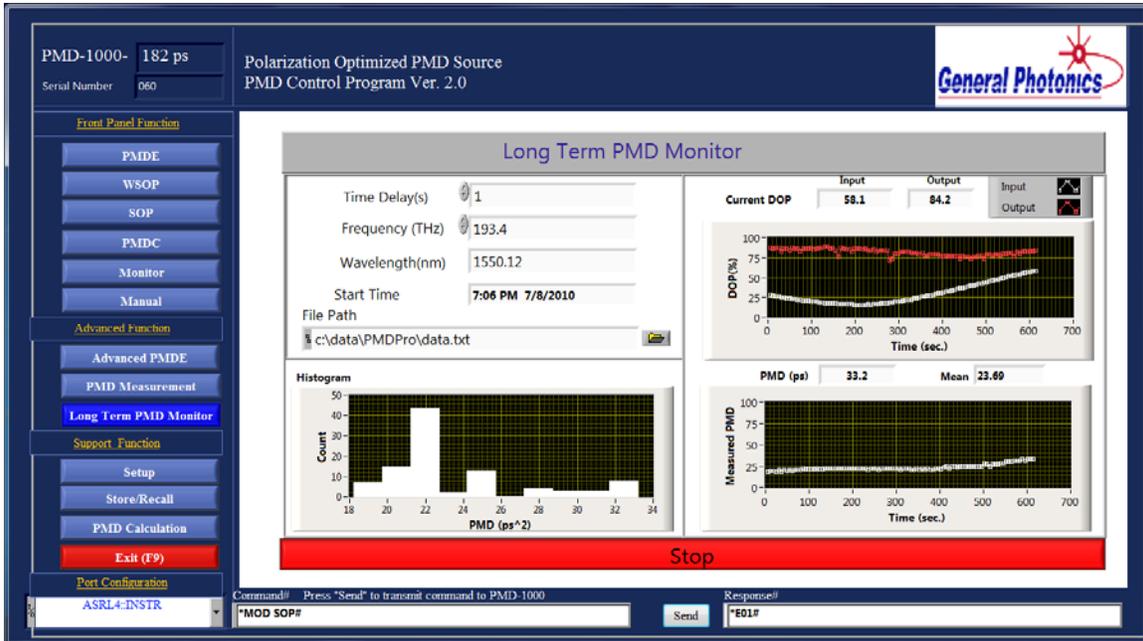
The picture above shows the control program interface screen for the long-term monitoring function.

Connect the DUT to the input of the PMDPro.

Setup parameters:
File Path: Click the folder icon to select the file path to which the data should be saved.
Time Delay: Time interval between measurements, in seconds.
Frequency: Frequency (in THz) of the signal to be measured. As this value is updated, the corresponding wavelength (in nm) will be displayed in the box immediately below the frequency box.

Once the setup is complete, click "Start" to begin recording data. The PMDPro will perform PMD measurements at the specified time intervals. After each measurement is complete, the PMDPro will record the following data to the file: optical head temperature, optimized DGD (the DGD value for which the maximum output DOP was found), input DOP, output DOP, and time stamp. The input and output DOP vs. time are plotted on the top right hand graph, and the measured PMD vs. time is plotted on the bottom right hand graph. The histogram tracks the distribution of measured PMD values.

After a long enough period of measurement, the histogram will typically follow a Maxwellian distribution. The mean of the distribution can be taken to be the mean PMD of the system under test.

The program will continue recording data until the "Stop" button is clicked.

Support Functions:

This section includes the interface screens for setting operation parameters, storing and recalling programmed PMD scan sequences and PMDC results, and performing wavelength dependence simulations for PMD states in the discrete mode lookup table.

Setup:

This screen allows the user to set the basic operation parameters for the PMD-1000.
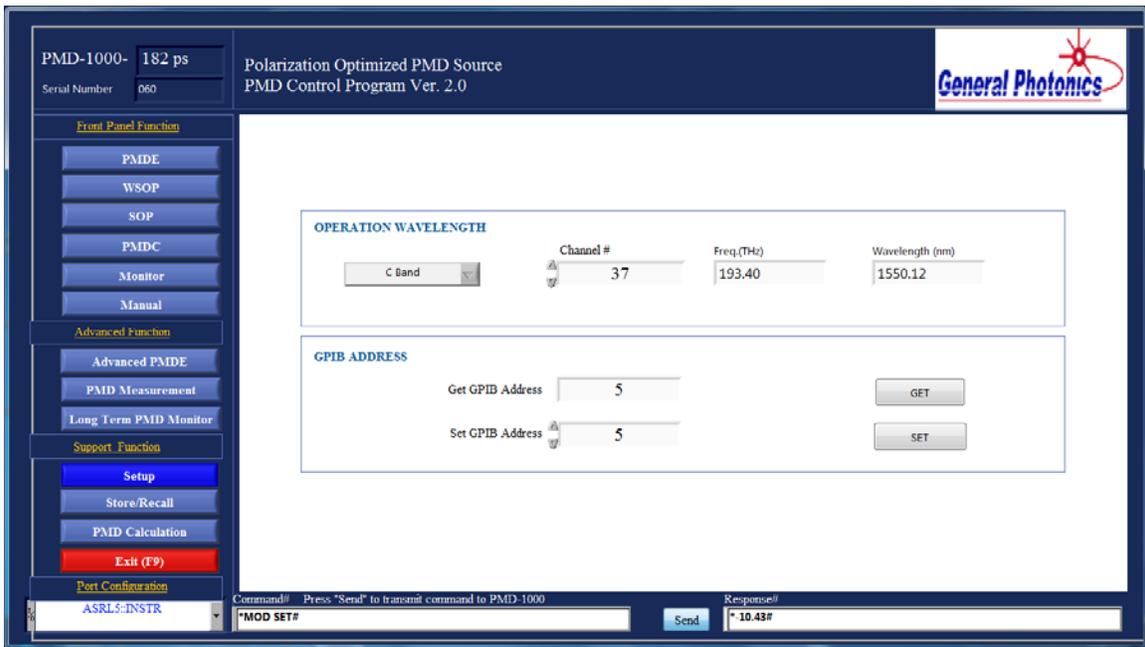
Setup parameters:

Operation Wavelength: First, select the wavelength band (e.g. C or L band). Then, select the ITU grid channel number. The indicator boxes will display the corresponding frequency (in THz) and wavelength (in nm) of the selected channel. The wavelength setting updates in real time.

GPIB address: Click "Get" to query the current GPIB address for the PMD-1000. To set a new address, select the desired GPIB address in the "Set GPIB address" box, then click "Set".
Note: This function can only be used if the current interface is something other than GPIB.

Store/Recall:

This screen is used to store PMD sequences for scans or PMDC measurement results to memory, or to recall stored data from memory.

PMD-1000- 182 ps
Serial Number 060

Polarization Optimized PMD Source
PMD Control Program Ver. 2.0

General Photonics

PMD Memory Bank Store/Recall | PMDC Memory Bank Store/Recall

PMD RECALL/STORE

Memory Bank
☐A ■B ☐C ☐D ☐E

Memory Start ID# 0   Memory End ID# 20

CLEAR

RECALL   STORE

EXPORT   IMPORT

PMD Value in the Memory

Sequence Number	Discrete/Continuous (1/0)	PMD ID	DGD (ps)	SOPMD (ps2)
0	1	6560	181.390	137.39
1	1	5560	137.826	1770.89
2	1	4560	110.737	5073.19
3	1	2560	68.621	220.97
4	1	1560	26.994	298.79
5	1	560	60.691	21.66
6	0	0	60.34	500.0
7	0	0	50.04	400.0
8	0	0	29.90	300.0
9	1	6560	181.390	137.39
10	0	0	100.60	1000.0
11	0	0	110.96	2035.0
12	0	0	120.88	2535.0
13	0	0	131.24	2946.0
14	0	0	141.12	3246.0
15	0	0	151.30	3246.0

Front Panel Function
PMDE
WSOP
SOP
PMDC
Monitor
Manual
Advanced Function
Advanced PMDE
PMD Measurement
Long Term PMD Monitor
Support Function
Setup
Store/Recall
PMD Calculation
Exit (F9)
Port Configuration
ASRL4::INSTR

Command# Press "Send" to transmit command to PMD-1000   Response#
*MOD STR#   Send   *E01#

PMD Memory Bank Store/Recall:

The PMD-1000 has 5 memory banks, with 100 locations each, for PMD sequence storage. The user can thus store up to 5 sequences of PMD values which can be used for the "Scan Stored PMD" function.

PMD sequence storage:
To store a PMD sequence, first select the desired memory bank (A-E).
Enter the values to be stored into the table at the right of the screen:

      Sequence Number: Memory location index number

      Discrete/Continuous (1/0): Indicates whether a discrete or a continuous mode PMD value is to be stored at that location.
        1 = Discrete (lookup table) value
        0 = Continuous PMD value

      PMD ID: If a discrete value is to be stored at the current location, type in the index number of the desired DGD/SOPMD pair from the lookup table. Index number range is 0-6560. For a discrete value, this fully specifies the PMD. The DGD and SOPMD fields do not have to be filled in. For a continuous PMD state, the PMD ID field does not have to be filled in.

      DGD: For a continuous PMD state, type in the desired DGD, in ps.

      SOPMD: For a continuous PMD state, type in the desired SOPMD, in ps^2.

When all of the PMD states to be stored have been entered in the table, click the "STORE" button to store the PMD sequence to memory. Note that for continuous states, the state stored in memory and used for the scan is the closest-matched set of calculated values to the user-requested DGD/SOPMD values.

PMD sequence recall:
To recall data from memory and display it on-screen, select the desired memory bank. Then, define the range of memory locations from which to recall data by selecting the start and end ID#s in the corresponding boxes. Click "RECALL" to display the data in the table on the right.

Export:
After stored data is recalled to the table on screen, it can be exported to a text file by clicking the "EXPORT" button. The program will prompt for a file name and location. Data is stored in the format in which it is displayed in the on-screen table.
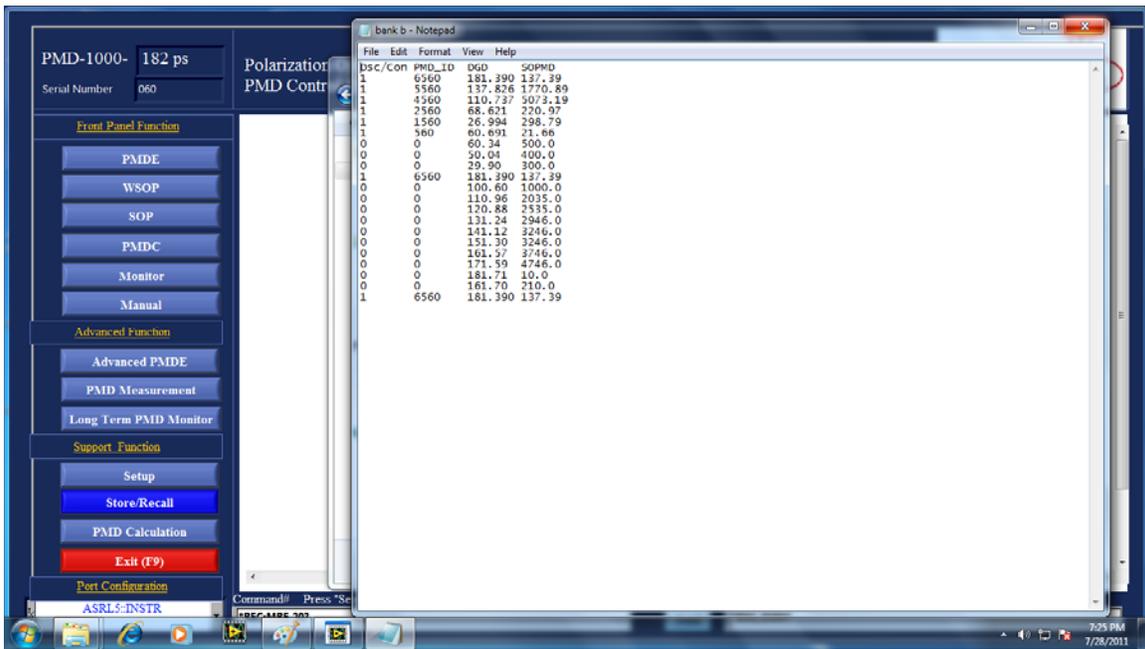
Import:
Data previously exported to a text file can be imported by clicking the "IMPORT" button. The program will prompt for a file name and location, and the imported data will be displayed in the table on-screen. It can then be stored to a memory bank by selecting a memory bank (A-E) and clicking the "STORE" button.

Clear:
The selected memory bank can be cleared by clicking the "CLEAR" button. The program will prompt the user to confirm:
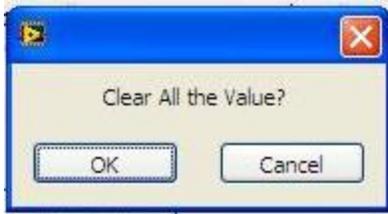
Click "OK" to delete the stored data.

PMDC Memory Bank Store/Recall:

The PMDPro can also perform individual DGD measurements and save the results to memory. Up to 100 results can be stored.
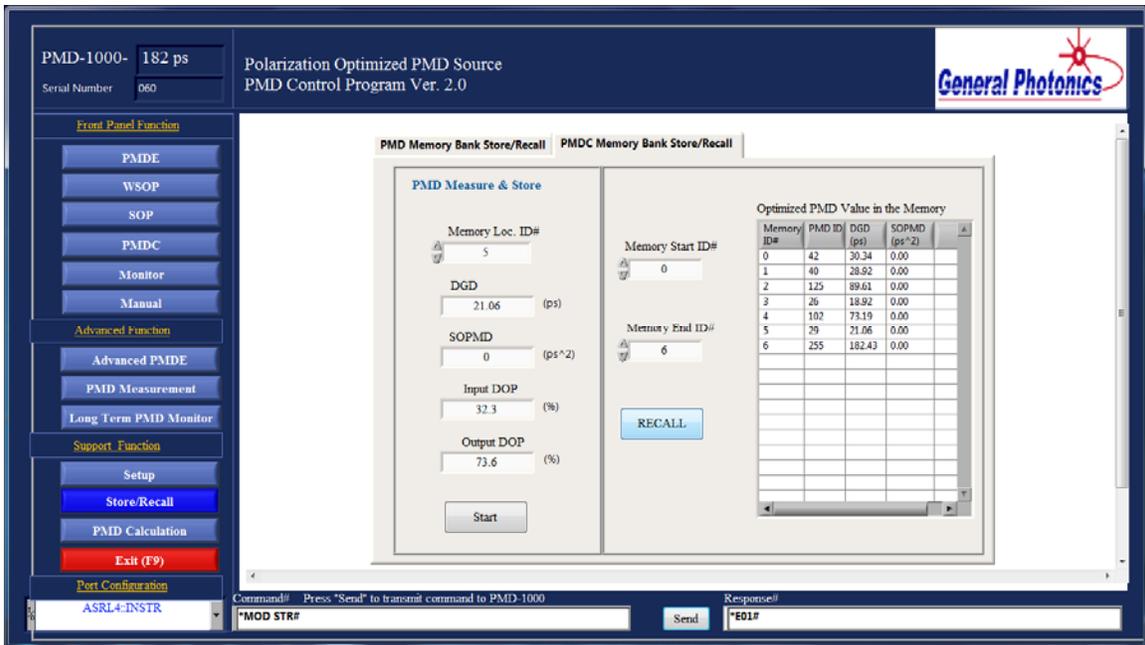
Store DGD measurement:
To perform a DGD measurement and store the result, select the memory location in which to store the data ("Memory Loc ID#" box). Click the "Start" button. The PMDPro will perform the measurement and store the results to the selected location. The indicator boxes immediately below the "Memory Loc ID#" box will display the data (DGD, SOPMD, input and output DOP) after the measurement is completed.

Recall PMD measurement results from memory:
To recall stored PMD measurement results and display them in the table on-screen, specify the range of memory locations to be queried by selecting the start and end ID#s from the corresponding boxes to the left of the data table. Then, click the "RECALL" button to display the data on screen.

PMD Calculation

For a particular PMD index number in the discrete lookup table, this function displays the calculated wavelength dependence of the DGD and total SOPMD, as well as the depolarization and polarization dependent chromatic dispersion (PDCD) components of the SOPMD.
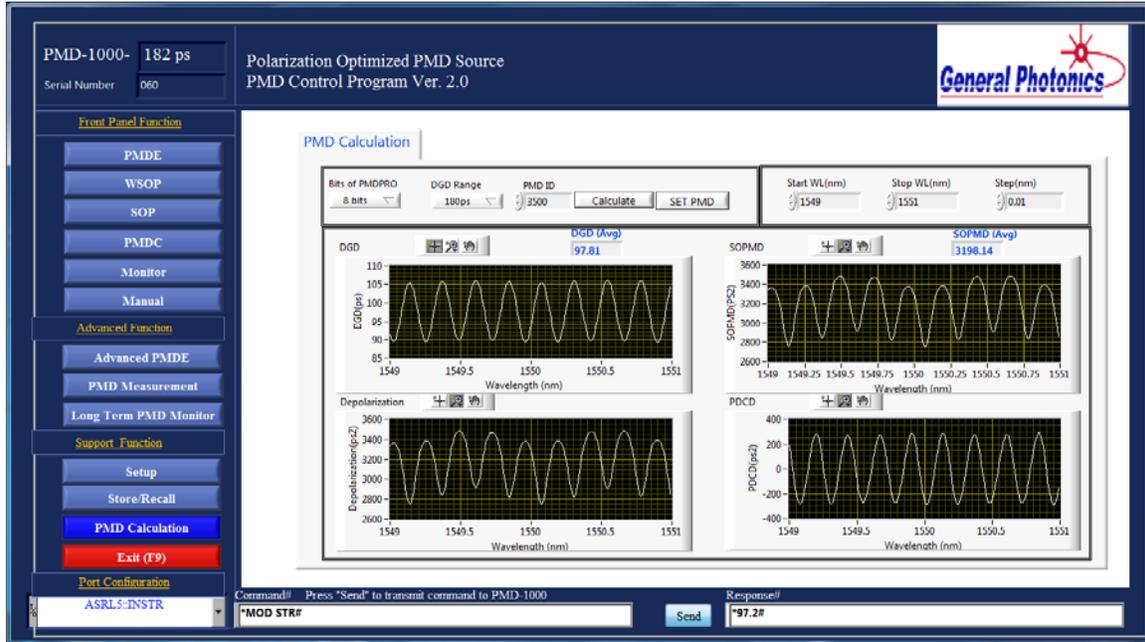
Selection parameters:
   Bits of PMDPro: Discrete mode resolution (# of bits) of the PMD-1000. By default, this value is 8.
   DGD range: DGD range of the PMD-1000 (90 or 180 ps)
   PMD ID#: index number for the PMD setting to be used for simulation

   Start WL: starting wavelength (in nm) to be used for simulation
   Stop WL: ending wavelength (in nm) to be used for simulation
   Step: wavelength step (in nm) to be used for simulation

Once the parameters for the simulation are selected, click "Calculate" to run the simulation.

Click "SET PMD" to execute the setting. The PMDPro's output PMD does not change until this button is clicked.

Exit

The Exit button (or the F9 function button on the keyboard) exits the program.

4.3.8 Remote Control Command List

The command list allows users to write their own programs for basic control of the PMDPro and facilitates integration with other instruments. The command format is the same for all communication interfaces (RS-232, USB, Ethernet, or GPIB).

Once the connection has been established and the instrument has been detected by the control computer, any program that supports the communication protocol being used (RS-232, USB, Ethernet, or GPIB) can be used to send ASCII commands to the instrument. Commands should be sent one at a time. A new command should not be sent until the instrument's response to the preceding command is received.

Table 1 PMD-1000 Communication Command List

Command	Description	Response
*IDN?	Query product number	*GP-PMD-Pro V2.0#
*VER?	Query firmware version	*V1.3.1.110423A -G 8-Bit Ana-091ps#
*SER?	Query product serial number	Example: *106800000040#
PMDE MODE	**=== Single Value Control===**	**===========================**
*PMD *idn#*	Discrete mode PMD control: Set DGD/SOPMD to values corresponding to index number *idn*. This command does not change the operation mode or update the LCD display.	*E00# if successful. See Table 2 for other error code definitions.
*PMD?	Discrete mode PMD query: Query current or most recently set PMD-ID# Range: 0 to 6560.	Example: *1005# If not in PMD mode, will return the last PMD ID# set.
*PMD:CON CAL?	Continuous mode PMD query: Query most recent set of calculated DGD/SOPMD values.	*dgd,sopmd# Eg: *30.37,100.0# DGD given in ps, SOPMD in ps^2
*PMD:CON MAX?	Continuous mode PMD query. Queries 1)DGD range of PMDPro and 2) maximum SOPMD available with the DGD corresponding to the most recently set continuous DGD/SOPMD pair.	*dgd-max,sopmd-max# Ex. If the most recently set state on a 90 ps PMDPro is 30.37,100.0, this query will return #91.3,xxxx.x, where xxxx.x is the maximum SOPMD available with DGD =30.37.
*PMD:CON *pmd,sopmd#*	Continuous mode PMD control: Calculates closest available DGD and SOPMD values to the ones requested and generates the calculated values. pmd: Requested DGD, in ps. Range: 0-91.04 for 90 ps unit 0.36-182.4 for 180 ps unit sopmd: Requested SOPMD, in ps^2. Range: 0-2079.97 for 90 ps unit 0-8319.9 for 180 ps unit	#E00# if successful. #E06# if one of the requested values is out of range. See Table 2 for other error code definitions.
*PME?	Query PMD generator operational mode	Response: *CON# Continuous PMD trace scan *STP# Step PMD trace scan *ANA# Continuous Mode single-state setup *DGD# DGD lookup table scan *PMD# PMD lookup table scan *DSC# Discrete Mode single-state setup

*PME:SET:PMD *idn#*	Discrete mode PMD control: Set DGD/SOPMD to values corresponding to ID# *idn* Range: 0 to 6560.	*E00# if successful. See Table 2 for other error code definitions. LCD display will update.
PMDE MODE	===PMD Scans===	===========================
*PME:SCN DGD *min,max#*	Discrete mode DGD scan: Scan DGD values in lookup table from start ID value *min* to end ID value *max*. Range for *min* and *max*: 0 to 255; min <max.	*E00# if successful. *E06# if values out of range. See Table 2 for other error code definitions. LCD display will update.
*PME:SCN DGD?	Query DGD scan limits Range Boundaries: Min:0 and Max:255	DGD ID#s of start and end points Example: *84,255#
*PME:SCN PMD#	Discrete mode PMD scan: Scan through all PMD values in lookup table in order of index number (i.e. from 0 to 6560)	*E00# if successful. See Table 2 for other error code definitions. LCD display will update.
*PME:CUR PMD?	Query Current PMD ID during a discrete mode DGD or PMD scan.	*46#
*PME:SCN:SPD *time#*	Set the dwell time per point, in ms, for discrete mode DGD or PMD scan. Range: 1 to 60000	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN SPD?	Query dwell time per point, in ms, for discrete mode DGD or PMD scan.	*346#
*PME:SCN:CYC *cyc#*	Set the number of times (cycles) to run a scan (Discrete scan or continuous/step trace) Range: 1 to 9999	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN CYC?	Query scan cycle number setting	*485#
*PME:SCN:CYC CUR?	Query Current Cycle count.	Number of completed cycles. Example: *85#
*PME:SCN:CON ENA#	Begin Continuous Trace Scan using current settings.	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:CON DIS#	Disable (stop) Continuous Trace Scan	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:STE ENA#	Begin Step Trace Scan using current settings.	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:STE DIS#	Disable (stop) Step Trace Scan	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:DWL *dwell#*	Set dwell time per point for step trace scan. Range: 1 to 9999 ms	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN DWL?	Query the Dwell time, in milliseconds	*234# i.e. 234 ms
*PME:SCN:DIR UPD#	For continuous or step trace scan: Set the Scan Start Direction to UP i.e. Scan from lower DGD limit to upper limit	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:DIR DND#	For continuous or step trace scan: Set the Scan Start Direction to DOWN i.e. Scan from upper DGD limit to lower limit	*E00# if successful. See Table 2 for other error code definitions.

*PME:SCN DIR?	For continuous or step trace scan:
	Query the scan direction.
		Valid: *UPD#: UP-Direction
		    *DND#: DOWN-Direction
		    *END#: Scan done/ not scanning

*PME:SCN:MOD UNI#	For continuous or step trace scan: Set the Scan MODE type to UNI-Directional (one-way scan)	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:MOD BID#	For continuous or step trace scan: Set the Scan MODE type to BI-Directional (round-trip scan) e.g. For direction "UP", one cycle = round trip scan from lower DGD limit to upper limit and back.	*E00# if successful. See Table 2 for other error code definitions.

*PME:SCN MOD?	Query the scan MODE.	*UNI# For UNI-Directional *BID# For BI-Directional See Table 2 for error code definitions.
*PME:SCN STE?	For step trace scan: Query the DGD step size, in picoseconds.	*34.6#
*PME:SCN:STE *step#*	For step trace scan: Set the DGD step size, in picoseconds. Range: 0.1 to 64.3 ps for max. range scan. Maximum step size is limited by range set.	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN RTE?	For continuous trace scan: Query the scan rate. Result given in ps/s	*34.6#
*PME:SCN:RTE *rate#*	For continuous trace scan: Set the SCAN RATE in ps/s Range: 0.1 to 100.0 ps/s	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:CON *dgd#*	For continuous or step trace scan: Set the start DGD. PMDPro will match to DGD value of closest DGD ID# and calculate corresponding trace endpoint. Example: *PME:SCN:CON 14#	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN CON?	For continuous or step trace scan: Query scan start point (DGD) and end point (DGD, SOPMD)	*min-dgd,max-dgd,max-sopmd# e.g. *19.99,52.19,1137.9#
*PME:SCN:MBA *mn,mx#* *PME:SCN:MBB *mn,mx#* *PME:SCN:MBC *mn,mx#* *PME:SCN:MBD *mn,mx#* *PME:SCN:MBE *mn,mx#*	Scan PMD values stored in a memory bank From memory location mn to mx: Range for mn/mx: 0 to 99, mn < mx MBX = Memory Bank X X = A, B, C, D or E	*E00# if successful. See Table 2 for other error code definitions.
*PME:SCN:TYP *bnk,mn,mx*?	Query whether Location Range: *mn* to *mx* of Memory Bank: *bnk* contains only one type (discrete (lookup table) or continuous) of PMD values or a mixture of types.	*MIX#: Range contains both discrete and continuous PMD values *UNI#: Range contains only discrete or only continuous PMD values
*PME:SCN DIS#	Stop Scan (Discrete mode DGD/PMD scan or Memory bank scan)	*E00# if successful. See Table 2 for other error code definitions.
MAXWELLIAN MODE	==**STATISTICAL DGD EMULATION**==	=========================
*PME:MXW ENA #	Start 1st order PMD Maxwellian statistical emulation	*E00# if successful. See Table 2 for other error code definitions.
*PME:MXW DIS#	Stop Maxwellian statistical emulation	*E00# if successful. See Table 2 for other error code definitions.
*PME:MXW:AVE *dgd#*	Set Maxwellian average DGD value, in ps Range: 0 to (Max DGD)/2	*E00# if successful. See Table 2 for other error code definitions.
*PME:MXW AVE?	Query average DGD value setting. Value given in ps.	*20#
*PME:MXW DGD?	Query current DGD ID# during scan	*23#
*PME:MXW:SMP *sample#*	Set number of samples for Maxwellian emulation Range: 1 to 999,999	*E00# if successful. See Table 2 for other error code definitions.
*PME:MXW SMP?	Query sample number setting	*10000#
*PME:MXW:CYC *cyc#*	Set number of cycles to run the Maxwellian emulation Range: 1 to 99,999	*E00# if successful. See Table 2 for other error code definitions.
*PME:MXW CYC?	Query cycle number setting	*1000#*

MAXWELLIAN MODE	==STATISTICAL DGD EMULATION== WITH CORRESPONDING SOPMD	=======================
*PME:EMU ENA#	Start PMD-statistical emulation (1st and 2nd order)	*E00# if successful. See Table 2 for other error code definitions.
*PME:EMU DIS#	Stop PMD-statistical emulation	*E00# if successful. See Table 2 for other error code definitions.
*PME:EMU AVE?	Query average DGD value setting for PMD Emulation. Default: 10.0 ps	*dgd# (Units in ps) Example: *23.5#
*PME:EMU:AVE dgd#	Set PMD-emulation average DGD value Range: 90ps PMDPro = 0.0ps to 30ps 180ps PMDPro = 0.36ps to 60ps	*E00# if successful. See Table 2 for other error code definitions. (Units in ps)
*PME:EMU SMP?	Query number of samples for PMD emulation Range: 1 to 9,999, Default:100	*smp# *100#
*PME:EMU:SMP smp#	Set number of samples for distribution Sample Range: 1 to 9,999	*E00# if successful. See Table 2 for other error code definitions.
*PME:EMU PMD?	Query current DGD and SOPMD values during an emulation run.	*23.5,235,8# (Units in ps and ps²)
*PME:EMU:CYC cyc#	Set number of cycles to run the emulation. Range: 1 to 99,999	*E00# if successful. See Table 2 for other error code definitions.
*PME:EMU CYC?	Query PMD-emulation cycle number setting. Default: 10 cycles	*cyc# Example: *1000#
*PME:EMU:INT int#	Set dwell time per point for emulation. Interval Range: 1 to 99,999 ms	*E00# if successful. See Table 2 for other error code definitions.
*PME:EMU INT?	Query dwell time setting. Default: 100.0 ms. Interval Range: 1 TO 99,999 ms	Example: *1000# (Units in ms)
SOP CONTROL MODE	=============================	=============================
*SOP:RAN ENA#	Begin (enable) random scrambling	*E00# if successful. See Table 2 for other error code definitions.
*SOP:RAN DIS#	Stop (disable) random scrambling	*E00# if successful. See Table 2 for other error code definitions.
*SOP:RAN FRQ?	Query random scrambling frequency setting	*123# Results are in Hz.
*SOP:RAN:FRQ frq#	Set frequency for random scrambling, in Hz Range: 1 to 6000	*E00# if successful. See Table 2 for other error code definitions.
*SOP:TRI FRQ?	Query triangle scrambling frequency setting	*331.1# Results are in Hz.
*SOP:TRI:FRQ frq#	Set frequency for triangle scrambling, in Hz Range: 0.01 to 500.0, default 100.0	*E00# if successful. See Table 2 for other error code definitions.
*SOP:TRI ENA#	Begin (enable) triangle wave scrambling	*E00# if successful. See Table 2 for other error code definitions.
*SOP:TRI DIS#	Stop (disable) triangle wave scrambling	*E00# if successful. See Table 2 for other error code definitions.
*SOP:SSS s1,s2,s3#	Set S1, S2, and S3 Range for S1, S2 and S3: −1.000 to +1.000	*E00# if successful. See Table 2 for other error code definitions.
*SOP SS1?	Query the set value of S1	Return: *0.463# (Example)
*SOP SS2?	Query the set value of S2	Return: *0.123# (Example)
*SOP SS3?	Query the set value of S3	Return: *−0.423# (Example)
*SOP:SSS ENA#	Execute SOP setting. If no Stokes parameters were entered, or if an incorrect set of Stokes parameters was entered, executes setting (1, 0, 0)	*E00# if successful. See Table 2 for other error code definitions.
*SOP:SSS DIS#	Disables active SOP maintenance, returns to Stokes setting screen.	*E00# if successful. See Table 2 for other error code definitions.

*SOP:SPL STA?	Query the special SOP state setting (current or most recently set)	*0# *45# *−45# *90# *RHC# *LHC#
*SOP:SPL 0# *SOP:SPL 45# *SOP:SPL -45# *SOP:SPL 90# *SOP:SPL RHC# *SOP:SPL LHC#	Set SOP to one of 6 special states 0:　　　0° linear 45:　　45° linear 90:　　90° linear −45:　　−45° linear RHC:　Right Hand Circular LHC:　Left Hand Circular	Special SOP polarization control *E00# if successful. See Table 2 for other error code definitions.
*SOP:TRA:SPD *time#*	Set SOP trace scan speed (dwell time per point, in ms) Range: 1 to 60000 Example: *4000# Default Units: ms　Default value: 100	
*SOP:TRA SPD?	Query the trace scanning speed (dwell time)	Ex: *234#　　Default: 100ms
*SOP:TRA STP *stp#*	Set the SOP trace scan step size. Units: degrees Default: 1 Range: 0.0 to 99.9	*E00# if successful. See Table 2 for other error code definitions.
*SOP:TRA STP?	Query the SOP trace scan step size setting	Ex. *99.9#
*SOP:TRA STA?	Query the SOP trace scan axis setting	*0# *45# *-45# *90# *S3=0# *ALL#
*SOP:TRA 0# *SOP:TRA 45# *SOP:TRA -45# *SOP:TRA 90# *SOP:TRA S3=0# *SOP:TRA ALL#	Set trace scan axis. 0° 45° −45° 90° S3=0: Trace equator of Poincaré sphere All: Perform all 5 traces sequentially	Set the trace scan axis *E00# if successful See Table 2 for other error code definitions.
WAVEFORM MODE	=============================	=============================
*SOP:MPC ENA#	Begin (enable) waveform generation with current settings on all channels	*E00# if successful. See Table 2 for other error code definitions
*SOP:MPC DIS#	Stop (disable) waveform generation.	*E00# if successful. See Table 2 for other error code definitions
*SOP:CHx AMP?	Query Channel x Amplitude setting x: 1 to 4 Amplitude range 0V to 150V. Default: CH1=30V, others 0V	Sample: *SOP:CH1 AMP? Response: *23.5#　(Units in Volts)
*SOP:CHx FRQ?	Query Channel x Frequency setting x: 1 to 4 Frequency range 0 Hz to 120Hz Default: CH1=10Hz,　others 0Hz	Sample: *SOP:CH1 FRQ? Response: *12.6#　(Units in Hz)

*SOP:CHx MOD?	Query Channel x waveform type setting x: 1 to 4; Waveforms: SIN=sine SQU=square TRI=triangle Default: Sine (all channels).	Possible Responses: *SIN# *SQU# *TRI#
*SOP:CHx:AMP *amp*#	Set Channel x Amplitude to value *amp* Volts x: 1 to 4 Range for *amp*: 0 to 150.0	*E00# if successful. See Table 2 for other error code definitions
*SOP:CHx:FRQ *frq*#	Set Channel x Frequency to value *frq* Hz x: 1 to 4 Range for *frq*: 0 to 120 Hz	*E00# if successful. See Table 2 for other error code definitions
*SOP:CHx SIN#	Set Channel x to Sine Wave Mode x: 1 to 4	*E00# if successful. See Table 2 for other error code definitions
*SOP:CHx SQU#	Set Channel x to Square Wave Mode x: 1 to 4	*E00# if successful. See Table 2 for other error code definitions
*SOP:CHx TRI#	Set Channel x to Triangle Wave Mode x: 1 to 4	*E00# if successful. See Table 2 for other error code definitions
WSOP MODE	=========================	=============================
*WSP SOP#	Enable worst case input SOP alignment based on equal power split between DGD axes. **Valid in discrete PMD mode only, for PMD ID# in range 0 to 255.**	*E00# if successful. See Table 2 for other error code definitions.
*WSP DOP#	Enable worst case input SOP alignment based on minimum output DOP. Valid for any PMD setting. **PMD setting used is the most recently set discrete or continuous PMD value.**	*E00# if successful. See Table 2 for other error code definitions.
*WSP DIS#	Stop (disable) automatic worst-case SOP control	*E00# if successful. See Table 2 for other error code definitions.
MONITOR MODE	===============================	=============================
*MON PMD?	Query current or most recent PMD setting. Units: DGD: ps, 2nd order PMD: ps^2	Return: *$dgd,sopmd$# Example: *63.06,314.3# If not in PMD mode, will return the last PMD value set.
*MON POW?	Query output power Default Units: dBm	Example: *–6.7#
*MON:DOP INP?	Query input DOP value, in %.	Ex: *98.6#
*MON:DOP OUT?	Query output DOP value, in %.	Ex: *18.4#
*MON:SOP INP?	Query input SOP value. Returns the values of S1, S2 and S3 from the input polarimeter	*S1 -0.60,S2 0.60,S3 0.53#
*MON:SOP OUT?	Query output SOP value Returns the values of S1, S2 and S3 from the output polarimeter	*S1 -0.60,S2 0.60,S3 0.53#
MANUAL MODE		
*CV1 x.x# *CV2 x.x# *CV3 x.x# *CV4 x.x# *CV5 x.x# *CV6 x.x#	Set control voltages for single channels of the polarization controller. Using these commands will put the PMDPro into manual mode, if it is not in that mode already, and set the voltage of the indicated channel to the specified value. Range of x.x: 0-150.0 Volts	*E00# if successful See Table 2 for other error code definitions.

*CV1? *CV2? *CV3? *CV4? *CV5? *CV6?	Query the voltage of indicated channel. Range: 0-150.0 Volts	Example: *123.45# indicates that the control voltage is 123.45V for the queried channel.
PMDC MODE	=======================	=========================
*PMC STA?	Query PMDC operational status	*END#: PMDC search complete *RUN#: PMDC is still running
*PMC:DGD OPT#	Scan available DGD values and optimize polarization to maximize output DOP. Scans through DGD index values 0-255.	*E00# if successful See Table 2 for other error code definitions.
*PMC:PMD OPT#	Scan available PMD values and optimize polarization to maximize output DOP. Scans through PMD index values 0-6560.	*E00# if successful See Table 2 for other error code definitions.
*PMC:DGD:CMP *idn*#	Optimize SOP to maximize output DOP at specified DGD value (PMD ID# *idn*) Range: 0-255 Ex: *PMC:DGD:CMP 16#	*E00# if successful See Table 2 for other error code definitions.
*PMC:PMD:CMP *idn*#	Optimize SOP to maximize output DOP at specified PMD value (PMD ID# *idn*) Range: 0 to 6560 Ex: *PMC:PMD:CMP 683#	*E00# if successful See Table 2 for other error code definitions.
*PMC CMP#	Optimize SOP to maximize output DOP at current PMD setting (discrete or continuous)	*E00# if successful See Table 2 for other error code definitions.
MEMORY MODE	=======================	=========================
*SAV:DSC:MB*X loc,id* #	**Discrete mode PMD sequence storage:** Store PMD ID#: *id* to memory location: *loc*, in memory Bank X. Range for loc: 0 to 99 Range for id: 0 to 6560 Range for X: A, B, C, D, or E	Example: *SAV:DSC:MBE 02,36# Save PMD ID#:36 to memory location 02 in Bank E
*SAV:CON:MB*X loc,dgd,so*#	**Continuous mode PMD sequence storage:** Store DGD value *dgd* (in ps) and SOPMD value *so* (in ps^2) to memory location *loc* in memory Bank X Range for loc: 0 to 99 Range for X: A, B, C, D, or E	Example: *SAV:CON:MBA 2,5.90,205.0# Save DGD 5.90ps, SOPMD 205.0ps² to memory location 2 in Bank A.
*REC:MB*X loc*#	Recall and generate PMD values stored at memory location *loc* in memory bank X. If value stored is a continuous setting (dgd, sopmd), the PMDPro will recall the stored values, calculate the closest available match, and generate the calculated values. Range for loc: 0 to 99 Range for X: A, B, C, D, or E	Ex: *REC:MBC 32# Recall PMD stored at location 32 in Memory Bank C and set PMDPro to that value.
*REC:MB*X loc*?	Query PMD values (continuous) or ID# (discrete) stored at memory location *loc* in memory bank X. Will not set PMDPro to recalled PMD value. Range for loc: 0 to 99 Range for X: A, B, C, D, or E	Continuous: *CON,dgd,sopmd# Example: *CON,25.5,180.0# Discrete: *DIS,id# Example: *DIS,19#

*SAV:PMC *loc#*	Store the most recent PMDC Search result to PMDC memory location *loc*. Range for loc: 0 to 99	Ex: *SAV:PMC 14#
*REC:PMC *loc#*	Recall the stored PMDC Search result from PMDC memory location *loc* and set PMDPro to the recalled setting. Range for loc: 0 to 99	*E00# if successful. *E12# if location is empty or contains invalid data. See Table 2 for other error code definitions.
SETUP MODE	========================	========================
*CHA?	Query ITU grid channel number setting. See Appendix A for wavelength/frequency correspondence. L Band Range: L001 to L130 C Band Range: C001 to C087	Example : *L112# or *C012#
*CHL nnn# Set L-BAND *CHC nnn# Set C-BAND	Set wavelength/frequency channel setting using ITU grid index#- see Appendix A L Band Range: L001 to L130 C Band Range: C001 to C087	*E00# if successful. See Table 2 for other error code definitions. Available range depends on PMDPro configuration ordered.
*ADR *adr#*	Set GPIB address Range: 1 to 30	*E00# if successful. See Table 2 for other error code definitions. Example: *ADR 5#
*ADR?	Query GPIB address	Return : *30#
Set Ethernet Mode and Query IP Address	**Note: This set of commands must be sent from RS-232 only**	
~7DHCP#	Set instrument to dynamic IP mode	OK
~6STIP#	Set instrument to static IP mode	OK
~8IP?#	Request IP address (Note: Returns either dynamic or static IP address, depending on which mode is active.)	(IP Address will be returned)

Table 2 Error Code Definitions

E00	No error (Correctly formatted command received)
E01	Undefined Command
E06	Parameter outside the allowed range
E07	String of characters too long(>buffer limit)
E08	Input power too high
E09	Input power too low
E10	Option Not Supported when in Continuous Mode
E11	ID# out of range
E12	Memory data location is empty or stored data is invalid
E13	Option Not Supported when in Discrete Mode
E50	Invalid Stokes parameter values Sum of squares of Stokes values $\neq 1$

Section 5. Applications:

This section includes brief descriptions of several application examples for a polarization optimized PMD source.

5.1 PMD Tolerance Testing with Polarization Multiplexed Signals

For polarization multiplexed signals, the measured DOP at the input and output of the PMDPro are not accurate indicators of the PMD effect on the signal. Therefore, the functions that depend on them, including the WSOP and PMDC functions, should not be used with polarization multiplexed signals.

However, the polarization controller's scrambling function can be used in conjunction with the basic PMD generation function to perform PMD tolerance testing with polarization multiplexed signals.

Front Panel Control:

1. Set the PMD value:
   Press the PMDE button to bring up the PMD generation menu.
   Select either option 1 (SET DISCRETE PMD) or option 2 (SET CONTINUOUS PMD).

2. For discrete mode, use the arrow buttons to select the index number corresponding to the desired DGD/SOPMD pair. The DGD/SOPMD values will be updated in real time as the index numbers are changed.

```
SET PMD   ID#:        _ _ _1
0.36 ps               0.0 ps2
```

The continuous mode edit screen is shown below:

```
DGD:          _ 0.00 < 91.04
SOPMD:      _ _ _ 0.0 < 0.0
```

For both DGD and SOPMD, the number to the left of the "<" symbol is the value set by the user. The number on the right is the maximum available value. The maximum available DGD value is determined by whether the PMDPro is a 90 ps or 180 ps unit. The maximum available SOPMD value is determined by the DGD value the user selects. As the user changes the requested DGD value, the maximum available SOPMD value will change accordingly.
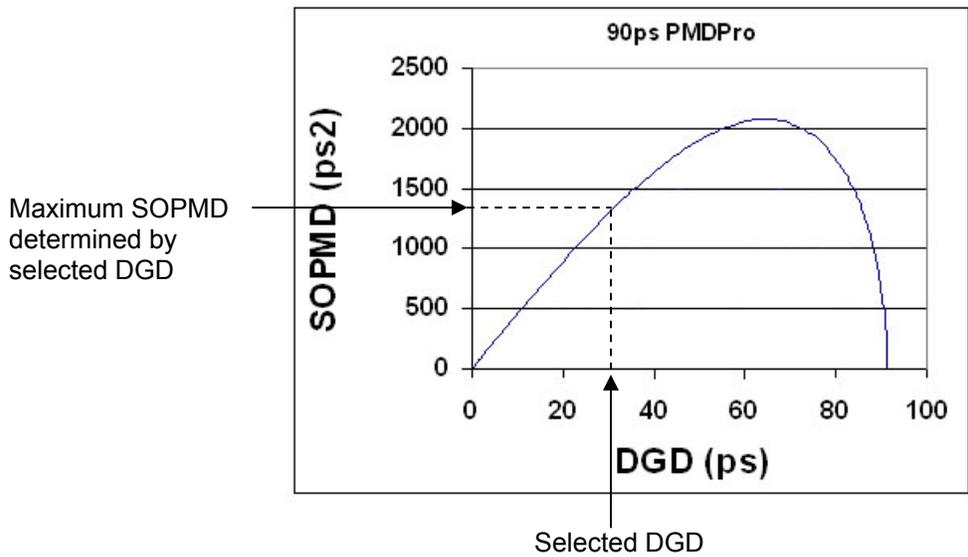
Figure 28 DGD/SOPMD range determinants for continuous control

Use the left and right arrow keys to move the cursor and the up and down arrow keys to increment the digits to set the DGD and SOPMD values to be matched. Note that the left and right arrow keys will scroll through all modifiable cursor positions. For example, pressing the right arrow key from the rightmost digit of the DGD setting line will move the cursor to the leftmost position of the SOPMD setting line

When the DGD and SOPMD values are set, press the ENTER key to calculate the closest available matches to the requested values. If the requested SOPMD is out of range, the PMDPro will flash an "SOPMD out of range" error message before returning to the PMD selection screen. If the selected values are within range, the LCD will display

```
DGD:            31.04 C 31.10
SOPMD:        _ 530.0 C 530.0
```

where the number to the right of the "C" on each line is now the calculated match to the requested value. At this point, the PMDPro has not yet changed the output DGD or SOPMD values; it has only displayed the results of the match calculation.

If the user is satisfied with the matched values, he can press the ENTER key again to execute the setting and change the output DGD and SOPMD to the calculated values. The LCD will display:

```
DGD:           31.04 E 31.10
SOPMD:      _ 530.0 E 530.0
```

where the "E" indicates that the calculated values have been enabled. From either the calculation or execution screens, the left arrow key can be used to return to the setting mode (the "C" or "E" will change back to the "<" symbol) and change the requested DGD and SOPMD values.

3. Press the SOP button to bring up the polarization control options.
    Select the SCRAMBLING option.
    Select TRIANGLE SCRAMBLE. The following screen will come up. The bottom line displays the current DGD and SOPMD value setting.

```
TRI SCRM    FR: 100.0Hz
10.71 ps    0.0 ps2
```

Select the desired scrambling frequency using the arrow buttons. The frequency range is 0.01-500 Hz. After the frequency is set, press the ENTER button to begin scrambling. The cursor will move to the bottom right of the screen while scrambling is enabled. Pressing the left arrow key will disable the scrambling and move the cursor back to frequency selection.

Control Program:

The setup process using the control program is similar to that using the front panel. See the remote control section for details on program installation and hardware setup. After running the program, the user can set the PMD value either using the discrete lookup table or using the quasi-continuous PMD control function.

Discrete control using lookup table:

1. Click the PMDE button on the left function panel to bring up the main PMDE interface:

---
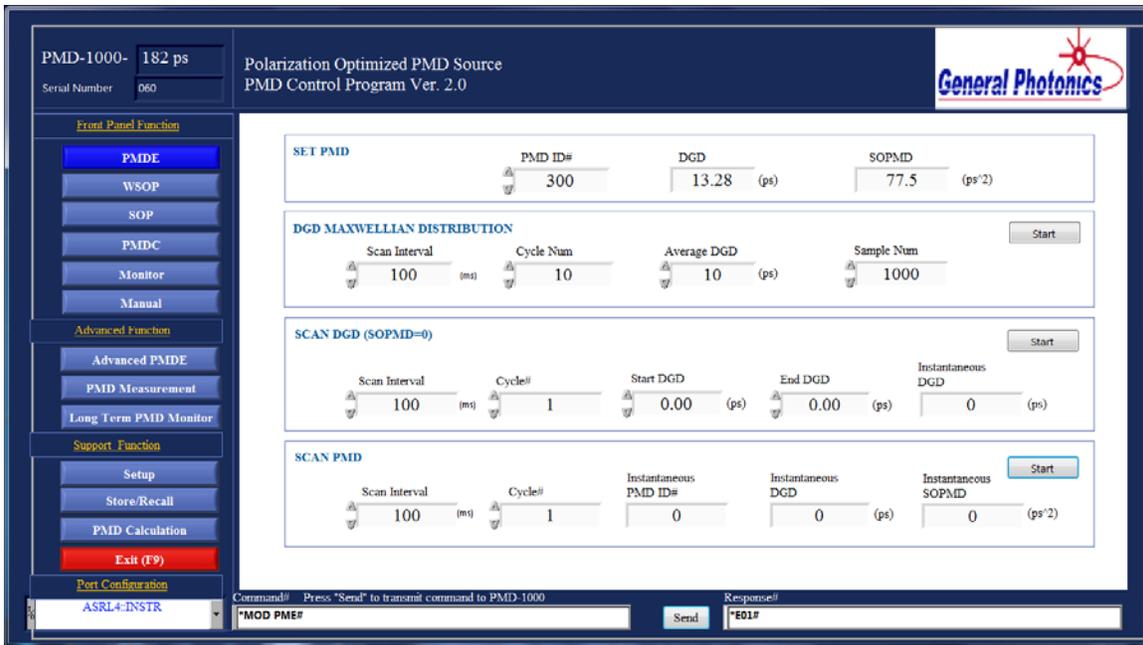
2. Set the PMD ID# in the top block of the interface screen. The corresponding DGD and SOPMD values will be displayed as the index number is updated, and the output PMD updates in real time.

3. Click the SOP button on the left function panel to bring up the polarization control interface screen:
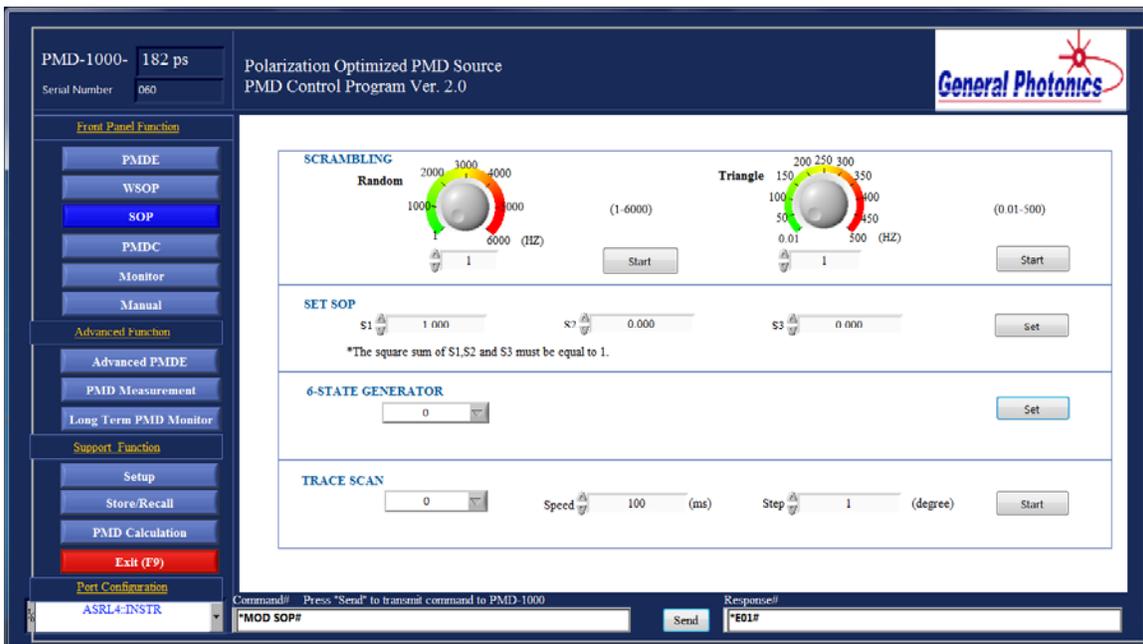
4. Select a frequency in the triangle scrambling section at the top left of the screen and click the "Start" button to begin scrambling.

Quasi-continuous PMD setting:

1. Click the Advanced PMDE button on the left function panel to bring up the advanced-function PMDE interface.

2. Click the "Continuous PMD + Polarization Control" tab.
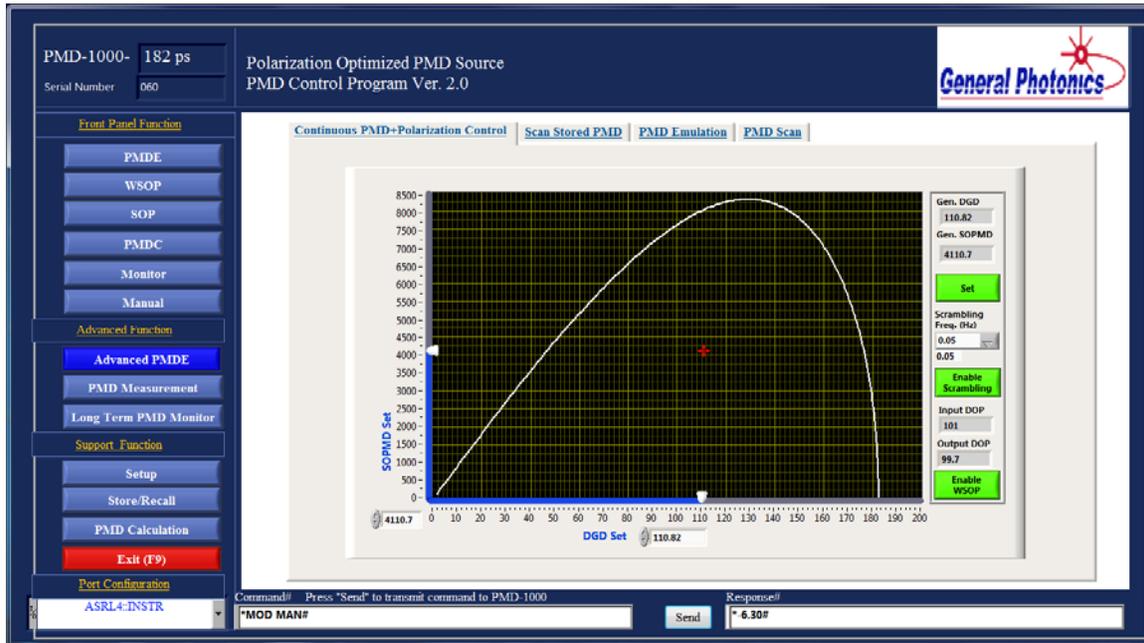
3. Set the DGD and SOPMD values by dragging the sliders, by entering the desired values in the value selection boxes under the plot axes and then clicking the mouse outside the text boxes, or by dragging the red cursor within the plot area. Click the "Set" button on the right of the screen to set the DGD/SOPMD values. The DGD and SOPMD indicator boxes on the right of the screen will display the closest available values to those selected.

4. Select the continuous SOP scrambling frequency by either selecting a value from the pull-down menu or typing a value in the box under the pull-down menu and clicking elsewhere on the screen. Then, click "Enable Scrambling".

5.2. PMD Mitigation in 40Gb/s systems

As the bit rate of fiber optic communication systems increases from 10 Gbps to 40Gbps, 100 Gbps, and beyond, polarization mode dispersion (PMD) has more and more impact on system performance. PMD generally causes the two principal polarization components of a light signal to travel at different speeds and hence spreads the bit-width of the signal, as shown in Figure 29A. Consequently, it causes an increase in bit-error rate (BER) and service outage probability. Unlike other system impairments, such as chromatic dispersion (CD), the PMD effect on the system is random in nature and changes rapidly with time, making it difficult to mitigate.
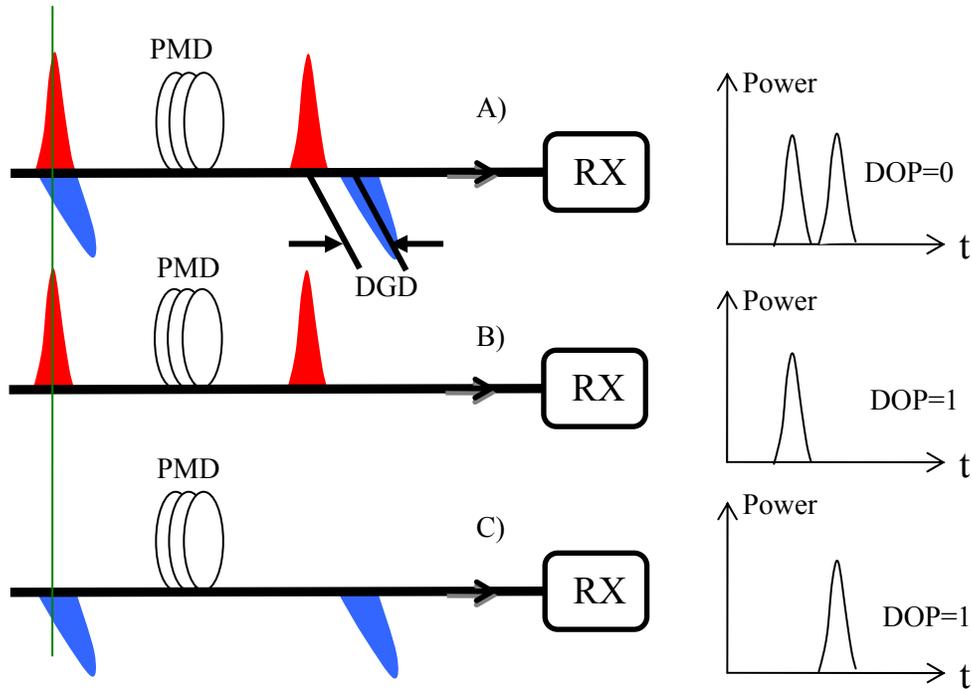
Figure 29 Illustrations of the PMD effect on an optical signal.
A) The SOP of the input signal is aligned 45 degrees from the PSP of the fiber link, causing the worst-case signal distortion. In this case, if the DGD is larger than the width of one bit, then the DOP=0 because the two orthogonal polarization components have the same power, with no phase relationship.
B) and C) The SOP of the input signal is aligned with the slow or fast PSP axis, respectively. In these cases, no signal distortion occurs except the slight late or early arrival, respectively, of the pulse. The DOP of the signal remains at 1. In all 3 cases, the PMD of the link remains the same, but the effect on the signal is different due to the different input polarization states.

Several methods with varying success rates exist to mitigate PMD effects for 40G deployment. The first is to select fiber routes with low PMD coefficients. Such a method requires extensive survey of all available fiber routes to identify and cherry-pick those with sufficiently low PMD. However, such an approach has three potential drawbacks: First, the PMD of a fiber route changes with time as the environmental conditions around the fiber change. Such changes can include land movements caused by earthquake, flood, or mud-slides. A route that is good today may become bad in the future. Second, interconnected fiber routes may always have bad fiber sections with high PMD, rendering the selection of low PMD fiber routes throughout the system impractical. Finally, the supply of fiber routes with low PMD values will eventually be exhausted as 40G deployments increase.

The second method is to use bandwidth-efficient modulation formats, such as DPSK or DQPSK. Such modulation formats reduce the effective bandwidth of a 40Gb/s channel to that of a 20Gb/s or even a 10Gb/s channel. Consequently, the impact of PMD on the signal is greatly reduced, though never eliminated.

The third approach is electronic PMD compensation, in which forward error correction (FEC) or other algorithms are used to reduce the PMD effect on the signal after the

optical signal is converted into an electrical signal. However, because the electrical signal does not contain the phase information of the corresponding optical signal, the resulting PMD effect reduction is limited.

Optical PMD compensation is another attractive approach. An optical PMD compensator generally contains one or more polarization controllers, a PMD generation device, a PMD monitoring device, and a microprocessor based circuit, as shown in Figure 30. The circuit receives an error signal from the PMD monitoring device and instructs the PMD generation device to adjust the PMD values and the polarization controller to adjust the polarization state input to the PMD generation device to minimize the error signal from the PMD monitoring device. The PMD is compensated when the PMD generated by the PMD generating device is the same in value as that of the fiber link, but with its slow axis aligned with the fast axis of the fiber link.
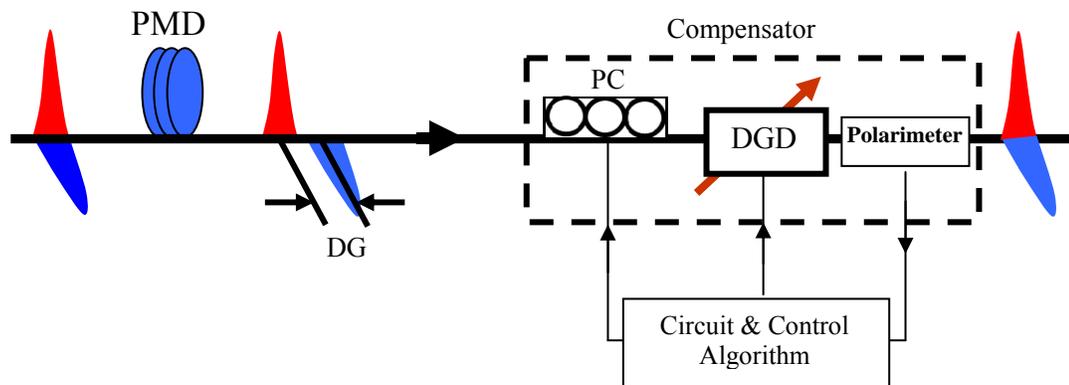
Figure 30 Optical PMD compensation. The DOP measured by the polarimeter is used as PMD effect indicator.

The final approach is polarization multiplexed coherent detection. Because the detected electrical signals in this approach contain all of the amplitude, phase, and polarization information of the corresponding optical signal, any optical signal impairments, including PMD, can be compensated by digital signal processing. In addition, because of the quadrupled spectrum efficiency resulting from QPSK modulation and polarization multiplexing, the effective optical signal bandwidth of a 40G channel is about the same as that of a 10G TDM channel. Consequently, the PMD effect on such a narrow band signal is also greatly reduced even without PMD compensation. Although transceivers incorporating polarization multiplexed coherent detection may still not be cost-effective compared with other approaches for 40Gb/s transmission, they are most attractive for 100Gb/s and higher speed transmissions.

5.3 Instruments required for PMD related tests

PMD source for PMD tolerance test

No matter which approach is taken, it is desirable to have an instrument capable of testing the performance of different methods in mitigating PMD effects. This test is called a PMD tolerance test. The general setup is shown in Figure 31A. The key instrument in this setup is the PMD source, which can generate precise 1st and higher order PMD values. The bit-error rate (BER) of the system, or another such performance indicator, is measured as the 1st order PMD (DGD) values generated by the PMD source are gradually increased until the BER reaches the limit set for the system, as shown in Figure 31B. The corresponding DGD is the 1st order PMD tolerance of the system. Both the 1st and 2nd order PMD (SOPMD) values can also be increased as the BER of the system is measured and plotted, as shown in Figure 31C. The system outage probability can be calculated from the data obtained.
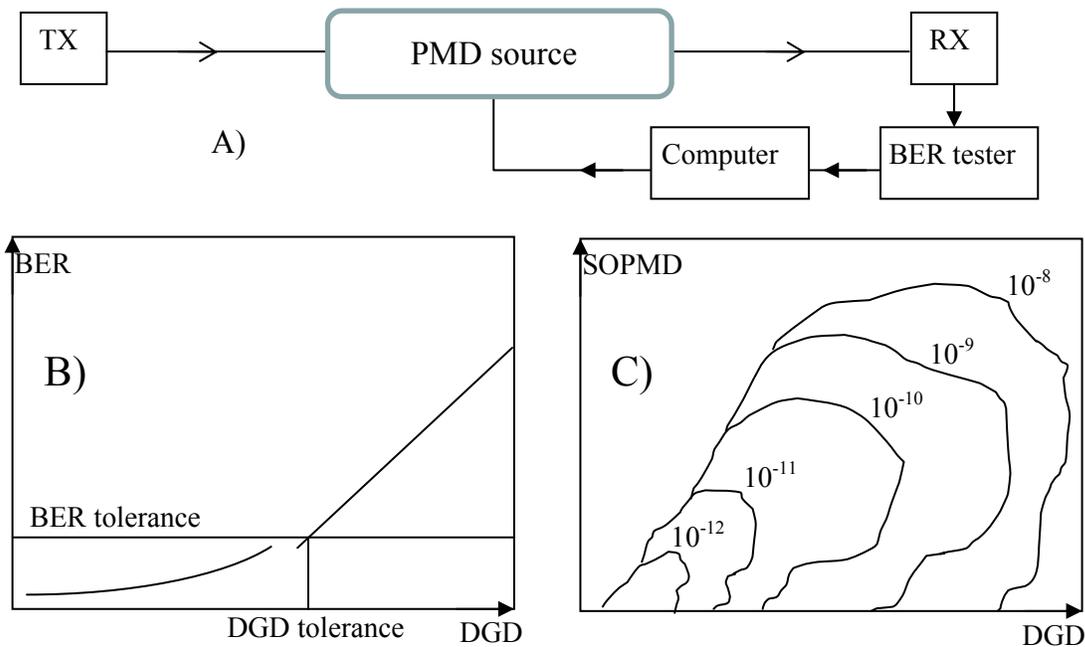
Figure 31 A) PMD tolerance test setup using a PMD source. The computer selects PMD settings and collects BER readings. B) BER vs. DGD curve. The DGD tolerance of the system for a given BER threshold can be deduced using the curve. C) Map of BER vs. DGD and SOPMD. Each contour represents a BER value. The PMD tolerance can be obtained from the contour plot.

PMD tolerance test results can be used by network operators to compare systems made by different vendors and to verify the PMD related specifications promised by the vendors. They can also be used by system vendors to 1) determine which PMD mitigation approach is most suitable to adopt, 2) to fine tune the PMD mitigation related parameters in the transceivers during system development, and 3) to perform output quality control of the final system, including transceivers, for the PMD related specifications.

Importance of polarization optimization: The PMD effect on a system is highly polarization dependent. When the input state of polarization (SOP) is aligned or counter-aligned with the principal state of polarization (PSP) of the fiber link or the PMD source, the PMD has no effect on the signal, and therefore no effect on system performance, as shown in Figure 29. By contrast, when the input SOP is aligned 45 degrees from the PSP of the fiber link or PMD source, the PMD has its maximum effect on the transmitted optical signal, and hence its worst-case effect on system performance. The effect of PMD on data can be characterized by the degree of polarization (DOP) of the optical signal, because PMD causes depolarization of the optical signal, as shown in Figure 29: the smaller the DOP, the larger the PMD effect. In general, the DOP of the signal passing through a medium with nonzero 1st order PMD can be expressed as:

$$DOP(\tau) = \sqrt{4(\gamma^2 - \gamma)[1 - R^2(\tau)/R^2(0)] + 1} \qquad (1)$$

where τ is the DGD value of the medium, γ is the power distribution ratio of the two polarization components with respect to the principal state of polarization (PSP) of the DGD element ($\gamma = \frac{1}{2}$ when the powers of the two polarization components are equal or when the input SOP to the medium is oriented 45 degrees from its PSP) and $R(\tau)$ is the self-correlation function of the optical signal, which decreases as τ increases. Clearly, the DOP reaches a minimum value of $R(\tau)/R(0)$ when $\gamma = \frac{1}{2}$ or when the input SOP is 45 degrees from the PSP of the DGD medium. At this SOP, the PMD has its worst effect on the quality of the signal. Conversely, when $\gamma = 1$ or when the input SOP is aligned with the PSP, the DOP remains at its maximum value of 1, regardless of the DGD value.

When higher order PMD is present, the PSP is different for different wavelength components of the signal and Eq. (1) may no longer hold. Nevertheless, there always exists an input SOP at which the PMD has its most severe impact on the quality of the signal, and at which the DOP of the signal at the output end is therefore at a minimum. There also exists an input SOP at which the PMD has the least effect on the quality of the signal, and at which the output DOP may therefore be much higher.

PMD source for PMD compensator evaluation

A PMD source is also necessary to evaluate the performance of a PMD compensator, whether optical or electrical, as shown in Figure 32. PMD compensator evaluation can include several types of tests. First, the system improvement margin at different PMD settings can be determined. Second, the PMD compensation range of the compensator can be determined by gradually increasing the input PMD while measuring the BER of the fiber link. 3) Third, the PMD compensator's PMD recovery time can be determined by performing a step PMD change and monitoring the PMD compensator's response. Finally, the PMD compensator's SOP recovery time at different PMD settings can be determined by changing the SOP rapidly at each PMD setting and monitoring the PMD compensator's response. Therefore, a PMD source with fast PMD variation and fast polarization control capabilities is attractive for PMD compensator evaluation.
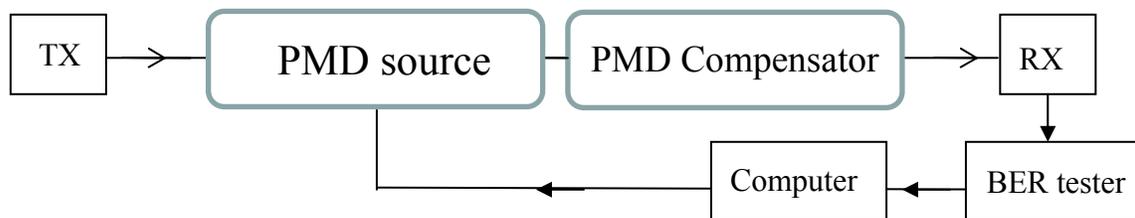
Figure 32 PMD compensator evaluation setup schematic. For electrical compensation, the compensator may be inside the receiver (RX). The plots shown in Figure 31 can be generated here with PMD compensation at different PMD settings of the PMD source.

PMD analyzer or monitor for link PMD determination

The PMD values of fiber routes generally must be measured before link deployment. This requires PMD analyzers. In general, a PMD analyzer requires a large-bandwidth light source, whether it is tunable-laser-based or broadband-source-based. As mentioned previously, the PMD of fiber routes may change with time due to changes in environmental conditions. For a ROADM network, once the fibers are lit, the wavelength channel for each transceiver pair is determined and is confined within a 50GHz bandwidth. Therefore, PMD analyzers requiring broadband light sources cannot be used to characterize such a system. In addition, it is undesirable to disconnect the transceivers and insert a PMD analyzer into the link, because this would cause a severe service interruption. It is therefore attractive to be able to determine the PMD value of an in-service link while both the transmitter and receiver are operational. This capability is important for the diagnosis of fiber routes with performance issues.

5.4 Desirable features for a PMD source

High repeatability and rapid generation of 1st and higher order PMD values are desirable in a PMD source because they enable fast, repeatable PMD tolerance tests and PMD compensator evaluation.

Automatic optimization of input SOP is also highly advantageous. As described previously, PMD tolerance tests can be greatly simplified if the input SOP to the PMD elements inside a PMD source can be controlled and optimized such that each PMD value has the most severe possible impact on the quality of the optical signal, regardless of polarization changes caused by disturbances to the fiber link. Specifically, the input SOP can be automatically maintained at an alignment of 45 degrees from the PSP of the PMD source, or the output DOP can be automatically maintained at a minimum value by actively controlling the input SOP.

PMD compensation is also an extremely attractive function. First, system vendors and network operators need to know how much improvement can be made in system performance by adding PMD compensation in order to decide whether to deploy PMD compensators on a link with performance issues. Second, if PMD compensation significantly improves the system performance, it can be determined that PMD is the major cause of performance degradation; otherwise, other impairments should be considered. Therefore, a PMD source with PMD compensation capability can be used for the diagnosis of system problems. Finally, optimized PMD compensation can help to determine the PMD values of the fiber link, because the PMD value used for optimal PMD compensation is close to the real PMD value of the fiber link. Such a feature is attractive for frequent PMD monitoring of an in-service fiber link, a task that cannot be accomplished with PMD analyzers currently on the market.

5.5 The polarization optimized PMD source

The PMDPro meets all of the requirements described above. It is constructed with a polarization controller (PC), a polarimeter at the input end, a PMD generator, a second polarimeter at the output end, and a digital signal processor (DSP) based electronic circuit, as shown in Figure 33. The two polarimeters are used to provide feedback signals to the DSP circuit for full polarization optimization. The circuit receives the polarization measurements from the two polarimeters, processes them, then sends commands to control the PMD generator and the polarization controller. The circuit can use the SOP information from the input polarimeter as the feedback to control the PC and generate any SOP the user prefers. In particular, it can automatically align the SOP to 45 degrees from the PSP of the PMD generator. This polarization state causes the PMD generator to cause the worst-case 1st order PMD (DGD) effect on the optical signal at any DGD setting, and is therefore the preferred SOP for DGD tolerance tests for transceivers and fiber systems. Alternatively, the circuit can use the DOP information from the output polarimeter as the feedback to control the PC. The input SOP that minimizes the output DOP causes the PMD generator to have the worst-case total PMD effect on the optical signal, and is therefore the optimal polarization state for total PMD tolerance tests of

---

transceivers and fiber systems. Finally, the optimized input SOP obtained by maximizing the DOP from the second polarimeter enables PMD compensation.
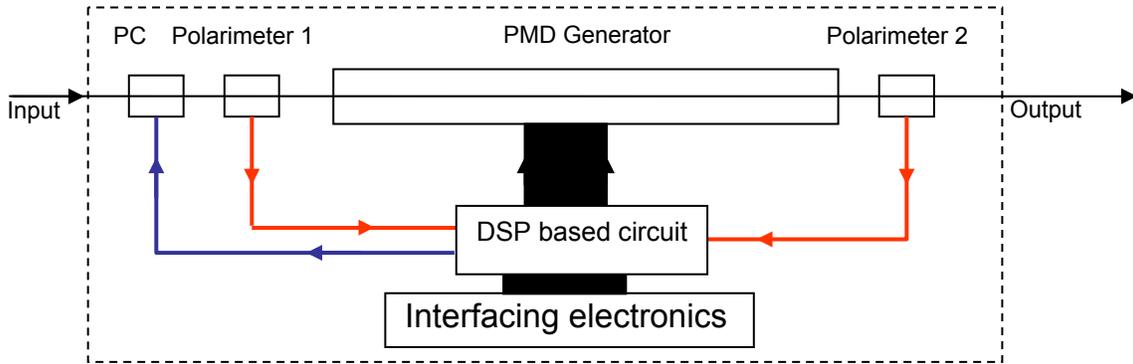
Figure 33 System diagram of polarization optimized PMD source. The DSP based circuit is used to 1) process information from the polarimeters and control instructions from users, 2) instruct the PMD generator to select desired PMD values, 3) control the PC to optimize the input SOP for various functions.

The PMD generator used in the PMDPro is based on General Photonics' patent pending ternary polarization rotation technology. The generator is constructed using a series of birefrigent crystals, with a ternary polarization rotator sandwiched between each pair of adjacent crystal segments, as shown in Figure 34. The crystals are arranged in descending order, with lengths decreasing sequentially by a factor of 2. Each rotator is capable of rotating the state of polarization (SOP) by +45, 0, or −45 degrees.
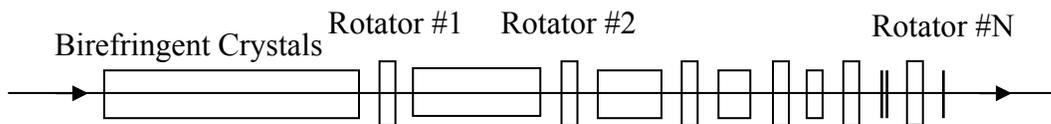
Figure 34 The construction of a PMD generator made with birefringent crystals and ternary polarization rotators which can rotate SOP in 3 ways.

When the rotator between two adjacent crystals rotates the SOP +45°, the optical axes of the two crystals are aligned to produce the maximum combined DGD. When the rotator between two adjacent crystals rotates the SOP −45°, the optical axes of the two crystals are counter-aligned to produce the minimum combined DGD. When the rotator between two adjacent crystals rotates the SOP 0° (no rotation), the optical axes of the two crystals

---

are aligned 45° from each other, producing higher order PMD. This higher order PMD generation capability is not available in previous DGD generator designs in which the polarization rotators can only generate ± 45°. polarization rotations. The 0 degree polarization rotation is essential for the generation of higher order PMD.

The total number of PMD values that can be generated with N+1 sections of birefringent material and N rotator pairs is 3^N. For N=8, the total number of PMD states is 6561. The total number of DGD-only (1st order PMD) states is 2^N. For N=8, the total number of DGD-only states is 256.

Unlike the analog crystal rotators used in other PMD source designs, which suffer from slow speed and low repeatability, the digital ternary operation method of this PMD source makes PMD generation fast and highly repeatable.

In addition to the digital ternary rotators described above, the PMDPro uses a quasi-continuous rotator to achieve independent DGD and SOPMD control, allowing it to uniformly cover the PMD space, as shown in Figure 35. Note that the SOPMD values generated using this method are wavelength independent, so there are no FSR issues.
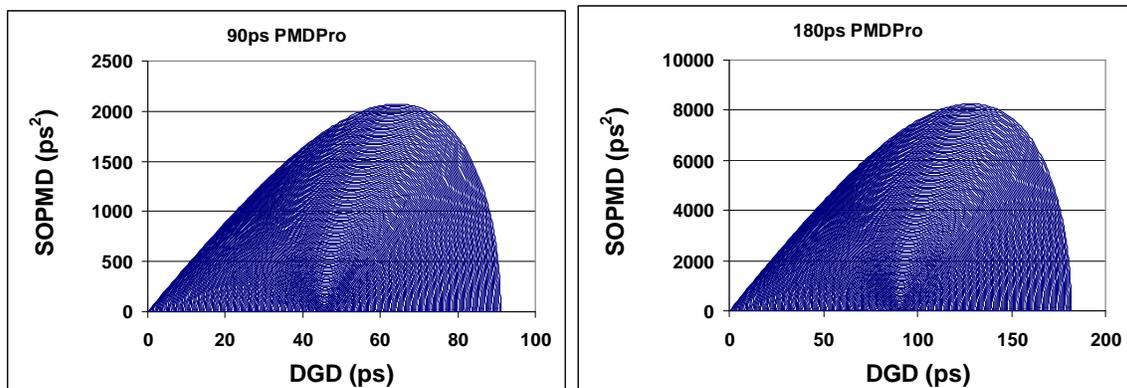
Figure 35 DGD and wavelength independent SOPMD range

A) 90 ps PMDPro™   B) 180 ps PMDPro™

5.6 Advantages and applications of the polarization optimized PMD source

The polarization optimized PMD source, constructed with digital ternary polarization rotators, offers the following attractive features for PMD related testing:

1) High precision, high repeatability PMD generation, resulting from the highly repeatable rotation angles of each ternary rotator. In its discrete digital control mode, the PMD source can generate a total of 6561 different PMD states, of which 256 are DGD-only, 1024 have DGD and wavelength independent SOPMD, and the rest are wavelength dependent PMD. In its quasi-continuous operation mode, it can generate states with independently controllable DGD and wavelength independent SOPMD values. Users can select individual PMD states or scan sequences of PMD states at user defined time intervals.

2) High PMD generation speed (minimum time interval around 1 ms), resulting from the high speed switching of the ternary polarization rotators. This high speed operation can speed up PMD tolerance tests and can be used to test the response time of a PMD compensator against sudden PMD changes.

3) Automatic optimization of input polarization for worst-case 1st order and 2nd order PMD tolerance tests, regardless of rapid polarization changes before the input to the PMD source. The polarization optimization eliminates test uncertainties and significantly reduces the time required to complete tests. It is, therefore, ideal for PMD tolerance tests for transceiver production lines, as shown in Figure 31.

4) PMD compensation using either an automatically optimized PMD value or a user selected PMD value. The PMD compensation is accomplished by maximizing the DOP detected by the polarimeter at the output port. Both PMD and DOP values will be shown on the front panel LCD display. By stepping the PMD values up and down and looking at the maximized DOP values, the user can directly see how the PMD value chosen affects PMD compensation. When optimized PMD mode is selected, the instrument will go through all PMD states and search for the maximum DOP. The PMD state with the maximum DOP is selected as the optimized PMD for PMD compensation.

5) PMD value determination of an in-service fiber link. The optimized PMD compensation mode can be used to determine the PMD in the link, as shown in Figure 36, because the optimized PMD value for compensation should be close to the PMD value of the fiber link. Therefore, the PMD value of a fiber link can be determined by simply inserting a polarization optimized PMD source in the light path and enabling the PMD compensation function. The optimized PMD value identified by the instrument is then the PMD value of the link. It may also be necessary to characterize the PMD of a particular channel route in an in-service ROADM network to determine its feasibility for 40G operation before installing 40G transmitters and receivers. In such a situation, an ASE source can be placed at the transmitter end and a polarization optimized PMD source at the receiver end to perform PMD compensation. The optimized PMD value identified by the PMD source is then the PMD value of the fiber route. With this information, it is possible to decide whether the route is suitable for 40G transmission and whether

a PMD compensator is required. An EDFA may be used before the PMD source to boost the signal level.
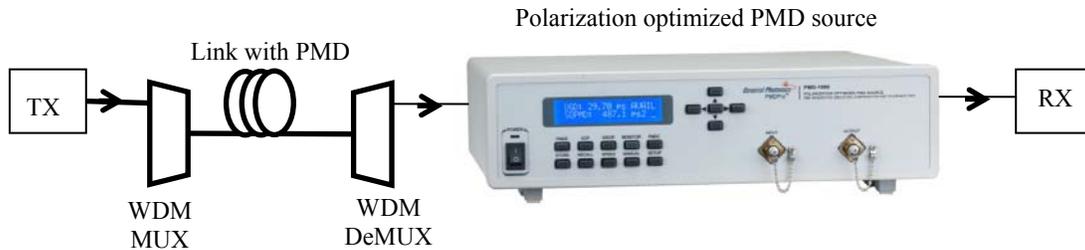
Figure 36 Polarization optimized PMD source in an in-service WDM link for the determination of its PMD and diagnosis of performance issues.

6) System impairment diagnosis. It can be difficult to identify the cause of performance problems in a fiber link. Signal degradation can be caused by PMD, chromatic-dispersion (CD), signal-to-noise ratio (SNR) issues, or other problems. Performing PMD compensation can help determine whether the problem is principally due to PMD: If PMD compensation substantially solves the transmission problem, it can be deduced that PMD is the principal cause of the problem. If not, it may be possible to rule out PMD. With such a diagnosis, it is possible to decide whether PMD compensation is required for the fiber link.
7) PMD emulation. The PMD generator can generate statistical PMD distributions to emulate PMD variations in fiber systems.
8) Polarization control functions. Using its built-in polarization controller and polarimeters, this instrument can perform all polarization control functions, including deterministic SOP generation, polarization scrambling, and polarization trace generation. It can therefore be used as a general purpose polarization synthesizer/controller for all polarization control needs.

Polarization optimization is used in the following three functions.
1) DGD tolerance test: Optimize input SOP using the SOP information from the first polarimeter as feedback to obtain the worst-case signal degradation caused by DGD.
2) PMD tolerance test: Optimize input SOP to minimize the DOP detected by the second polarimeter to obtain the worst-case signal degradation caused by both DGD and SOPMD.
3) PMD compensation: Optimize input SOP by maximizing DOP detected by the second polarimeter to minimize signal degradation caused by DGD and SOPMD.

Section 6. Troubleshooting:

The following table lists some of the major troubleshooting procedures.

Symptom	Possible Solution
A. The PMDPro does not execute the desired function.	1. Check the power supply indicator light. 2. Check the operation mode. 3. Check whether the PMDPro is in a setup or function execution state.
B. The measured PMD does not match the set value.	1. Check the measurement setup (polarization analyzer or other techniques); make sure the measurement parameters are reasonable (e.g., wavelength step). 2. Check the operation range (90 or 180 ps) and corresponding SOPMD table
C. The performance of the device changes suddenly (e.g., large sudden increase in loss).	1. Make sure that no sudden external force or vibration was applied to the instrument. 2. Use the DGD or PMD scan function to find out how many states are out of order. This information indicates the possibility of damage to the optical components inside the device. 3. If the problem persists, the control circuit of the module may have been damaged.
D. Front panel static Ethernet setup doesn't' work.	1. The static Ethernet parameters cannot be set from the front panel. Use the GP_SET_ETHERNET LabView program to perform the static Ethernet setup.
E. The control program does not function properly.	1. Check the language settings of the control computer. It should be set to English (United States). Changing the language settings can cause the program to read numerical values incorrectly.

Section 7. Technical Support

General Photonics is committed to high quality standards and customer satisfaction. For any questions regarding the quality and use of the PMDPro, or future suggestions, please contact General Photonics Corporation at (909)-590-5473 (telephone) or (909)-902-5536 (fax), or by e-mail at support@generalphotonics.com. General Photonics will respond to all customer questions within 24 hours during regular business hours. General Photonics can also be contacted by mail at:

General Photonics
5228 Edison Avenue
Chino, California 91710
USA

Appendix A: ITU Grid Channel Lookup Table

The following tables are references for the PMDPro operation wavelength setup. They list the frequency and wavelength corresponding to each channel in the C and L bands.

C-BAND		
CHANNEL#	FREQUENCY (GHz)	WAVELENGTH (nm)
C1	191600	1564.68
C2	191650	1564.27
C3	191700	1563.86
C4	191750	1563.45
C5	191800	1563.05
C6	191850	1562.64
C7	191900	1562.23
C8	191950	1561.83
C9	192000	1561.42
C10	192050	1561.01
C11	192100	1560.61
C12	192150	1560.20
C13	192200	1559.79
C14	192250	1559.39
C15	192300	1558.98
C16	192350	1558.58
C17	192400	1558.17
C18	192450	1557.77
C19	192500	1557.36
C20	192550	1556.96
C21	192600	1556.55
C22	192650	1556.15
C23	192700	1555.75
C24	192750	1555.34
C25	192800	1554.94
C26	192850	1554.54
C27	192900	1554.13
C28	192950	1553.73
C29	193000	1553.33
C30	193050	1552.93
C31	193100	1552.52
C32	193150	1552.12
C33	193200	1551.72
C34	193250	1551.32
C35	193300	1550.92
C36	193350	1550.52
C37	193400	1550.12
C38	193450	1549.72
C39	193500	1549.32

C40	193550	1548.91
C41	193600	1548.51
C42	193650	1548.11
C43	193700	1547.72
C44	193750	1547.32
C45	193800	1546.92
C46	193850	1546.52
C47	193900	1546.12
C48	193950	1545.72
C49	194000	1545.32
C50	194050	1544.92
C51	194100	1544.53
C52	194150	1544.13
C53	194200	1543.73
C54	194250	1543.33
C55	194300	1542.94
C56	194350	1542.54
C57	194400	1542.14
C58	194450	1541.75
C59	194500	1541.35
C60	194550	1540.95
C61	194600	1540.56
C62	194650	1540.16
C63	194700	1539.77
C64	194750	1539.37
C65	194800	1538.98
C66	194850	1538.58
C67	194900	1538.19
C68	194950	1537.79
C69	195000	1537.40
C70	195050	1537.00
C71	195100	1536.61
C72	195150	1536.22
C73	195200	1535.82
C74	195250	1535.43
C75	195300	1535.04
C76	195350	1534.64
C77	195400	1534.25
C78	195450	1533.86
C79	195500	1533.47
C80	195550	1533.07
C81	195600	1532.68
C82	195650	1532.29
C83	195700	1531.90
C84	195750	1531.51
C85	195800	1531.12
C86	195850	1530.72
C87	195900	1530.33

L-BAND		
CHANNEL #	FREQUENCY (GHz)	WAVELENGTH (nm)
L1	185100	1619.62
L2	185150	1619.19
L3	185200	1618.75
L4	185250	1618.31
L5	185300	1617.88
L6	185350	1617.44
L7	185400	1617.00
L8	185450	1616.57
L9	185500	1616.13
L10	185550	1615.70
L11	185600	1615.26
L12	185650	1614.83
L13	185700	1614.39
L14	185750	1613.96
L15	185800	1613.52
L16	185850	1613.09
L17	185900	1612.65
L18	185950	1612.22
L19	186000	1611.79
L20	186050	1611.35
L21	186100	1610.92
L22	186150	1610.49
L23	186200	1610.06
L24	186250	1609.62
L25	186300	1609.19
L26	186350	1608.76
L27	186400	1608.33
L28	186450	1607.90
L29	186500	1607.47
L30	186550	1607.04
L31	186600	1606.60
L32	186650	1606.17
L33	186700	1605.74
L34	186750	1605.31
L35	186800	1604.88
L36	186850	1604.46
L37	186900	1604.03
L38	186950	1603.60
L39	187000	1603.17
L40	187050	1602.74
L41	187100	1602.31
L42	187150	1601.88
L43	187200	1601.46

L44	187250	1601.03
L45	187300	1600.60
L46	187350	1600.17
L47	187400	1599.75
L48	187450	1599.32
L49	187500	1598.89
L50	187550	1598.47
L51	187600	1598.04
L52	187650	1597.62
L53	187700	1597.19
L54	187750	1596.76
L55	187800	1596.34
L56	187850	1595.91
L57	187900	1595.49
L58	187950	1595.06
L59	188000	1594.64
L60	188050	1594.22
L61	188100	1593.79
L62	188150	1593.37
L63	188200	1592.95
L64	188250	1592.52
L65	188300	1592.10
L66	188350	1591.68
L67	188400	1591.26
L68	188450	1590.83
L69	188500	1590.41
L70	188550	1589.99
L71	188600	1589.57
L72	188650	1589.15
L73	188700	1588.73
L74	188750	1588.30
L75	188800	1587.88
L76	188850	1587.46
L77	188900	1587.04
L78	188950	1586.62
L79	189000	1586.20
L80	189050	1585.78
L81	189100	1585.36
L82	189150	1584.95
L83	189200	1584.53
L84	189250	1584.11
L85	189300	1583.69
L86	189350	1583.27
L87	189400	1582.85
L88	189450	1582.44
L89	189500	1582.02
L90	189550	1581.60
L91	189600	1581.18

L92	189650	1580.77
L93	189700	1580.35
L94	189750	1579.93
L95	189800	1579.52
L96	189850	1579.10
L97	189900	1578.69
L98	189950	1578.27
L99	190000	1577.86
L100	190050	1577.44
L101	190100	1577.03
L102	190150	1576.61
L103	190200	1576.20
L104	190250	1575.78
L105	190300	1575.37
L106	190350	1574.95
L107	190400	1574.54
L108	190450	1574.13
L109	190500	1573.71
L110	190550	1573.30
L111	190600	1572.89
L112	190650	1572.48
L113	190700	1572.06
L114	190750	1571.65
L115	190800	1571.24
L116	190850	1570.83
L117	190900	1570.42
L118	190950	1570.01
L119	191000	1569.59
L120	191050	1569.18
L121	191100	1568.77
L122	191150	1568.36
L123	191200	1567.95
L124	191250	1567.54
L125	191300	1567.13
L126	191350	1566.72
L127	191400	1566.31
L128	191450	1565.90
L129	191500	1565.50
L130	191550	1565.09