Making Light Work Lighter

General Photonics

C o r p o r a t i o n

PSGA– 101A

Polarization Measurement System
PolaWise™

Operation Manual

Nov. 5, 2010

WARRANTY

All of General Photonics' products have been inspected and found to comply with our stringent quality assurance standards before shipping. If any damage occurs during shipment, please contact the carrier and inform us or our distributors as soon as possible.

Please do not, under any circumstances, attempt user repair of any General Photonics product. To avoid further damage, any repair of defective products must be performed by well-trained engineers.

General Photonics warrants that this product will be free from defects in materials or workmanship for a period of one year from the date of original shipment (listed on the certificate of quality or packing list enclosed with the original shipment). A product found to be defective during the warranty period will be repaired or replaced, at no charge, at General Photonics' option.

If a problem is found, please contact General Photonics for assistance. If necessary, return the defective product, freight prepaid, clearly labeled with the RMA number, with as complete a description of the problem as possible. The repaired or replacement product will be returned, freight prepaid, as soon as possible.

The above warranty specifically excludes products that have been repaired or modified by non-manufacturer-authorized personnel, as well as damage caused by misuse, abuse, improper storage or handling, or acts of nature.

This warranty is in lieu of all other warranties, expressed or implied. General Photonics will not be liable for any indirect or consequential damages or losses resulting from the use of its products.

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

Operating wavelength range[1]		1440 to 1620 nm (standard)
SOP generation accuracy		± 1° on Poincaré Sphere
SOP repeatability		±1°
Azimuth & ellipticity angle accuracy[2]		< 0.25°
Stokes vector accuracy[2]		± 0.5%
DOP measurement accuracy[2, 3]		± 1%
PER dynamic range		>40 dB (Input Power > −10 dBm)
PER axis accuracy[2]		± 0.2°
PMD measurement range		1 fs to 10 ps (Internal tunable laser)
		1 fs to 400 ps
		(External laser, $0.01\text{nm} < \lambda_{step} < 10 \text{ nm}$)
PDL measurement range		0 to 40 dB (Input power > −10 dBm)
Accuracy:	DGD	± (1fs + DGD*0.5%)
	SOPMD	± (SOPMD*1%)
	PDL	± (0.05 dB + PDL*2%)
Repeatability:	DGD[4]	0.03 fs
	SOPMD[4]	0.3ps^2
	PDL[5]	0.04 dB
Resolution	DGD	1 fs (1550nm, $\lambda_{step} = 2\text{nm}$)
	SOPMD	0.005 ps^2 (1550nm, $\lambda_{step} = 2\text{nm}$)
	PDL	0.01 dB
PMD		< 0.1 ps
Internal tunable laser		1528 to 1563 nm
Wavelength tuning step		50 GHz minimum for internal tunable laser
Operating power range		−40 to +2 dBm
Optical power accuracy		± 0.25 dB
Optical power damage threshold		300 mW
Operating temperature		5 ~ 40 °C
Storage temperature		−20 ~ 60 °C
Power supply: Universal -accepts either		100 ~ 120 VAC, 50 ~ 60 Hz, or
		200 ~ 240 VAC, 50 ~ 60 Hz
Computer interface		GPIB, Ethernet
Displays		8" flip-top graphic LCD
		2 x 20 character front-panel LCD

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[1] Specifications listed here apply to the standard 1440-1620nm model. Contact General Photonics regarding other wavelengths.
[2] At 23±0.5°C
[3] DOP measurement accuracy for C and L bands.
[4] Averaged over 10 steps, with wavelength step size = 2nm for DGD, 0.1nm for SOPMD.
[5] Measured by Mueller Matrix method.

External storage	USB removable storage media (flash drive)
Software	Control/display program (included)
Optical Connectors:	
Laser Output and PSG input/output	FC/PC, FC/APC, SC/PC, or SC/APC
PSA Input	FC free space
Dimensions	2U, 19 inch 3/4 rack width
	3.5"(H) x 14"(W) x 14"(L)

Section 2. Overview:

The PSGA-101A (PolaWise™) is a complete polarization measurement system for fiber optic applications, based on General Photonics' patented magneto-optic polarization generation and analysis technology and designed for accurate characterization of all polarization related properties of light sources and optical materials. Its major functions include polarization state generation (PSG), polarization state analysis (PSA), polarization extinction ratio (PER) measurement, polarization dependent loss (PDL) measurement, and polarization mode dispersion (PMD) measurement.

The instrument has three display options. The primary one is the flip-top LCD graphic display, for self-contained use of all graphic user interface-based instrument control and data display options. An external monitor can also be used via the VGA port. The front panel 2x20 character LCD allows push-button operation of the instrument for simple measurements that do not require a graphic display.

The internal tunable laser included in the standard version of the instrument allows measurement of PMD values up to 10 ps. The PSGA can also be used with external tunable lasers for measurement of PMD values outside this range.

The PSGA-101A can be remote controlled through industry standard GPIB or ETHERNET connections. The ETHERNET capability enables customers to measure the polarization properties of existing links at different network locations.

Section 3. Feature Description:

3.1 Optical Features:

The PSGA-101A system has four fiber adapters for optical beam inputs and outputs, as marked on the front panel (Figure 1). The far left connector is the output from the optional internal tunable laser. The two middle connectors are the input (to connect to either the internal laser source or an external source) and output of the polarization state generator (PSG). The far right connector is the input to the polarization state analyzer (PSA). The recommended (default) connector type for the internal tunable laser output and PSG input/output is FC/PC, although other connector types are available by customer request. The PSA input is free space and can accept either FC/APC or FC/PC connectors (FC/APC is recommended to reduce back reflection from the connector).

Figure 1 PSGA-101A front panel

The laser and PSG connectors 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.

Since the PSA input is free space, there is no internal ferrule that would need cleaning.

For the three connectors with internal ferrules, 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 that 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.
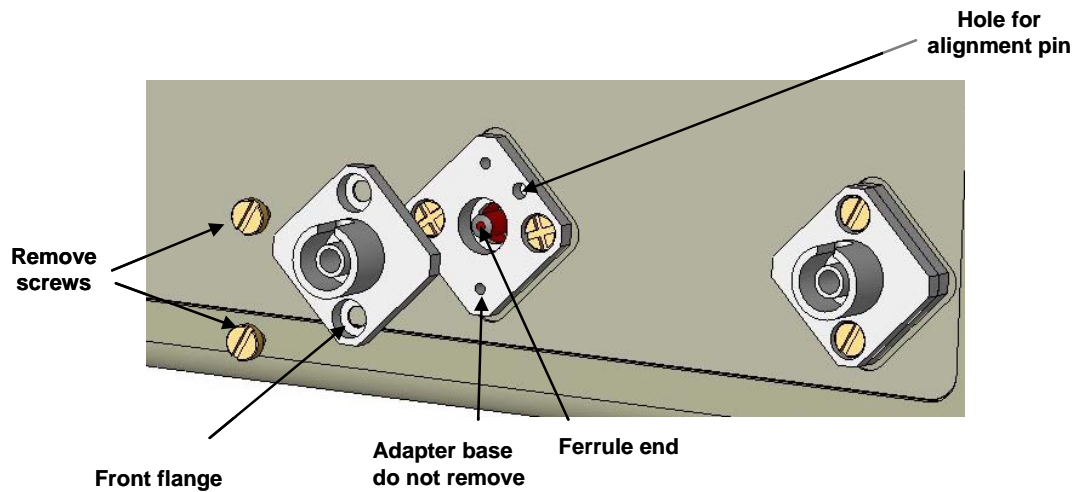

Figure 2 Diagram of universal connector interface

External fiber connectors should be cleaned using industry standard cleaning methods before connection to the PSGA-101A. 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.

Note:
The output power of the PSGA-101A's internal tunable laser is fixed, and may be as high as 13-14 dBm. To ensure that the light input to the PSA is within the specified dynamic range for accurate measurements (-40 to +2 dBm), a 10 dB optical attenuator is supplied as an accessory with the PSGA-101A. The attenuator should be connected between the laser output and the PSG input.

3.2 Electrical Features:

The PSGA-101A system uses the standard wall electricity supply (100~240V, 50~60Hz). 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 PSGA-101A is not user serviceable. It should be serviced only by factory-authorized personnel.

The front panel of the PSGA-101A contains the main power switch (Power), laser key (Light), liquid crystal display (LCD), push button control pads, keyboard connector, two USB connectors and four optical connectors, as shown in Figure 1. One of the USB connectors is generally used for mouse control; the other can be used for flash memory.

A flip-top LCD graphic display is located on top of the main body of the PSGA-101A.

Front panel description:

LCD display: displays data and operation mode information
Power: main electrical power on/off switch
Light: key enables/disables control of the internal tunable laser
Laser (OUT): output connector for internal tunable laser;
PSG (IN): PSG light input connector (for connecting external or internal light source to the PSG)
PSG (OUT): PSG output connector
PSA (IN): PSA input connector
Keypad: push buttons for measurement status control (see Section 7)
Keyboard: connector port to connect a keyboard to the PSGA-101A
USB: two USB ports for mouse control and flash memory

The AC power plug, fuse, Ethernet and GPIB interface connectors, external VGA connector, two BNC connectors, two cooling fans, and the chassis ground connector are mounted on the rear panel, as shown in Figure 3.
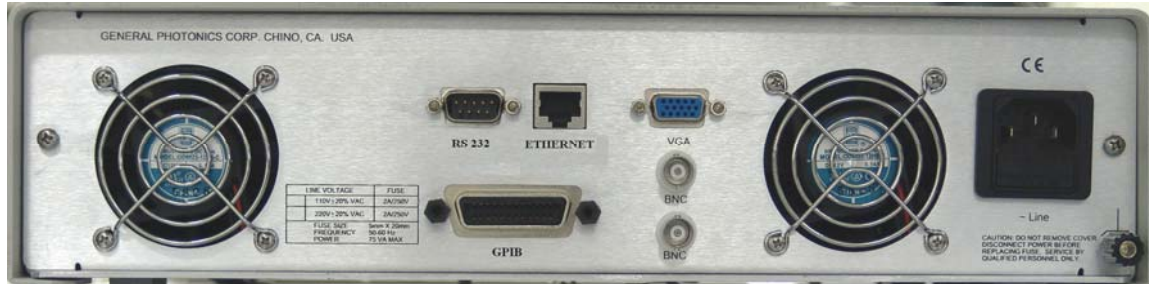

Figure 3 PSGA-101A rear panel

The PSGA-101A includes Ethernet and GPIB interfaces for external computer operation of the system and data readout. Control commands and instructions for remote control are listed in Section 9.

Rear panel description:

RS-232: serial port, not used in PSGA-101A
Ethernet: Ethernet interface port, used for PSGA-101A remote control
GPIB: GPIB interface port, used for PSGA-101A remote control
VGA: used to connect with external VGA monitor
Line: external AC supply input connector, 110 V or 220 V
BNC: not currently used in PSGA-101A
⏚ : chassis ground connector

Section 4. General Instructions:

Warnings:

- **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. Since the light from the PSGA's internal tunable laser is invisible, it is safer to turn it off before changing connections and when the laser is not in use.**

- **The PSGA-101A is designed for accurate measurements. Avoid water condensation or liquid spills during PSGA-101A storage and operation.**

- **Check optical power level of the input optical beam to the PSA. Make sure the optical power level at the input connector to the PSA is below +2 dBm (1.6 mW).**

- **When powering the instrument off, wait at least 20-30 seconds before powering it back on to avoid damage to electrical components.**

- **Be careful with the flip-up graphic display screen. Rapidly and repeatedly raising and lowering it may cause damage.**

4.1 Unpacking

Inspect PSGA-101A 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.

Major accessories include: power cord, keyboard, USB mouse, fixed optical attenuator (10 dB), and optical jumper cables (normally FC/PC to FC/PC).

Avoid excess vibration environments when using the PSGA-101A system.

4.2 Getting Started

Setup procedure is described below:

1. Make sure local AC voltage matches the AC voltage requirement of the PSGA-101A system (100~240V, 50~60Hz).
2. Connect power cord and plug it into wall receptacle. Make sure the ground pin of the power cord is connected to earth ground.
3. Connect the mouse to one of the USB ports and the keyboard (optional) to the keyboard connector.

4. Carefully slide off the metal cover for the LCD graphic display, then slowly raise the display to a convenient viewing angle.

5. Make sure that the optical path is correctly connected for the desired measurements, including the optical source, either external or internal.

6. Turn on the main power switch.
Note: If a flash drive is connected to a USB port during power up, the PSGA will not recognize the mouse. Please make sure to disconnect any flash drives before powering on the instrument.

7. Turn on the key for the internal tunable laser, if applicable.
Note: The key enables control of the laser. It does not automatically turn the laser on. Measurement functions involving wavelength scanning, such as PMD/PDL measurement or ER measurement, will automatically turn on the laser when they are run. However, when using the laser with basic PSA functions or single-wavelength PDL measurements, it is necessary to manually turn on the laser. To set the wavelength and turn the laser on, select "Internal TLS" from the Setup menu to bring up the laser control screen (see Section 8).

8. On power-up, the WinCE system will start and will automatically load the measurement software. After an initialization splash screen the display will show the interface pictured in Figure 4.

9. Follow the instructions in Sections 5-9 for PSGA-101A control and measurements.
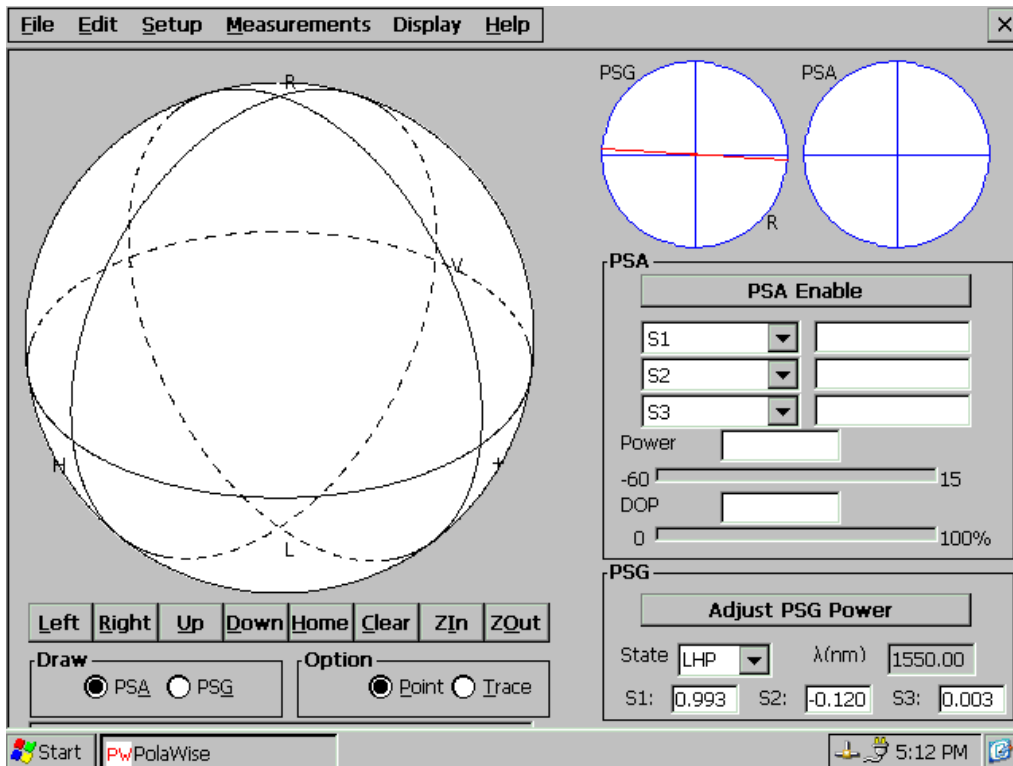

Figure 4 PSGA-101A PolaWise™ software interface screen

Major features of the main software interface screen:

This is a quick reference for the main software interface. Individual features and functions are described in greater detail in the following sections.

Menu bar:

File: Contains options to save or load long-term measurement data, print the current screen to a bitmap file, or to exit the control program.

Setup: Setup options for the polarization state generator (PSG), polarization state analyzer (PSA), polarization extinction ratio measurement (PER) laser setup, internal tunable laser (TLS), and GPIB.

Measurements: Measurement selection menu for PMD, PDL, PER, Mueller matrix, beat length, and angle measurements, and for long-term polarization data recording.

Display: Restores the most recently used PMD/PDL measurement display screen, if it has been hidden.

Soft keyboard (keyboard icon at bottom right corner of screen)

Most PSGA-101A functions can be controlled via mouse. However, there are some instances in which the user may need to input information from a keyboard. The PSGA-101 comes with an external keyboard which connects to the front panel of the instrument. For more self-contained operation, the control program also includes a virtual keyboard which can be accessed by clicking the keyboard icon at the bottom right corner of the screen. This brings up a pull-up menu offering the choice of a small or large virtual keyboard, as well as the option to hide the keyboard.

Poincaré sphere display (left half of the screen):

The Poincaré sphere display is a graphical representation of the polarization state of either the PSG output light or the PSA input light, depending on whether "**PSG**" or "**PSA**" is selected in the "**Draw**" box under the sphere. Click "**Point**" in the "**Option**" box under the sphere to display individual polarization states as colored points. Click "**Trace**" to display a line connecting sequential points, as shown in Figure 5. Points on the front half of the sphere are displayed in red, while points on the rear half of the sphere are blue.
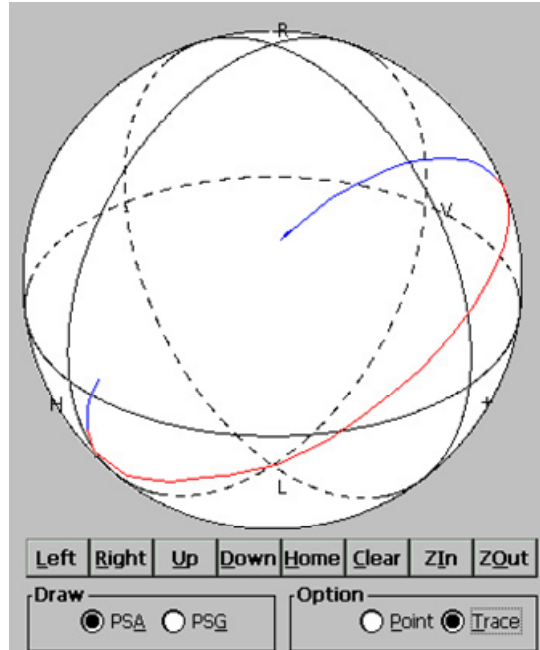
Figure 5 Polarization traces

For a clearer view of a particular section of the Poincaré sphere, click the **Left**, **Right**, **Up**, or **Down** buttons to rotate the sphere about its horizontal or vertical axis. The **Clear** button erases all points or traces drawn on the sphere. **ZIn** and **ZOut** zoom the sphere in and out, respectively.

Polarization Ellipses (top right of screen)

Figure 6 Polarization ellipses
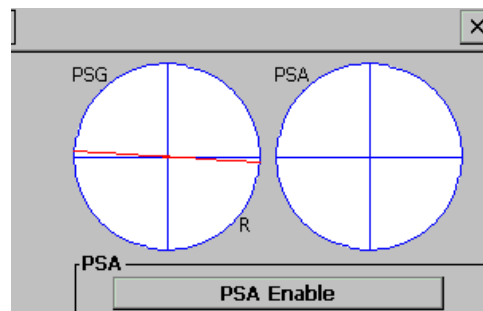
The polarization ellipse displays at the top right of the screen show 2-dimensional views of the polarization ellipse representations of the current polarization states of the polarization state generator output (PSG) and polarization state analyzer (PSA) input, respectively. The PSA ellipse only displays/updates information when the PSA is enabled (button at bottom of Figure 6).
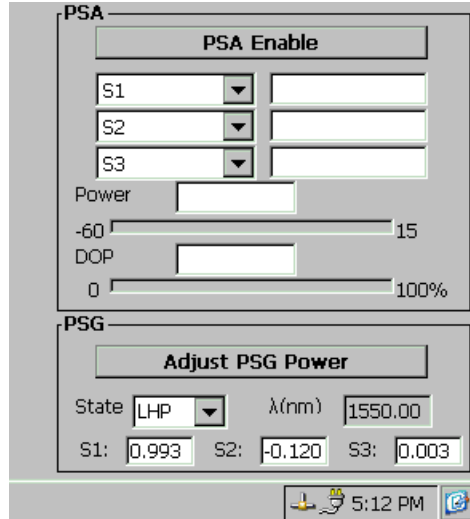
PSA and PSG status boxes

Figure 7 PSA and PSG status boxes

When the PSA is enabled, the PSA status box shows the current values of the selected polarization parameters in the pull-down menus (S1, S2, S3, etc.), as well as the power (in dBm) and degree of polarization (DOP) of the light input to the PSA.
Note: If the input power to the PSA is out of range, measurements cannot be performed properly. The PSA will indicate power out of range with a "Power High" or "Power Low" indication in the power box. See section 15.3 for more details.

The PSG status box shows the current selected wavelength and output polarization state of the PSG. See section 15.2 for more details.

Section 5. Polarization State Generation and Analysis

5.1   Polarization Parameters

The following are polarization parameters used throughout this manual:

- S_1, S_2 and S_3: The normalized Stokes parameters of the polarization state. The value of $\sqrt{S_1^2 + S_2^2 + S_3^2}$ is equal to 1.
- S_0: optical input power (unit: dBm)
- Azimuth: Azimuth angle ψ of polarization ellipse (unit: degrees).
- Ellipticity: Ellipticity angle χ of polarization ellipse (unit: degrees).
- DOP: Degree of polarization (usually given as a percentage of input light)
- DLP: Degree of linearity (usually given as a percentage of polarized input light)
- DCP: Degree of circularity (usually given as a percentage of polarized input light)

Graphical representations of polarization state

The polarization ellipse is the elliptical trace made by the tip of the electric field vector of a light signal in the (XY) plane perpendicular to the light propagation direction z, where the x, y and z axes define a right-handed coordinate system. Generally, the ellipse is characterized by its orientation and elongation. A common parameterization uses the **azimuth angle** ψ (the angle between the semi-major axis of the ellipse and the x-axis) and the **ellipticity angle** $\chi = \pm\tan^{-1}(E_{max} / E_{min})$, where E_{max} and E_{min} are the lengths of the semi-major axis and the semi-minor axis, respectively. If the rotation of the electric field vector tip appears clockwise to an observer facing the incoming light, the light is right-hand polarized and its ellipticity angle is positive; otherwise, the light is left-hand polarized and its ellipticity angle is negative. The direction of rotation (R/L) of the polarization is usually indicated by an arrow at the bottom right or bottom left of the polarization ellipse (see Figure 8).
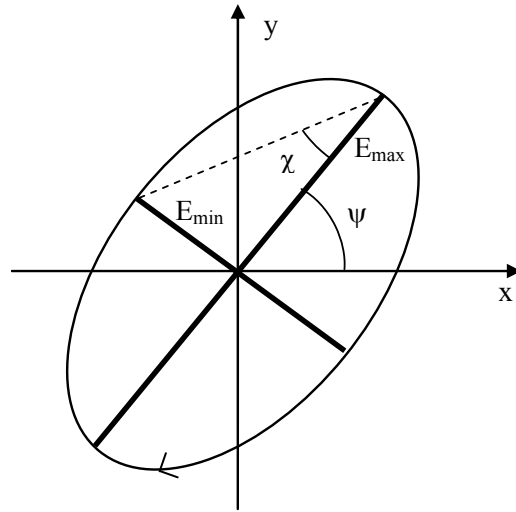
Figure 8 Right-handed Polarization Ellipse

Polarization states can also be graphically represented on a sphere of unit radius known as the Poincaré sphere. A polarization state corresponding to a polarization ellipse of azimuth angle ψ and ellipticity angle χ can be mapped to a point P with spherical coordinates $(2\psi, 2\chi, 1)$. The rectangular coordinates (S_1, S_2, S_3) of point P are the normalized Stokes parameters of the polarization state represented by P, with $\sqrt{S_1^2 + S_2^2 + S_3^2} = 1$.

Any polarization state can be represented as a point on the Poincaré sphere; and every point on the Poincaré sphere represents a unique polarization state (Figure 9).

Figure 9 Poincaré sphere representation of polarization states

The symbols H, V, +, -, R and L on the Poincaré sphere display represent the polarization states described in Table 1, and are used throughout the PSGA control interface, as well as the user manual:

Table 1. Special polarization states on Poincaré sphere.

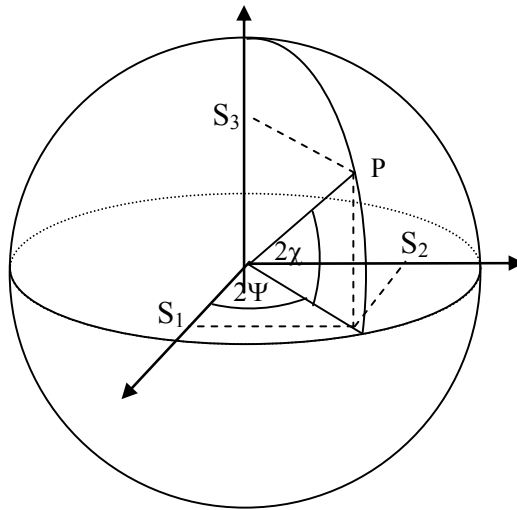| Symbols	Abbr.	Stokes Parameters	Corresponding Polarization States
LHP	H	$(1, 0, 0)$	Horizontal linearly polarized light with polarization angle 0° with respect to the reference plane of the PSA.
LVP	V	$(-1, 0, 0)$	Vertical linearly polarized light with polarization angle 90° with respect to the reference plane of the PSA.
+45	+	$(0, 1, 0)$	Linearly polarized light with polarization angle +45° with respect to the reference plane of the PSA.
-45	-	$(0, -1, 0)$	Linearly polarized light with polarization angle -45° with respect to the reference plane of the PSA.
RHC	R	$(0, 0, 1)$	Right-hand circularly polarized light
LHC	L	$(0, 0, -1)$	Left-hand circularly polarized light

5.2   Polarization State Generator (PSG) Module

The PSGA-101A polarization measurement system includes an all solid-state high speed 6-state polarization state generator (PSG) for Jones matrix, Mueller matrix, PMD, and PDL measurement.

The PSG can generate six non-degenerate polarization states: linear horizontal and vertical (LHP, LVP), linear +45°, linear −45°, RHC and LHC. Individual states can be selected from the PSG **State** pull-down menu on the PSG control interface box in the

bottom right corner of the screen (Figure 10). The state will be generated as soon as it is selected.

The SOPs of these six states are wavelength and temperature dependent and have been accurately calibrated. The Stokes parameters of the actual output SOP at the current temperature and the wavelength set in the PSG Setup screen (Figure 11) are shown in the bottom line of the PSG control interface. It should be noted that the SOP given here represents the polarization state of light at the output port of the internal PSG module, before passing through any fiber. This state is generally different from the SOP at the PSG output adapter on the PSGA front panel (PSG OUT), because the SM fiber between the internal PSG module and the PSG front panel output adapter can change the SOP of light passing through it.
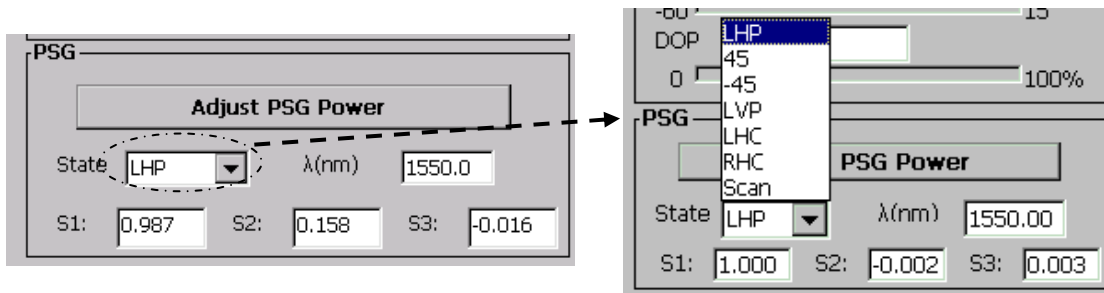

Figure 10 PSG state control interface

- **PSG output power optimization**

Because the PSG module uses a linear polarizer to define its input polarization state, its output power depends on the polarization state of the light input to the polarizer, with a range determined by the extinction ratio of the polarizer. If the SOP of the input light is close to orthogonal to the polarizer axis, the light output can be very low. To solve this problem, the PSGA includes a 90° controllable polarization rotator located before the PSG input. Clicking the "**Adjust PSG Power**" button in the PSG control interface box (Figure 10) rotates the polarization plane of the input light by 90°, changing the PSG output power accordingly. This function should be used if the initial PSG output power is very low.

- **PSG Scanning Mode**

The PSG can be set to scan its output polarization state through the 6 Poincaré sphere pole states in the following sequence: LHP, +45, −45, LVP, LHC and RHC. The dwell time at each state (in units of seconds) can be set from the **PSG Setup** interface (Figure 11).
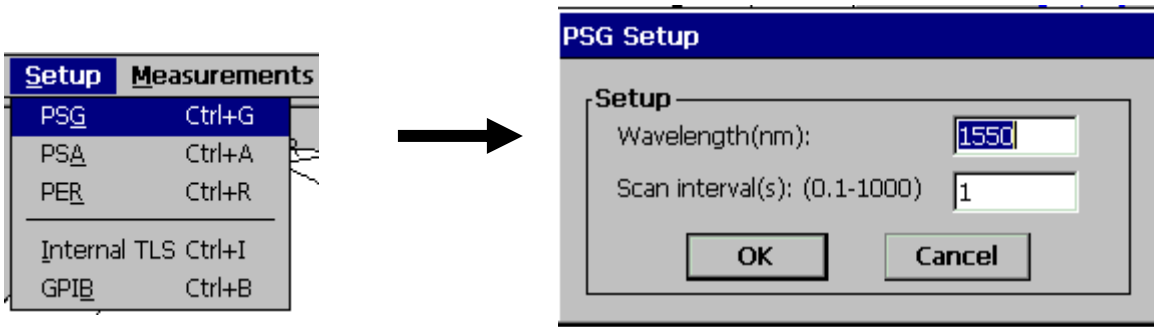
Figure 11 PSG setup for scanning mode

Once the dwell time is set, choosing "scan" from the "State" menu (Figure 10) will start the scan.

5.3   Polarization State Analyzer (PSA) Module

The polarization state analyzer (PSA) module inside the PSGA-101A can be used to analyze polarization-related parameters/properties for free-space setups as well as fiber guided light.

A special FC adapter with a collimator is supplied with the PSGA instrument (Figure 12). It can be used with either FC/APC or FC/PC connectors. The slot at the top of the FC adapter is for wide-key connectors, and the bottom slot is for narrow-key connectors.

This FC adapter can easily be removed for free space measurements. The diameter of a free-space input light beam should be less than 1mm to ensure that the PSA's detector can collect all of the energy of the input light.
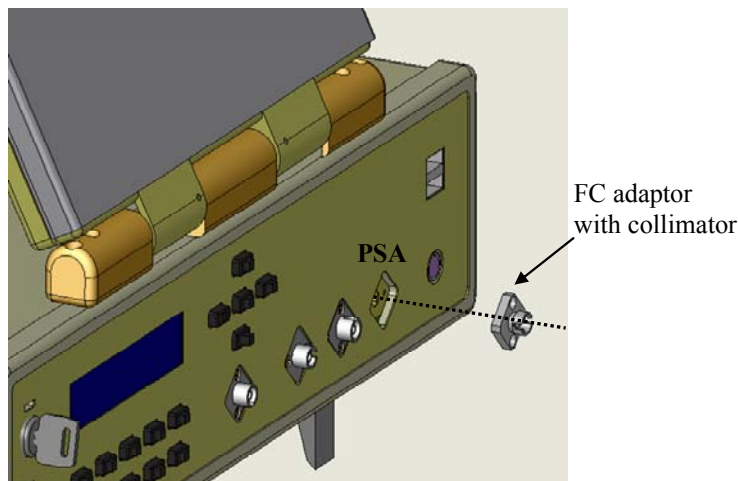
Figure 12 PSA module for free space and fiber guided light

5.3.1 PSA interface

The PSA control/data display interface (Figure 13-Figure 14) consists of the following:

- PSA setup window (accessed from Setup pull-down menu)
- Poincaré Sphere at the left of the main interface screen
- Polarization ellipse at the top right of the main interface screen
- PSA measurement parameter status box in the middle right of the main interface screen
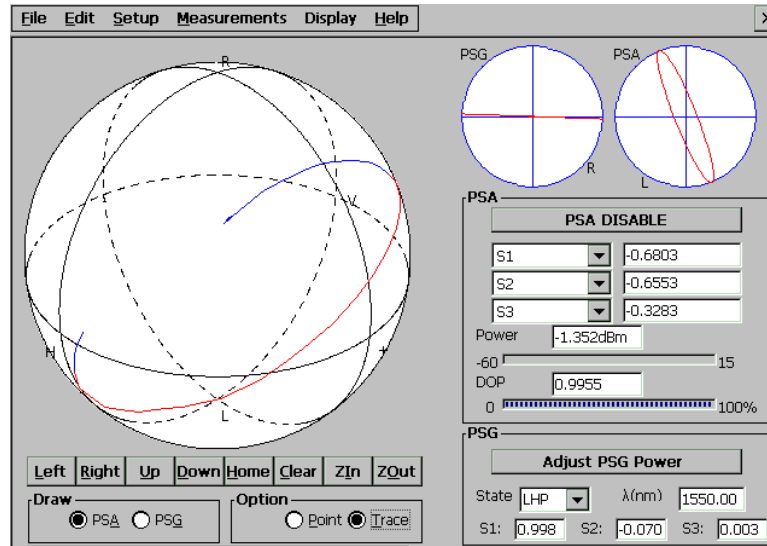
Figure 13 PSA primary interface

5.3.2 PSA Setup

The PSA has two operation modes: *high precision* and *high speed*. High precision mode is the default operation mode. It provides maximum precision with a low sampling rate (~10 samples/sec.), and does not require the wavelength of the input light to be specified. High speed mode provides a high sampling rate (~ 40 samples/sec) with slightly lower precision; however, the exact wavelength of the input light must be specified during setup.

PSA Setup procedure

- Select "PSA" from the **Setup** menu (Figure 14A). The "**PSA Setup**" dialog window will pop up.
- Select "high precision" or "high speed" mode in the "PSA Setup" window (Figure 14B).
- If high speed mode is selected, the wavelength of the input light should be set for accurate measurement.

A)   B)
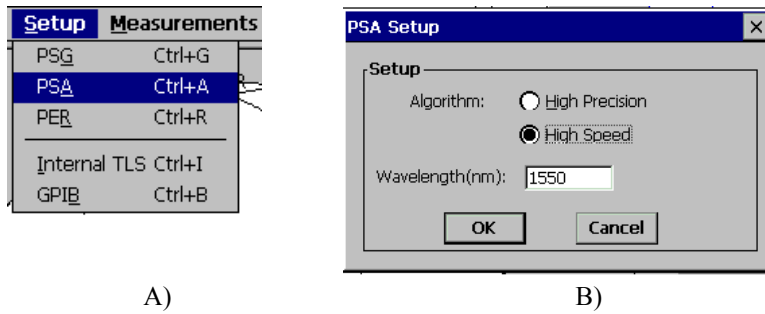
Figure 14 PSA Setup interface

5.3.3   Polarization Parameter Analysis

Polarization-related parameters are analyzed and displayed in real time in the PSA parameter status box in the middle right of the main screen (Figure 15). Select the desired parameters from the pull-down menus, then click the "PSA Enable/Disable" button to start/stop measurement. When the PSA is enabled, SOP information is also displayed on the Poincaré sphere and the 2-D PSA polarization ellipse display.
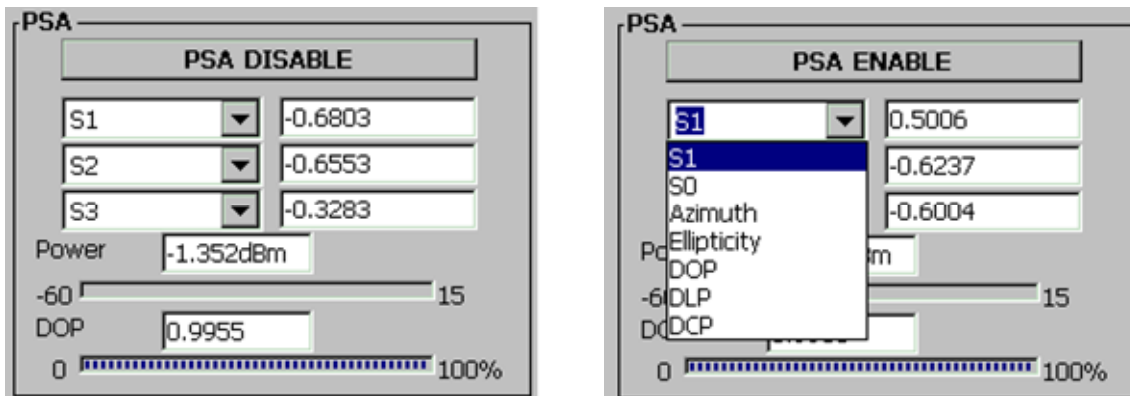
Figure 15 Polarization parameters of input light

5.3.4 Poincaré Sphere Display

The Poincaré Sphere display can be controlled using the on-screen buttons under the sphere. Button functions are listed below.

<u>**Left**</u>/<u>**Right**</u>:   Rotates the sphere around the S3 axis in a clockwise/counterclockwise direction.

<u>**Up**</u>/<u>**Down**</u>:   Rotates the sphere around the S2 axis in a clockwise/counterclockwise direction.

<u>**Home**</u>:   Restores the sphere's default perspective (orientation and size)

<u>**Clear**</u>:   Clears all points or traces from the sphere.

<u>**ZIn/ZOut**</u>   Zooms the sphere in/out.

<u>**PSA/PSG**</u>:   Selects the SOP data to be displayed on the Poincaré Sphere:
PSA: PSA input polarization
PSG: PSG output polarization

<u>**Point/Trace**</u>:   Displays SOP data as individual or connected points.

Please note that any change to the Poincaré Sphere display during standard PSA operation will clear the sphere. To maintain existing points on the sphere while manipulating the sphere display, use the long-term measurement function (see section 6.5).

Section 6. Measurements:

6.1 Polarization Mode Dispersion (PMD) Measurement

6.1.1   Introduction

In an ideal circularly symmetric fiber, light in any polarization state would propagate with the same velocity. However, real fibers are not perfectly circular and are subject to local stresses; consequently, propagating light is split into two local polarization modes which travel at different velocities. The differential group delay (DGD) between the two orthogonally polarized modes causes pulse spreading in digital systems and distortion in analog systems.

General Photonics' PSGA-101A polarization measurement system accurately characterizes various aspects of PMD, including the wavelength dependence of the differential group delay (DGD), the principal states of polarization (PSP), the second order PMD, etc.

The PSGA-101A supports four PMD measurement methods: wavelength scanning, Jones Matrix Eigenanalysis (JME), the generalized Mueller matrix method (MMM) and Poincaré sphere analysis (PS). A fifth menu option is the fast Jones matrix method, which provides quick measurement (with slightly reduced accuracy) for field applications. The Jones matrix eigenanalysis and generalized Mueller matrix methods are the most generally accurate and is recommended for most cases. The other methods are provided primarily for comparison and reference.

Table 2 Definitions and terms used in PMD measurement

PMD Phenomenon	In an ideal circularly symmetric fiber, light of any polarization state would propagate with the same velocity. However, in real fibers, local stresses and imperfections in the circular symmetry cause propagating light to split into two local polarization modes which travel at different velocities. This effect is known as the PMD phenomenon. The resulting differential group delay between the two orthogonally polarized modes causes pulse spreading in digital systems and distortions in analog systems.
PSP	The principal states of polarization (PSPs) are the two orthogonal input states of polarization for which output polarizations do not vary when the optical frequency changes slightly. These two PSPs are also the polarization states with the maximum (fast PSP) and minimum (slow PSP) values of group velocity. In the PSGA interface, "PSP" denotes the fast PSP.
DGD	Differential group delay (DGD) is the difference in delay between the slow PSP and fast PSP at a specified wavelength. It is given in units of picoseconds (ps).
PMD	Polarization mode dispersion (PMD) is defined as the linear average or the root-mean square (RMS) of the DGD values over a given wavelength range at a certain time, or over a given time window at a certain wavelength.
PMD coefficient	The PMD coefficient is the PMD value normalized to the measurement length. For random mode coupling, the PMD coefficient is the PMD value (PMD_{avg} or PMD_{RMS}) divided by the square root of the length ($L^{1/2}$) with units of $ps/\sqrt{km}$; For negligible mode coupling, the PMD coefficient is the PMD value (PMD_{avg} or PMD_{RMS}) divided by the length (L), with units of ps/km.
SOPMD	The second order PMD (SOPMD) at a given frequency is defined as: $$\text{SOPMD}(\omega)=\left\|\frac{d\mathbf{\Omega}(\omega)}{d\omega}\right\|=\left\|\frac{DGD(\omega_2)\mathbf{PSP}_f(\omega_2)-DGD(\omega_1)\mathbf{PSP}_f(\omega_1)}{\omega_2-\omega_1}\right\|,$$ where $\mathbf{\Omega}(\omega)$ is the polarization mode dispersion vector, $\omega=(\omega_1+\omega_2)/2$, and $\mathbf{PSP_f}(\omega_x)$ is the principal state of polarization at frequency ω_x.
SOPMD$_{RMS}$	The SOPMD$_{RMS}$ is the root-mean square (RMS) of the SOPMD values over a given wavelength range at a certain time

6.1.2. PMD measurement principles for JME, MMM and PS

The JME, MMM and PS methods all use the same measured data to calculate PMD. Setup and measurement procedures are therefore identical for the three methods. At a given wavelength, the PSG generates a set of distinct polarization states (for example, the Jones Matrix method uses the three linear polarization states 0° 45° and 90°). For each polarization state, the polarization state analyzer measures the corresponding Jones vector or Stokes parameters of the polarization state of light after the DUT (Figure 16). This procedure is repeated for each wavelength in the set specified in the measurement setup. The JME, MMM and PS methods then use different sets of calculations to determine the wavelength dependence of the differential group delay (DGD), principal states of polarization (PSP) and second order PMD from the wavelength dependence of the Jones vector or Stokes parameters.
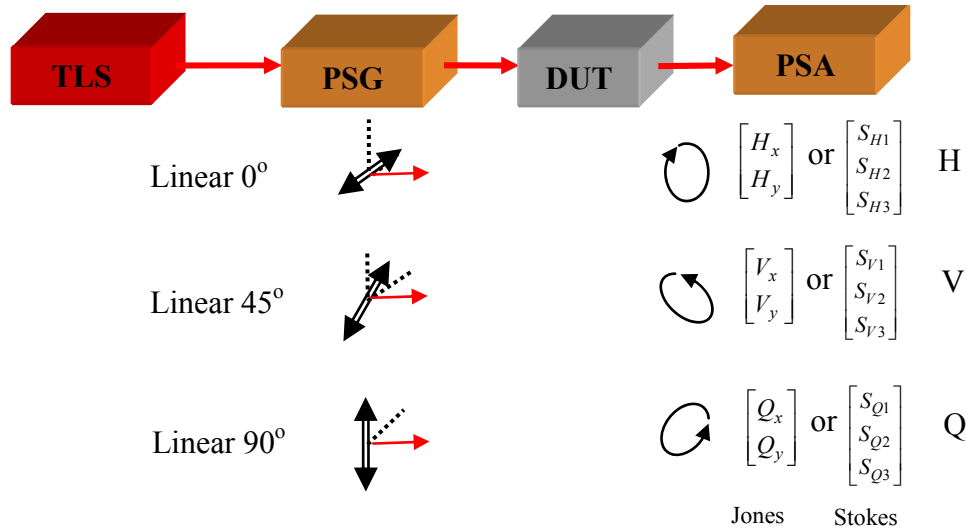
Figure 16 PMD measurement data acquisition for Jones Matrix Eigenanalysis

Jones Matrix Eigenanalysis data acquisition and analysis methods:

- Tunable laser (TLS) is set to the first wavelength λ_1.
- PSG outputs three non-degenerate polarization states: Linear 0°, 45°, 90°.
- For each state, PSA measures the corresponding polarization state after the DUT.
- Jones Matrix $M_J(\lambda_1)$ is calculated for λ_1.
- Process is repeated for the next wavelength λ_2
- Product $\Gamma = M_J(\lambda_2)M_J^{-1}(\lambda_1)$ is calculated.
- The $DGD\left(\dfrac{\lambda_1 + \lambda_2}{2}\right)$ and corresponding fast $\mathbf{PSP}(\dfrac{\lambda_1 + \lambda_2}{2})$ are determined from the eigenvalues and eigenvectors of Jones matrix Γ
- Process is repeated for the next wavelength to get $M_J(\lambda_3)$

- $DGD\left(\dfrac{\lambda_2 + \lambda_3}{2}\right)$ and the corresponding fast $\textbf{PSP}(\dfrac{\lambda_2 + \lambda_3}{2})$ are calculated.

- $SOPMD(\lambda_2 = \dfrac{\lambda_1 + \lambda_3}{2})$ is determined from $DGD\left(\dfrac{\lambda_1 + \lambda_2}{2}\right)$, $\textbf{PSP}(\dfrac{\lambda_1 + \lambda_2}{2})$, $DGD\left(\dfrac{\lambda_2 + \lambda_3}{2}\right)$ and $\textbf{PSP}(\dfrac{\lambda_2 + \lambda_3}{2})$

- DGDs are averaged over λ to obtain PMD, SOPMD(λ) is averaged over λ to obtain SOPMD.

Generalized Mueller Matrix Method data acquisition and analysis methods:

- Tunable laser (TLS) is set to the first wavelength λ_1.
- PSG outputs six non-degenerate polarization states: Linear 0°, ±45°, 90°, RHC and LHC.
- For each state, PSA measures the corresponding polarization state after the DUT.
- Mueller Matrix M(λ_1) of DUT is calculated (refer to section 6.4.1).
- Process is repeated for the next wavelength λ_2.
- The complex PMD vector $\vec{W}(\dfrac{\lambda_1 + \lambda_2}{2}) = \vec{\Omega} + i\vec{\Lambda}$ is calculated from M(λ_1) and M(λ_2).
- $DGD\left(\dfrac{\lambda_1 + \lambda_2}{2}\right) = \mathrm{Re}(\sqrt{\vec{W} \bullet \vec{W}})$ and $\textbf{PSP} = \dfrac{\pm\vec{\Omega} + \vec{\Omega} \otimes \vec{\Lambda}}{\vec{\Omega} \bullet \vec{\Omega}}$ are calculated.
- Process is repeated for the next wavelength to get M(λ_3).
- $DGD\left(\dfrac{\lambda_2 + \lambda_3}{2}\right)$ and the corresponding $\textbf{PSP}(\dfrac{\lambda_2 + \lambda_3}{2})$ are calculated.
- $SOPMD(\lambda_2 = \dfrac{\lambda_1 + \lambda_3}{2})$ is determined from $DGD\left(\dfrac{\lambda_1 + \lambda_2}{2}\right)$, $\textbf{PSP}(\dfrac{\lambda_1 + \lambda_2}{2})$, $DGD\left(\dfrac{\lambda_2 + \lambda_3}{2}\right)$ and $\textbf{PSP}(\dfrac{\lambda_2 + \lambda_3}{2})$.
- DGDs are averaged over λ to obtain PMD, SOPMD(λ) is averaged over λ to obtain SOPMD.

Poincaré Sphere Analysis data acquisition and analysis methods:

- Tunable laser (TLS) is set to the first wavelength λ_1.
- PSG outputs three non-degenerate polarization states: Linear 0°, linear 45°, and RHC.
- PSA measures the corresponding polarization states $\vec{H}$ (λ_1), $\vec{V}$ (λ_1), $\vec{Q}$ (λ_1), after DUT.

- Process is repeated for the next wavelength λ_2
- The following are calculated from the measured normalized Stokes vectors:

$$\vec{h} = \vec{H} \qquad \vec{q} = \frac{\vec{H} \times \vec{Q}}{\left|\vec{H} \times \vec{Q}\right|} \times \vec{H} \qquad \vec{v} = \frac{\vec{q} \times \vec{V}}{\left|\vec{q} \times \vec{V}\right|} \times \vec{q}$$

$$\text{and } \vec{c} = \vec{h} \times \vec{q} \qquad \vec{c}' = \vec{q} \times \vec{v}$$

- For each frequency increment, the finite differences are computed:

$$\Delta\vec{h} = \vec{h}(\lambda_2) - \vec{h}(\lambda_1) \qquad \Delta\vec{q} = \vec{q}(\lambda_2) - \vec{q}(\lambda_1) \qquad \Delta\vec{v} = \vec{v}(\lambda_2) - \vec{v}(\lambda_1)$$
$$\Delta\vec{c} = \vec{c}(\lambda_2) - \vec{c}(\lambda_1) \qquad \Delta\vec{c}' = \vec{c}'(\lambda_2) - \vec{c}'(\lambda_1)$$

- $$DGD(\frac{\lambda_2 + \lambda_1}{2}) = \frac{1}{\Delta\omega}\left[\arcsin(\frac{1}{2}\sqrt{\frac{1}{2}(\Delta\vec{h}^2 + \Delta\vec{q}^2 + \Delta\vec{c}^2)}) + \arcsin(\frac{1}{2}\sqrt{\frac{1}{2}(\Delta\vec{q}^2 + \Delta\vec{v}^2 + \Delta\vec{c}'^2)})\right]$$

- Average DGDs are averaged over λ to obtain PMD, SOPMD(λ) is averaged over λ to obtain SOPMD

Wavelength step size selection for PMD measurement using JME, MMM or PS

The accuracy of the JME method is influenced by drifting birefringence in the test path, stability of the test path, optical source incremental wavelength accuracy, polarimeter accuracy, and the repeatability of the stimulus polarizations. Larger wavelength steps generally provide better accuracy. However, in order to unambiguously measure the polarization change produced by the step, the rotation of the output state about the principal state axis on the Poincaré sphere produced by any single wavelength step must not exceed 180 degrees. In the region of 1550nm, this "alias limit" limits the range of PMD values that can be measured with a given wavelength step size as follows:

$$\Delta\tau(ps)\Delta\lambda \le 4.0(ps \cdot nm) \qquad \text{(external lasers)} \qquad (6.1)$$

$$\text{or} \quad \Delta\tau(ps)\Delta ch \le 10 ps \qquad \text{(internal laser)} \qquad (6.2)$$

where $\Delta\lambda$ is the wavelength step for external lasers and Δch is the step size (# of ITU grid channels) for the internal tunable laser (with a minimum wavelength step of ~0.4 nm). For example, when $\Delta\lambda$ is set to 1nm, the maximum DGD that the PSGA-101A can measure is 4 ps. Similarly, when Δch is set to 1 (the minimum step), the maximum DGD that the PSGA-101A can measure is 10ps. In general, the user should select the largest step size that satisfies these equations for the expected range of the PMD to be measured.

6.1.3 PMD measurement principle for wavelength scanning method

The setup for the wavelength scanning method is the same as for the other methods. The difference is that the PSG maintains only one output polarization state during wavelength scanning. The resulting SOP vs. wavelength curves measured by the PSA contain many peaks and valleys. By counting the number of these extrema, the average DGD (PMD) can be calculated

Wavelength scanning method data acquisition and analysis

- PSG output is set to one of the six non-degenerate states.
- The TLS is tuned to wavelength λ_1.
- PSA measures the SOP (S_1, S_2, S_3) of DUT output.
- The process is repeated to obtain $S_1(\lambda)$, $S_2(\lambda)$, and $S_3(\lambda)$ curves.
- PMD is calculated using the following formula:

$$PMD == \frac{\kappa(N_e - 1)\lambda_a\lambda_b}{2(\lambda_a - \lambda_b)c},$$

(6.3)

where λ_a and λ_b are the positions of the first and last extrema of $S_i(\lambda)$, k is a mode-coupling constant that equals 1.0 in the absence of strong mode coupling and 0.824 in the limit of strong mode coupling, and N_e is the number of peaks and valleys measured over the frequency range from λ_a to λ_b

Wavelength range selection for wavelength scanning method

The wavelength range over which the PMD measurement is performed should be great enough to produce a statistically significant number of extrema. For optical components without mode coupling, a basic measurement can be based on a single cycle of amplitude change, or even a single peak and valley pair. Near 1550nm, the wavelength change required to span two peaks for a given component is approximated by

$$\Delta\lambda_{betweenpeaks}(nm) = \frac{7.8(ps \cdot nm)}{\Delta\tau(ps)}$$

(6.4)

A component with a 1ps average differential group-delay produces peaks which are spaced an average of 7.8 nm apart. For random mode-coupled devices, the relationship is

$$\Delta\lambda_{betweenpeaks}(nm) = \frac{6.5(ps \cdot nm)}{\Delta\tau(ps)}$$

(6.5)

"Delta" parameter selection

Once a wavelength-scanning response has been measured, it must be analyzed to identify and count peaks and valleys (extrema). The parameter "Delta" specifies the threshold value of magnitude change used to differentiate a peak from an adjacent valley. For maximum accuracy, it must be small enough to differentiate legitimate peaks and valleys, and large enough that fluctuations from noise are not identified as extrema. The default value of this parameter is 0.05.

Calculation method selection

Two methods can be used for PMD calculation from the scanning data.

(i) For the "First to Last" method, λ_a in Equation 6.3 is the wavelength of the first extremum, and λ_b is the wavelength of the last extremum

(ii) For the "Full Scan" method, λ_a in Equation 6.3 is the start wavelength of the scan, and λ_b is the end wavelength of the scan.

The "Full scan" method should be used for the measurement of single mode fiber; for optical components or PM fiber, the "First to Last" method can give better accuracy.

6.1.4 Setup for PMD measurement

The recommended PMD measurement setups using the PSGA-101A's internal tunable laser (TLA) and an external tunable light source (TLS) are shown in Figure 17a and b, respectively. All fiber used in the measurement should be firmly fixed in place. Any fiber movement will affect the polarization states and reduce the measurement accuracy. If using the internal tunable laser, make sure that the laser key is turned to the "on" position.

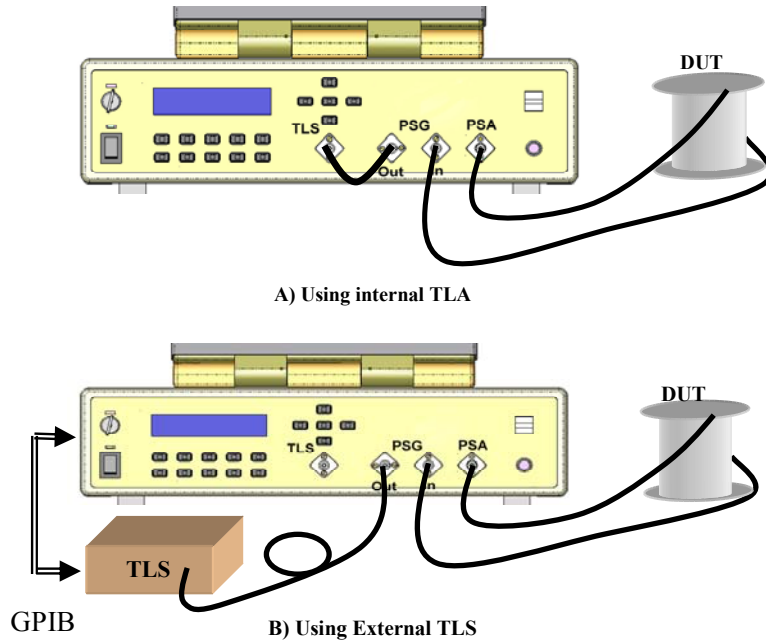
A) Using internal TLA

B) Using External TLS

Figure 17 PMD measurement setups

6.1.5 PMD measurement procedures for JME, MMM and PS methods

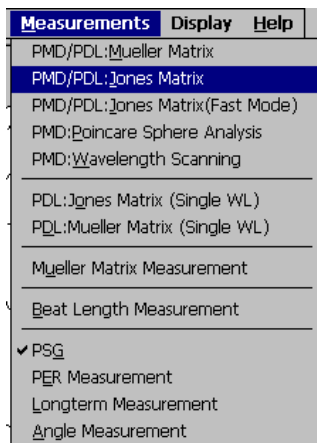Select the preferred measurement method from the "**Measurement**" menu (Figure 18).

Figure 18 PMD measurement method selection

After the measurement method is selected, a tunable laser setup dialog window (Figure 19) pops up.

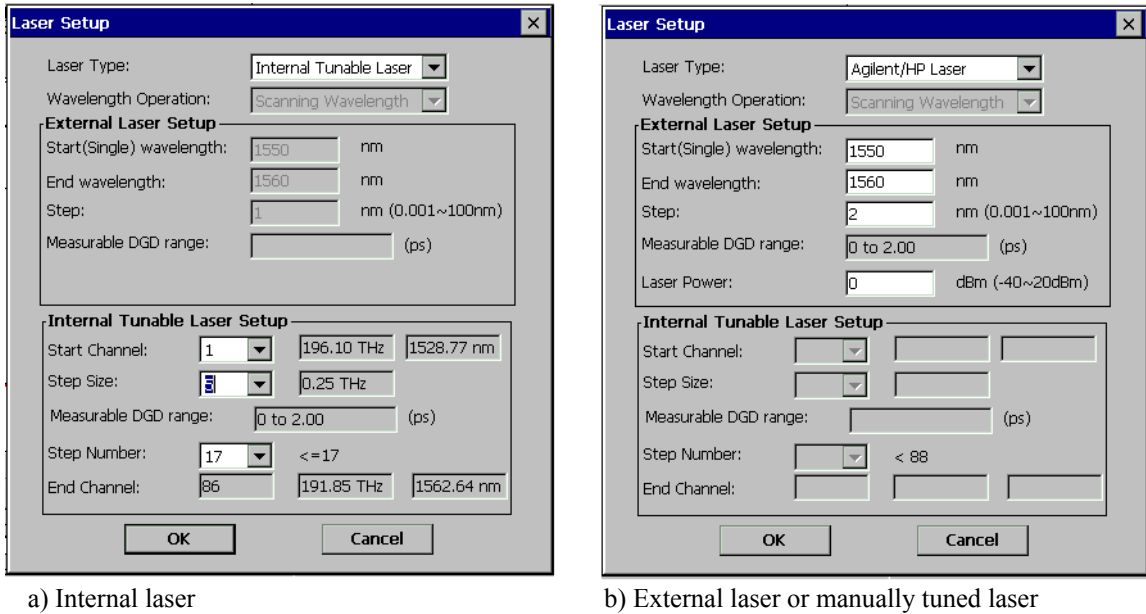a) Internal laser   b) External laser or manually tuned laser

Figure 19 Laser setup for PMD measurement

Select **Laser Type** from the pull-down menu. Standard options are internal tunable laser, Agilent/HP laser, Santec laser, Ando laser, and manually tuned laser (this option allows the PSGA to be used with external lasers that cannot be controlled by the PSGA). Control options for other tunable laser sources can be added by customer request.

If the internal laser is selected, set the "**Start channel**", "**Step Size**" and "**Step number**" from the corresponding pull-down menus in the "**Internal Tunable Laser Setup**" box. Please refer to Section 8 for a detailed description of the optional internal tunable laser. Note that the internal laser cannot be tuned continuously; it can emit 89 discrete wavelengths (channel 1 to channel 89), which match the 50GHz ITU-grid in the C-band.

After the "**Start channel**", "**Step Size**" and "**Step number**" for the internal tunable laser are set, the frequencies and wavelengths corresponding to the selected values are calculated and displayed next to the parameter pull-down menus. **Note:** The sum of "**Start_channel + (Step_size*Step_number)**" must be less than 89. Also, the step size chosen will affect the range and accuracy of the measurement. Please refer to the "wavelength step size selection" description in Section 6.1.2 for directions on how to choose the correct step size for measurement of a particular device under test (DUT).

If the external laser or manually tuned laser is selected, set "Start wavelength", "End wavelength", "Wavelength step" and "Laser output power" by typing the values in the

corresponding boxes. **Note:** Please refer to the "wavelength step size selection" description in Section 6.1.2 for directions on how to choose the correct wavelength step. Click the "**Ok**" button to save the laser setup and bring up the PMD measurement interface (Figure 20).
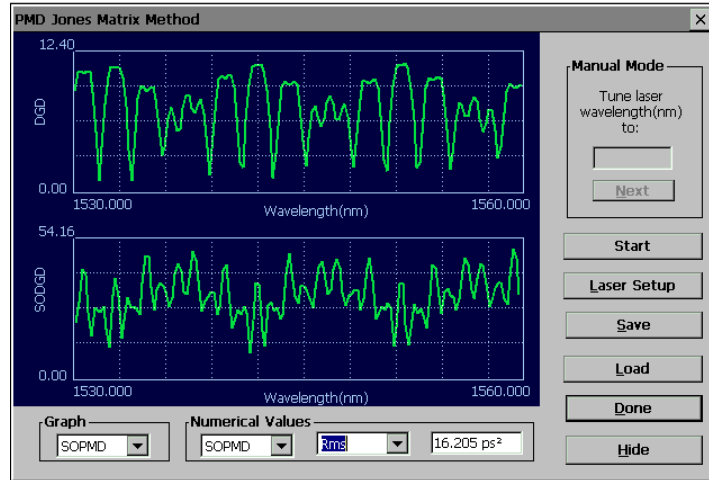

Figure 20 PMD measurement interface

Automatic mode (Internal tunable laser or PSGA-controlled external laser):

Click the "Start/Stop" button to begin the PMD measurement.

DGD and second order PMD vs. wavelength plots will be drawn as the measurement proceeds. Once the measurement is finished, DGD and second order PMD (SOPMD) values will be displayed at the bottom of the screen. If the Jones Matrix method or Mueller Matrix method are used, the wavelength dependence of the SOPMD, PDL, PSP, $\Omega_{//}$ (absolute value of the parallel component of SOPMD), $\Omega_{\perp}$ (absolute value of the perpendicular component of SOPMD) and phase change are measured concurrently with DGD. The pull-down menu in the Graph box can be used to select the parameter to be displayed in the second graph. If PSP is selected, the graph will display the wavelength dependence of the Stokes parameters S1 (green), S2 (red) and S3 (yellow) of the PSP. The pull-down menus in the Numerical Values box can be used to select the average, RMS, standard deviation, maximum, minimum, or current value of DGD, PDL, SOPMD, $\Omega_{//}, \Omega_{\perp}$ or PSP Stokes parameters to be displayed in the adjoining box. If "current" is selected before measurement begins, the box will update as each point is measured.

To hide the measurement window and return to the main screen Poincaré sphere display, click "Hide". The measurement window can be recovered by clicking "Display" in the menu bar of the main screen.

Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data.

Note: Saved files will include all of the measured data. For JME or MMM, the file includes DGD, SOPMD, PDL, PSP, $\Omega_{//}$, $\Omega_{\perp}$ and phase change vs. wavelength. A Poincaré Sphere method file will include the same set of data as JME and MMM except for PDL. A wavelength scanning method file includes S1, S2, and S3 vs. wavelength, as well as the PMD values calculated from each Stokes parameter curve.

Previously saved data can be recalled from the measurement screen by clicking the "Load" button. Once the user chooses the desired file, the data will be displayed on the screen. For JME or MMM files, the user can use the pull-down menu to change the parameter displayed in the second graph.
Note: Files generated by JME, MMM, or PS methods can be recalled from any of those measurement screens, but not from the wavelength scanning method screen.

To start a new measurement with the same laser setup, click "Start" again. To change the laser setup before a new measurement, click "Laser Setup" to bring up the laser setup window.

Manual mode:

If the laser type is set as "**Manually tuned**", the "manual mode" box in the interface will be enabled (Figure 21).

- Click the "**Start**" button in the "manual mode" box to start the measurement.

- The start wavelength entered from "External Laser Setup" will appear in the "Manual Mode" box. Manually tune the external laser to this wavelength.

- Click "**Next**" to execute the measurement process for this wavelength. When the measurement is finished, the next wavelength in the sequence will appear in the box.

- Tune the external laser to the next measurement wavelength, then click "**Next**" for the next measurement.

- When measurement is completed for all wavelengths in the sequence entered in the external laser setup, the "**Next**" button will revert to "**Start**".

- Clicking "**Start**" will begin a new measurement.
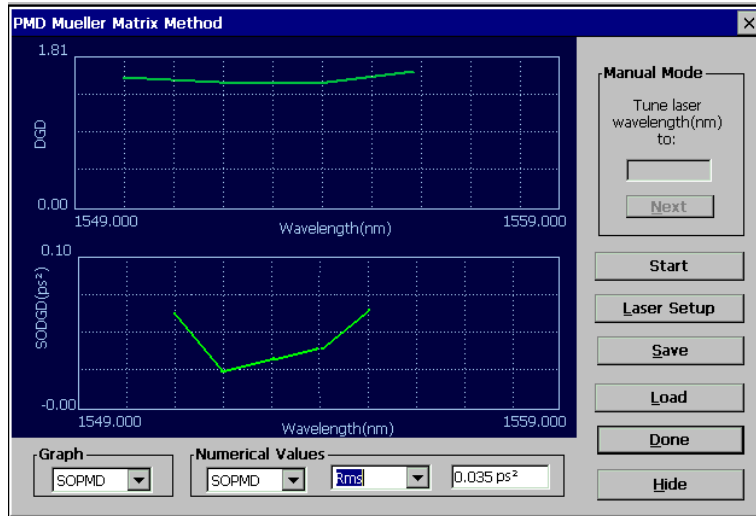
Figure 21 PMD measurement using a manually tuned laser source

Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data.

Previously saved PMD data can be recalled from this screen by clicking the "Load" button. Once the user chooses the desired file, the data will be displayed on the screen.

6.1.6   PMD measurement procedure for wavelength scanning method

Select "**PMD: Wavelength Scanning**" from the "Measurement" menu (Figure 18). After completing the laser setup (see previous section), the measurement screen will appear (Figure 22). Note: The "Manually Tuned Laser" option does not work with the wavelength scanning method.
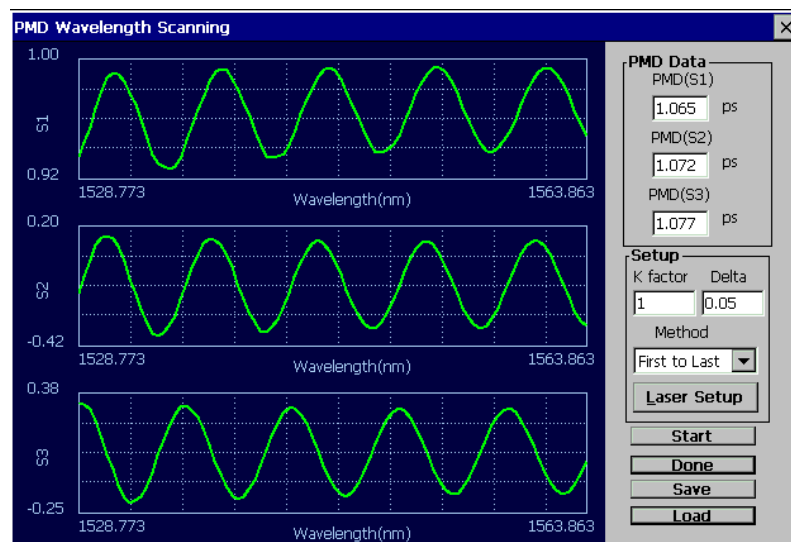
Figure 22 PMD measurement using wavelength scanning method

- Set the value of the mode-coupling constant k in the "K factor" box in the "Setup" section on the right of the screen; k is equal to 1 in the absence of strong mode coupling, and to 0.82 for the limit of strong mode coupling. The default value of k is 0.82.

- Set the parameter "delta" (range is 0~1). Once a wavelength-scanning response has been measured, it must be analyzed to identify and count the peaks and valleys (extrema). "Delta" is a minimum feature size parameter defining the magnitude change used to differentiate a peak from an adjacent valley. The default value of this parameter is 0.05.

- Select the calculation method. The average DGD (PMD) can be calculated as:

$$PMD \; == \frac{\kappa(N_e - 1)\lambda_a \lambda_b}{2(\lambda_a - \lambda_b)c}, \tag{6.6}$$

where N_e is the number of extrema.

(i) For the "First to Last" method, λ_a is the wavelength of the first extremum, and λ_b is the wavelength of the last extremum

(ii) For the "Full Scan" method, λ_a is the start wavelength of the scan, and λ_b is the end wavelength of the scan.

The "Full scan" method should be used for the measurement of single mode fiber or DUTs with variable PMD values and strong mode coupling. For optical components, PM fiber, or other DUTs with fixed PMD values and weak mode coupling, the "First to Last" method can provide greater accuracy.

- Click the "Start" button to begin measurement. The PSGA plots out Stokes parameters S_1, S_2, and S_3 vs. wavelength as the measurement proceeds. When the measurement is finished, it displays the PMD values calculated from the extrema in each graph in the "PMD Data" box at the top right of the screen.

Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data. The file includes S1, S2, and S3 vs. wavelength, as well as the PMD values calculated from each Stokes parameter curve.

Previously saved wavelength scanning data can be recalled from this screen by clicking the "Load" button. Once the user chooses the desired file, the data will be displayed on the screen.

6.2 Polarization Dependent Loss (PDL) Measurement

The phenomenon of polarization dependent loss (PDL) describes the insertion loss variation, gain variation or coupling variation of an optical component over all possible input signal polarization states. Polarization dependent loss is defined as the maximum insertion loss (IL) (expressed in dB) minus the minimum IL (expressed in dB) due to input polarization variation. The PSGA-101A measures polarization dependent loss (PDL) or gain (PDG) using either the Mueller matrix method or the Jones matrix method.

6.2.1 PDL Measurement Principle

At each wavelength specified in the measurement setup, the Mueller matrix (Section 6.4) or Jones matrix of the DUT is measured by measuring the polarization states of the DUT outputs corresponding to different input polarization states generated by the PSG.

- If the Mueller matrix of the DUT is

$$
\begin{bmatrix}
m_{00} & m_{01} & m_{02} & m_{03} \\
m_{10} & m_{11} & m_{12} & m_{13} \\
m_{20} & m_{21} & m_{22} & m_{23} \\
m_{30} & m_{31} & m_{32} & m_{33}
\end{bmatrix}
$$

Then the PDL can be calculated as:

$$
PDL = -10 \times \log(\frac{P_{Min}}{P_{Max}}) = -10 \times \log \frac{m_{00} - \sqrt{m_{01}^2 + m_{02}^2 + m_{03}^2}}{m_{00} + \sqrt{m_{01}^2 + m_{02}^2 + m_{03}^2}} \tag{6.7}
$$

- If the measured Jones matrix of the DUT is

$$
J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}
$$

let $M = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} J_{11}^* & J_{21}^* \\ J_{12}^* & J_{22}^* \end{bmatrix} = \begin{bmatrix} m_{11} & m_{12} \\ m_{21} & m_{22} \end{bmatrix}$,

Then the PDL of the DUT can be calculated as follows:

$$
PDL = 10 * \log\left|\frac{r1}{r2}\right| \tag{6.8}
$$

Where

$$r_{1,2} = \frac{m_{11} + m_{22}}{2} \pm \sqrt{(\frac{m_{11} + m_{22}}{2})^2 - m_{11}m_{22} + m_{12}m_{21}}$$

are the eigenvalues of matrix **M**.

Differences between Mueller matrix and Jones matrix methods

If different polarization states with the same power pass through an optical device, the output power will generally be polarization dependent because of the PDL of the device. If power variations are measured for at least four non-degenerate polarization states, then the PDL can be calculated using the Mueller matrix method. Because the Mueller matrix method for PDL measurement is based on measurement of power variations, the measurement accuracy is insensitive to polarization changes (for example, because of fiber movement) between the PSG and PSA). However, any PSG output power variation (due to fluctuation of laser output power, changes of polarization state along the fiber between the laser and PSG, etc.) during testing will produce significant measurement error. Therefore, accurate PDL measurement using the Mueller matrix method requires that the laser source be highly stable and that the fiber between the laser source and the PSG be firmly fixed in place.

If different polarization states with the same power pass through an optical device, the relative angles between the input and the output polarization states will be different because of PDL. If these angle changes are measured for at least three non-degenerate polarization states, then the PDL can be calculated using the Jones Matrix method. Because the Jones matrix method is based on measurement of angle variations, the measurement accuracy is insensitive to PSG output power fluctuations. However, any polarization disturbance in the fiber between the PSG and PSA will cause significant measurement error. Therefore, accurate PDL measurement using the Jones matrix method requires that the fiber between the PSG and PSA be fixed.

Because the Mueller matrix method (MMM) for PDL measurement is based on power measurement, it can measure small PDL values with high accuracy, but has relatively narrow dynamic range which is limited by the dynamic range of the detector. The Jones matrix method (JME) is based on angle measurement, so it provides high dynamic range, but its resolution is limited by the angle measurement resolution of the PSA. Therefore, for maximum accuracy, the MMM should be used for measurement of small PDL values and the JME for measurement of high PDL values.

6.2.2 Setup for PDL measurement

The optical connections used for PDL measurement are the same as those for PMD measurement, as shown in Figure 23. If using the internal tunable laser, make sure that the laser key is turned to the "on" position before beginning measurement.
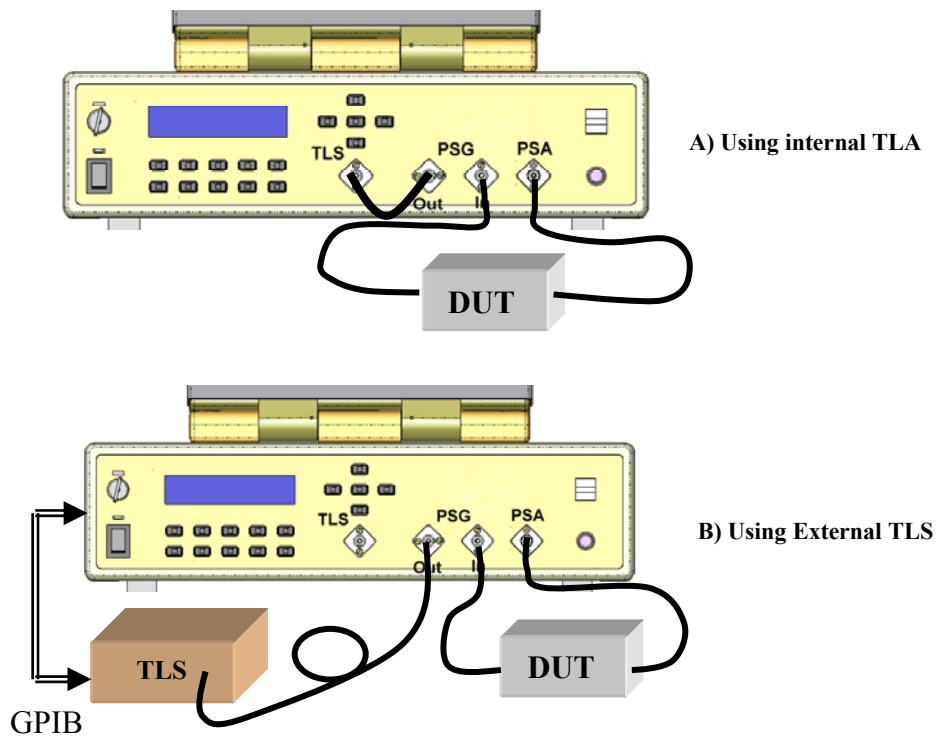
Figure 23 Setup for PDL measurement

6.2.3 PDL Measurement procedure

From the "**Measurements**" pull-down menu, select the desired measurement method. For single wavelength measurements:"**PDL:Jones Matrix (Single WL)**" or "**PDL:Mueller Matrix (Single WL)**". For PMD/PDL vs. wavelength measurements: "**PMD/PDL:Jones Matrix**", "**PMD/PDL:Jones Matrix (Fast Mode)**" or "**PMD/PDL:Mueller Matrix**". (Figure 24).
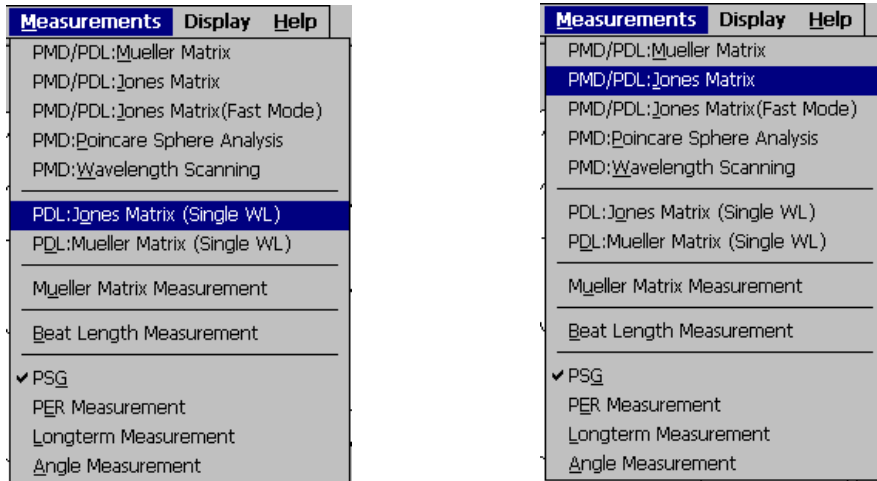
Figure 24 PDL measurement options on the "Measurement" menu

Single-wavelength measurements:

If "**PDL:Jones Matrix (Single WL)**" or "**PDL:Mueller Matrix (Single WL)**" is selected, the single-wavelength measurement interface window (shown below) appears.

Figure 25 Single wavelength PDL measurement.

Input the measurement wavelength in the "λ" box and the number of measurements to be averaged in the "count" box, then click "**Start**" to begin measurement. Make sure that the laser is set to the correct wavelength before starting the measurement (see section 8 for directions on how to set the wavelength for the internal tunable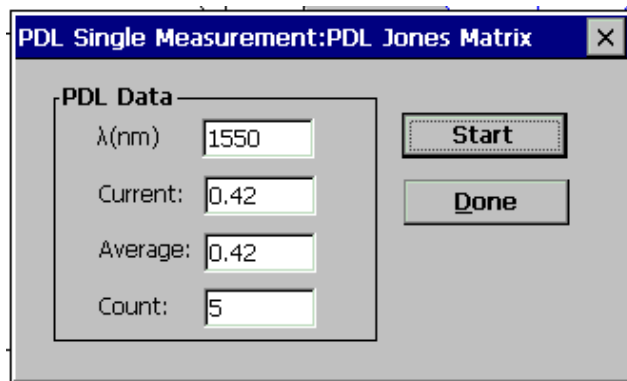 laser). The results will be displayed in the "current" (result of last single measurement) and "average" (average of results from all measurements) boxes. The number of measurements to be averaged can be chosen to compensate for instabilities in the measurement setup.

Wavelength-dependent measurement:

1) Laser setup: If a wavelength dependent measurement ("**PMD/PDL:Jones Matrix**" or "**PMD/PDL:Mueller Matrix**") is selected, a **Laser Setup** dialog box will pop up (Figure 26). Select the laser type from the pull-down menu. Available options include internal tunable laser, Agilent/HP laser, Santec laser, Ando laser, and manually tuned laser.
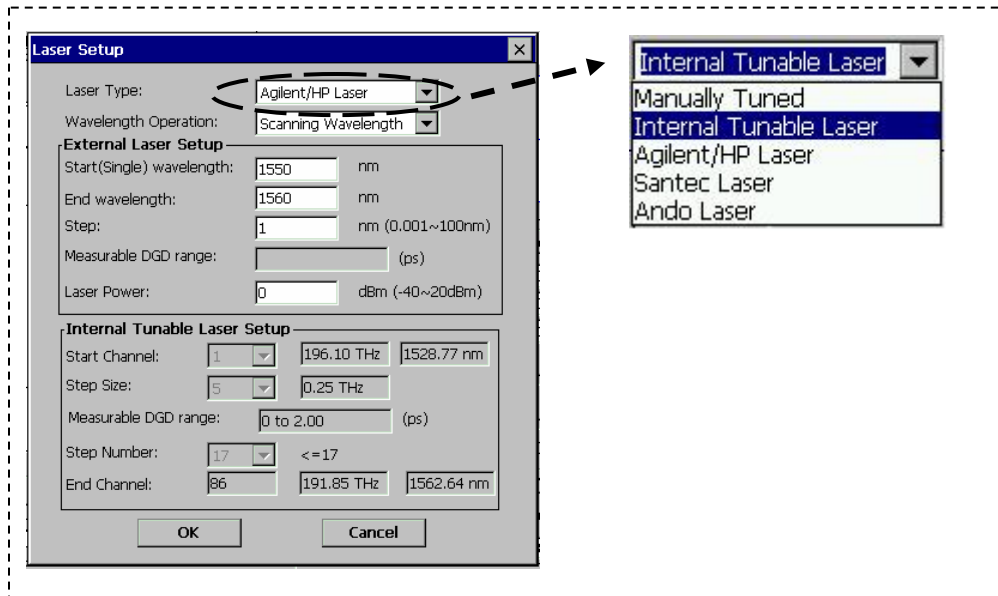
Figure 26 Wavelength scanning (Laser) setup for PDL measurement

If "internal laser" is selected, the "**Internal Tunable Laser Setup**" box will be enabled. Set the "Start channel" (channel 1-89), "Step Size" (number of channels in each step) and "Step number" (number of steps in the scan) from the pull-down menus (Figure 26). After the scan parameters are set, the corresponding frequencies and wavelengths are calculated and displayed in the boxes next to the parameters.
Note: The sum of "**Start_channel + (Step_size*Step_number)**" must be less than 89.

If the external or manually tuned laser is selected, set the "Start wavelength", "End wavelength", "Wavelength step" size and "Laser output power" in the "**External Laser Setup**" box (Figure 26).
The laser setup screen can also be accessed from the measurement window by clicking the "Laser Setup" button.

2) After the laser setup is finished, click "**OK**" to proceed to the measurement interface (Figure 27). Click "**Start**" to start the measurement. Select "PDL" from the pull-down menu in the Graph box. The real time wavelength dependence of the PDL will be shown on the lower graph. After the measurement is finished, use the pull-down menus in the "Numerical Values" box at the bottom of the screen to display the average, RMS, standard deviation, maximum, or minimum value of the measured PDL.
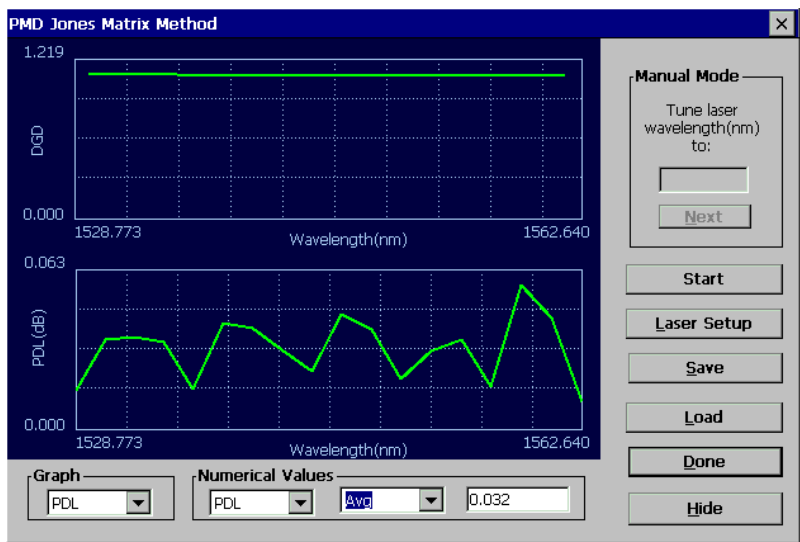
Figure 27 PDL Measurement interface

Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data. As previously noted, the saved file includes DGD, SOPMD, PDL, PSP, $\Omega_{//}$ (absolute value of the parallel component of SOPMD), $\Omega_{\perp}$ (absolute value of the perpendicular component of SOPMD) and phase change vs. wavelength.

Previously saved PDL data can also be recalled from this screen by clicking the "Load" button. Once the user chooses the desired file, the data will be displayed graphically on-screen.

6.3 Polarization Extinction Ratio (PER) Measurement:

To minimize polarization dependent effects, it is often desirable to maintain a constant state of polarization as light propagates through an optical system. With regard to such systems, polarization extinction ratio (PER), or polarization crosstalk, is a measure of the degree to which the light is confined in the principal polarization mode. It is defined as the ratio of the power in the principal polarization mode to the power in the orthogonal polarization mode after propagation through the system, expressed in dB.

6.3.1   PER measurement principle

Polarization maintaining (PM) optical fibers have an optical (slow) axis defined by a strong linear birefringence. If light input to an ideal PM fiber is polarized along the fiber's optical axis, the polarization state will be maintained during propagation through the fiber. However, if it is misaligned, or is not fully polarized, the component polarized along the slow axis propagates at a different speed than the component polarized along the fast axis. Thus, the polarization state of the light changes with the relative phase delay between the two components as it propagates through the fiber. For the case of a linearly polarized light beam launched into a PM fiber with its polarization axis rotated by an angle θ from the PM fiber's slow axis, as shown in Figure 28, the extinction ratio due to the misalignment can be calculated as

$$PER = -10log(tan^2\theta) \tag{6.9}$$
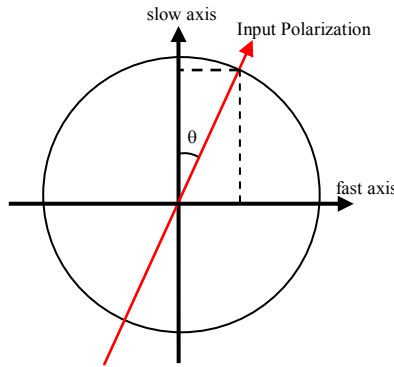
Figure 28 A representation of linearly polarized light misaligned by an angle θ from the slow axis of a PM fiber

The misalignment angle is difficult to measure directly, as it depends on the determination of the orientation of the fiber's slow axis. Variations in the input wavelength or in the fiber length due to temperature changes or mechanical stress change the relative phase delay between the two orthogonal polarization components, causing the state of polarization of the output light to rotate along a circle on the Poincaré sphere. The rotation axis of the circle is defined by the optical (slow) axis of the PM fiber and the

radius of the circle by the misalignment of the light to the slow axis, as shown in Figure 29.
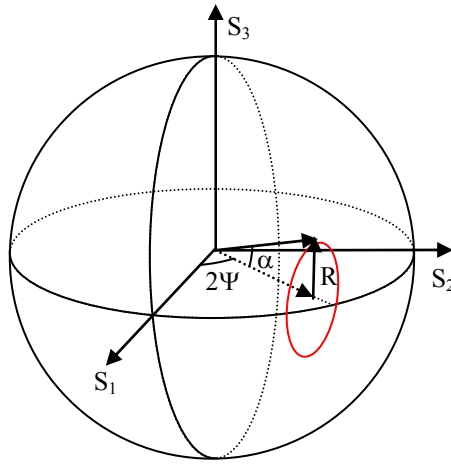
Figure 29 Poincaré Sphere illustration of polarization state rotation of output light from a PM fiber due to thermal or mechanical stress

The polarization extinction ratio, then, can be calculated directly from the size of the circle:

$$PER = -10\log(\frac{\sin^2\frac{\alpha}{2}}{\cos^2\frac{\alpha}{2}}) = -10\log(\frac{1-\cos\alpha}{1+\cos\alpha}) = -10\log(\frac{1-\sqrt{1-R^2}}{1+\sqrt{1-R^2}}) \qquad (6.10)$$

For complete confinement in one mode, R → 0 (the circle collapses to a point), corresponding to PER → ∞. At the other extreme, if the light is evenly distributed between the two orthogonal polarization modes, R → 1 (the circle becomes a circumference of the sphere), corresponding to PER → 0.

In the PSGA system, the output light is directly coupled into the PSA through a free space interface, so the rotation axis of the circle is on the plane of the equator of the Poincaré sphere, and the angle Ψ is the angle between the slow axis and the reference plate of the PSA. Because the key slot of the PSA adapter is aligned perpendicular to the reference plate, the angle 90-Ψ represents the angle between the slow axis of the PM fiber and the connector key. For example, Ψ=90° means that the slow axis of the PM fiber is vertical and aligned to the alignment key direction; Ψ=0° means that the slow axis of the PM fiber is horizontal and perpendicular to the alignment key direction.

In practical measurement, the center of the circle generally deviates from the plane of the equator. This deviation is caused by stress and/or other defects at the connector. Generally, greater deviation from the equator indicates higher stress.

6.3.2 PER Measurement Setup

The PER measurement setup is shown in Figure 30. If using the internal tunable laser, make sure that the laser key is turned to the "on" position before beginning measurement.
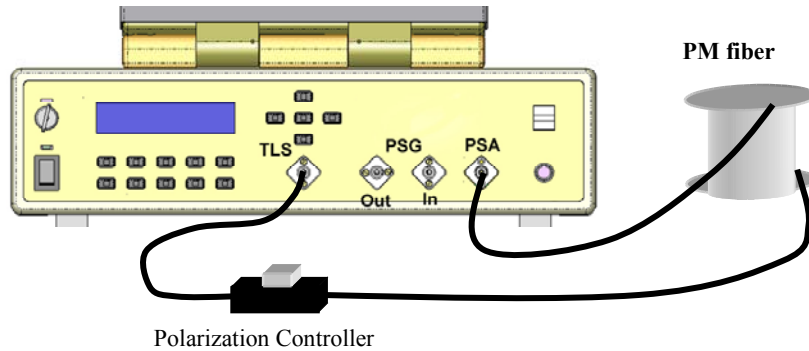
Figure 30 Measurement setup for PER measurement of PM fiber

Note: The manual polarization controller is useful for characterizing lengths of PM fiber, but is not necessary for all DUTs.

6.3.3 PER Measurement Procedure

- If using the λ-scan method with the PSGA's internal tunable laser, select "PER" from the Setup menu:
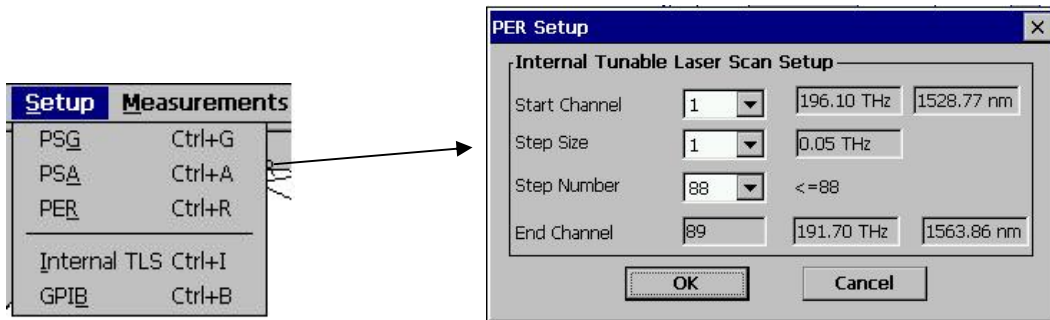
Figure 31 PER laser setup

Select the start channel, step size, and step number for the wavelength scan.

- Select "**PER Measurement**" from the "**Measurements**" menu (Figure 32).
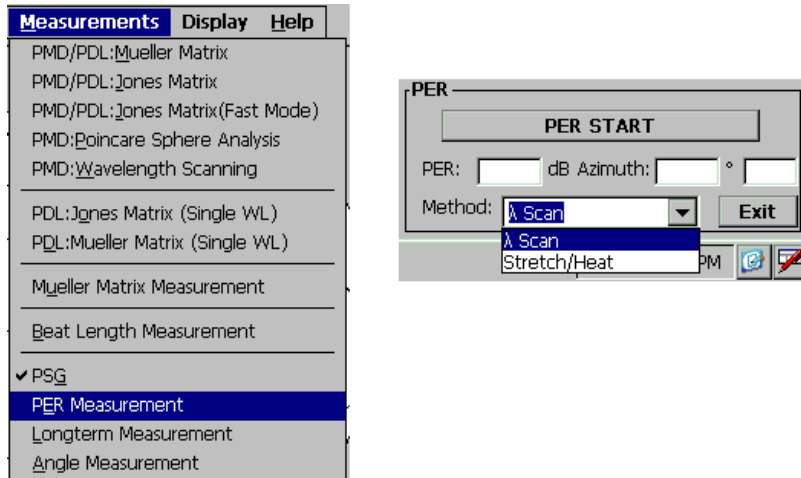
Figure 32 PER measurement selection

The PER measurement box will replace the PSG box in the bottom right corner of the main interface screen.

- As mentioned in the previous section, PER is determined by measuring output polarization rotation caused by changes in the relative phase between the two polarization components. The changes in relative phase can be caused either by variation in input wavelength or by changes in the fiber's optical path length. The PSGA's measurement method options are based on these two principles. In the **Stretch/Heat** method, the input wavelength remains constant, and the user stretches or heats the PM fiber to cause polarization rotation. In the λ **scan** method, the tunable laser is used to scan the input wavelength, while the PM fiber is left unchanged. Select the desired method from the **Method**s pull-down menu in the PER measurement area in the bottom right corner of the main screen (Figure 32).

Stretch/Heat method

- Press **PER START** to begin the measurement. The PSGA will begin to draw the PM fiber's output polarization state on the Poincaré sphere.
- Gently stretch or heat a section of fiber near the PSA input port until at least half a circle has been traced out on the Poincaré sphere. Hold the fiber straight while it is being stretched or heated.
- Once a sufficient section of a circle has been traced out, click the "**PER STOP**" button to calculate the PER and the key alignment angle (Figure 33).

λ Scan Method

- Click "**PER START**" to begin measurement. The internal tunable laser will scan the wavelength using the parameters set up from the PER laser setup screen, as described above. After the scan is finished, the PER, azimuth angle with respect to

the horizontal direction, and PM fiber axis to which the light is aligned (slow/fast) are calculated and displayed in the PER measurement box at the bottom right of the main screen. It should be noted that if the PMD of the PM fiber is greater than 10ps, the PSGA cannot identify the slow or fast axis of the PM fiber.
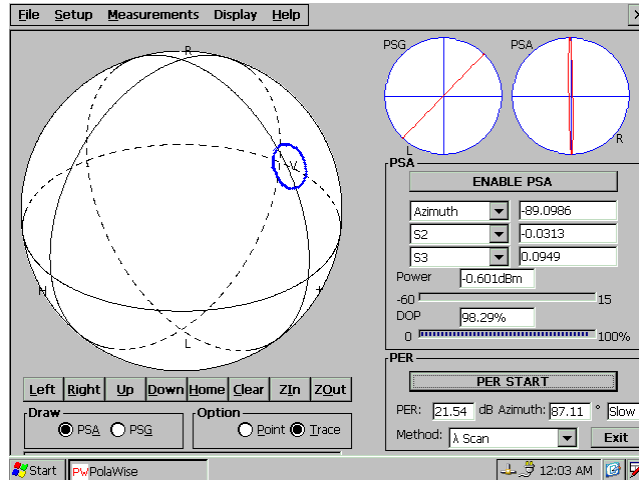
Figure 33 PER Measurement Results

To measure the PER of a length of PM fiber, independent of connector effects, etc. the following iterative procedure can be used:

- After the first measurement is completed, carefully adjust the polarization controller to move the polarization state to the center of the circle.
- Press **PER START** and repeat the measurement
- Adjust the polarization controller again and repeat until the highest PER measurement is found.

6.4 Mueller Matrix measurement

The PSGA can measure the Mueller matrix of a DUT.

6.4.1 Principle of Mueller matrix measurement
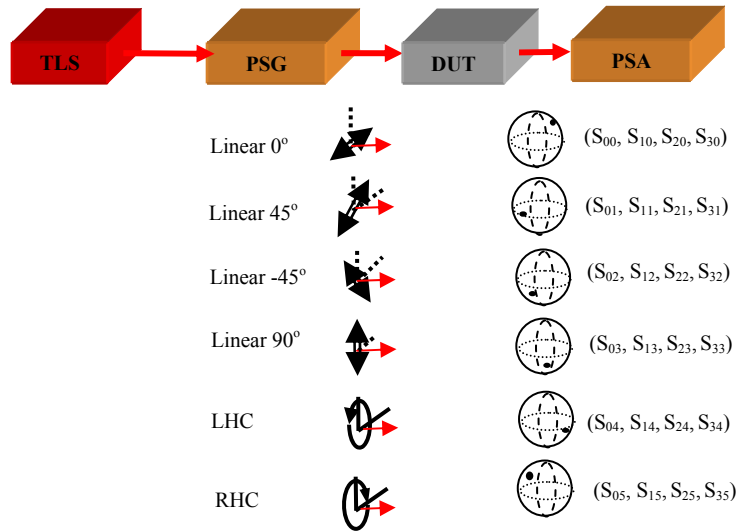
Figure 34 Principle of Mueller matrix measurement

- The PSG generates six non-degenerate states: Linear 0°, 45°, -45°, 90°, LHC and RHC, in sequence.

- The Stokes parameters (S1, S2, S3, S4, S5 and S6) of these six PSG output states are calculated for wavelength λ according to PSG calibration data.

- The PSA measures the corresponding output Stokes parameters (S1', S2', S3', S4', S5' and S6') without DUT.

- Reference matrix $\mathbf{M_{Ref}}$ is calculated from the calculated and measured Stokes parameters using the following formula:

$$\mathbf{M_{Ref}} = \mathbf{S'_{PSA}} \bullet \mathbf{S_{PSG}}^{\mathbf{T}} \bullet (\mathbf{S_{PSG}} \bullet \mathbf{S}^{\mathbf{T}}_{\mathbf{PSG}})^{-1}$$

Where

$$\mathbf{S_{PSA}} = \begin{pmatrix} S'_{01} & S'_{02} & S'_{03} & S'_{04} & S'_{05} & S'_{06} \\ S'_{11} & S'_{12} & S'_{13} & S'_{14} & S'_{15} & S'_{16} \\ S'_{21} & S'_{22} & S'_{23} & S'_{24} & S'_{25} & S'_{26} \\ S'_{31} & S'_{32} & S'_{33} & S'_{34} & S'_{35} & S'_{36} \end{pmatrix} \text{ and } \mathbf{S_{PSG}} = \begin{pmatrix} S_{01} & S_{02} & S_{03} & S_{04} & S_{05} & S_{06} \\ S_{11} & S_{12} & S_{13} & S_{14} & S_{15} & S_{16} \\ S_{21} & S_{22} & S_{23} & S_{24} & S_{25} & S_{26} \\ S_{31} & S_{32} & S_{33} & S_{34} & S_{35} & S_{36} \end{pmatrix}$$

- The DUT is placed between the PSG and PSA, and the procedure described above is repeated to obtain matrix Mx.

- The Mueller matrix of the DUT is calculated: $M_{DUT} = Mx * M^{-1}_{Ref}$

6.4.2 Measurement setup for Mueller matrix measurement

The setup for Mueller matrix measurement is shown in Figure 35. The light source can be the internal laser or an external laser source. For free space measurement, the FC adapter at the PSA input should be removed. A pigtailed collimator connected to the PSG output should be used to generate a parallel light beam. Align the position and orientation of the collimator to maximize the power received by the PSA. In order to obtain the actual Mueller matrix of the DUT, a reference matrix without the DUT in the light path must first be measured. Connections for reference matrix measurement are shown in red.
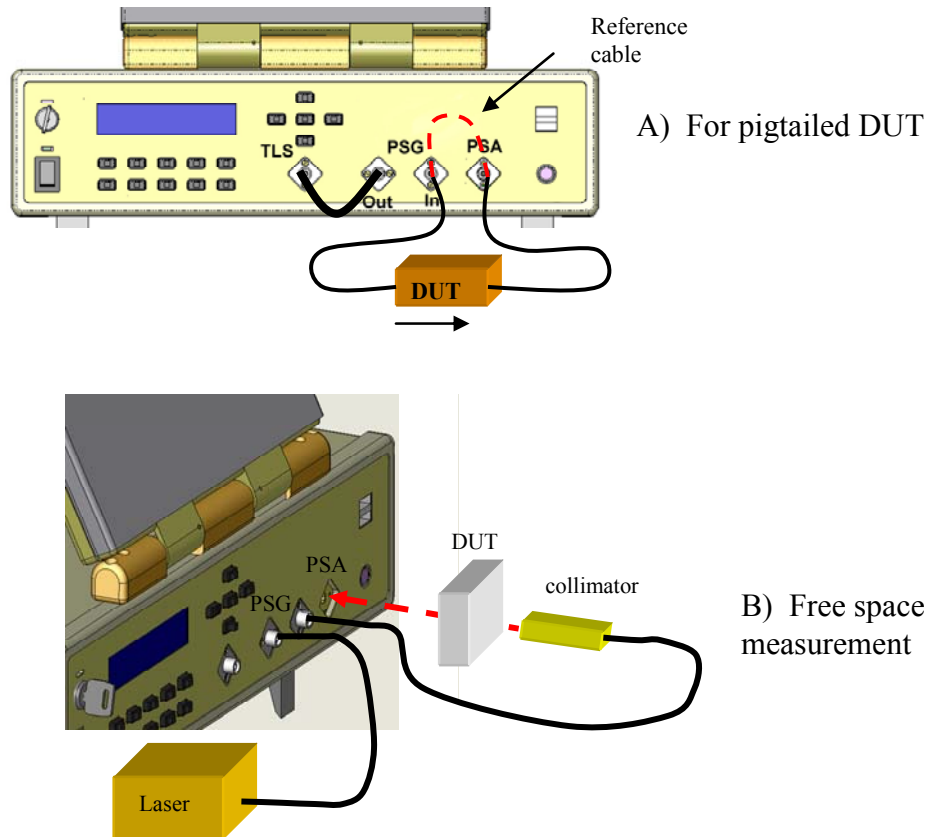
Figure 35 Setup for Mueller matrix measurement

6.4.3 Test procedure for Mueller matrix measurement

- Select **Mueller Matrix Measurement** from the **Measurements** menu at the top of the main interface screen (Figure 36).
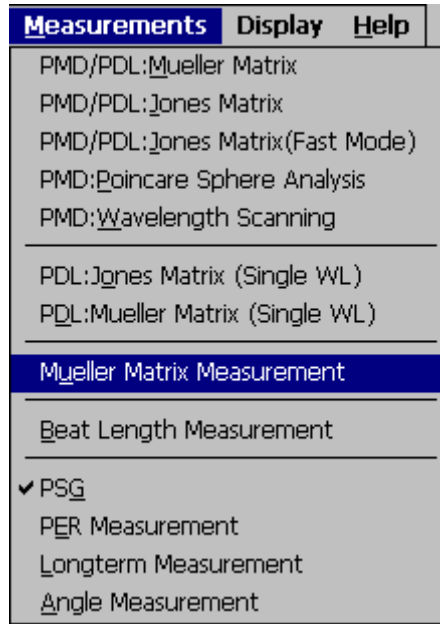
Figure 36 Mueller Matrix measurement selection

- For a pigtailed DUT, connect a reference patchcord between the PSG output and the PSA input to measure the reference matrix.
  For free space applications, use a pigtailed collimator to guide the light into the PSA with the adapter removed.
  Click "**Reference**" to obtain the reference matrix (Figure 37).

- Connect a pigtailed DUT between the PSG output and the PSA input, or place a free space optical component between the collimator output and the PSA. Click "**DUT**" to begin the measurement.
  The Mueller matrix of the DUT will be displayed in the "DUT" box in the lower half of the screen (Figure 37). The corresponding polarization dependent loss (PDL) and insertion loss (IL) are also calculated and displayed.
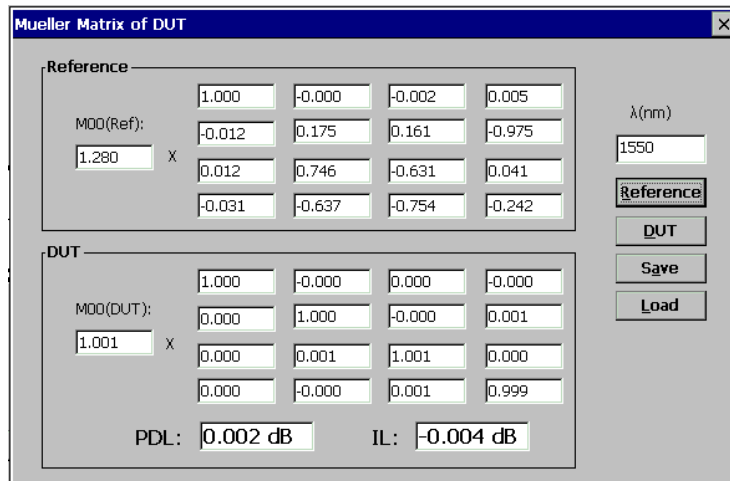
Figure 37 Measured Mueller matrix

The M00 (DUT) is the first element of the Mueller matrix (in the first column and the first row). The Mueller matrix is divided by M00 and the results are shown next to M00 (DUT).

6.5 Long Term Measurement

The long term measurement function allows the user to measure, record and display the time dependence of the SOP of input light.

Long Term Measurement Procedure

- Select **Long Term Measurement** from the **Measurements** menu at the top of the main interface screen (Figure 38a). A long-term measurement interface box will appear at the bottom right corner of the main screen (Figure 38b) in place of the PSG control box.
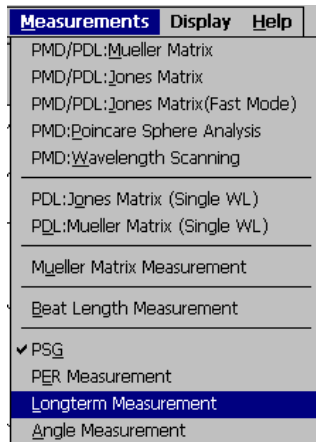
a) Measurement menu   **b) Long-term measurement setup**

Figure 38 Long Term Measurement selection

- Select a measurement option from the "Option" pull-down menu.

    Free Run: The PSGA records the number of SOP points specified in the "Point #" box at the fastest possible sampling rate (sampling rate is determined by the currently selected PSA operation mode- "high speed" or "high precision". See Section 5.3.2 for details).

    Timed: The PSGA records the number of SOP points specified in the "Point #" box at a rate of one sample per period, with the period (interval between measurements) specified in the "period" box in units of seconds.

- Specify measurement parameters:

    Point #: The total number of points to be measured (must be specified in both measurement modes).

    Period(s): The time interval between two adjacent SOP measurements in timed measurement mode.

- Click "**START**" to begin measurement. SOP points will appear on the Poincaré sphere as they are recorded.

- Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data. Previously saved long-term SOP data can be recalled from this screen by clicking the "Load" button. Once the user chooses the desired file, the data will be displayed on the Poincaré sphere.

- Poincaré sphere data from a completed or in-progress long-term measurement can be viewed from different vantage points by using the "left," "right," "up," "down," "ZIn," and "ZOut" buttons under the sphere display. Recorded data points will rotate or zoom with the sphere.
  Note: During measurement, the PSA plots points at its normal speed, but only recorded points will be maintained on the sphere during sphere manipulation. For a "timed" measurement, depending on the sampling period chosen, this can cause most of the points to disappear as the sphere is rotated or zoomed. "Free Run" mode is better for tracking fast polarization changes.

- The **Long Term Measurement** function can be terminated by clicking the **Exit** button. The long term measurement interface box will be replaced by the PSG control box.

6.6 Angle Measurement

The PSGA-101A can measure the angle between specified points on the Poincaré sphere.

Angle Measurement Procedure

- Select **Angle Measurement** from the **Measurements** menu at the top of the main interface screen (Figure 39a). An **Angle Measurement** interface will appear at the bottom right corner of the screen, replacing the PSG control box (Figure 39b).
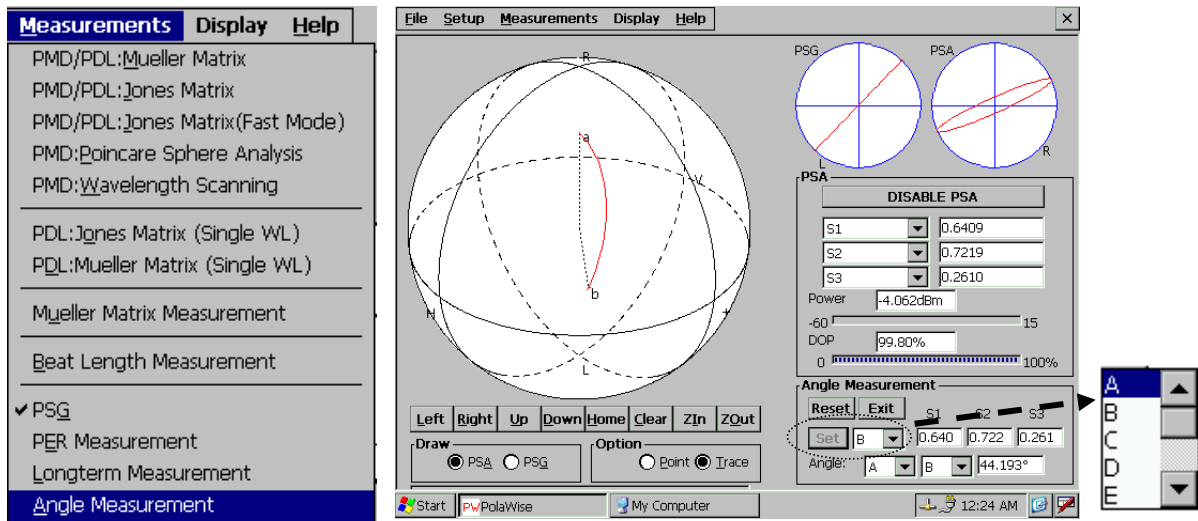
a) Measurement menu **b) Sphere display with angle interface** **c)**

Figure 39 Angle Measurement selection

- To mark the current SOP point on the Poincaré sphere, select a marker name from the pull-down menu in the dialog box (Figure 39c), then click **Set** to mark that point. A labeled marker will appear on the sphere, and the Stokes parameters of the point will be displayed in the S1, S2, and S3 boxes in the Angle Measurement area. Up to 10 separate points can be marked. Selecting the marker name of a particular marked point from the pull-down menu in Figure 39c will recall the Stokes parameters of that point.

- To calculate the angle between two marked points, select the marker names of the points between which the angle is to be calculated from the pull-down menus in the "Angle" line ("A" and "B" in the example above). The angle between the selected points will be calculated and displayed in the adjacent box.

- Clicking **Reset** clears all markers.

- The **Angle Measurement** function can be terminated by clicking the **Exit** button**.** The angle measurement interface box will be replaced by the PSG interface box.

6.7 Beat-length Measurement

Beat length is important because it indicates how well a fiber maintains polarization. It is a measure of how fast the two orthogonal modes become decoupled and thus cease to exchange energy. Fibers with short beat lengths preserve polarization more strongly than those with long beat lengths. For bowtie-type PM fibers, beat lengths are typically only a few millimeters, whereas for standard non-PM single-mode fibers, beat lengths are on the order of tens of meters.

6.7.1 Principle of Beat Length

Beat length L_B is defined as the ratio of the wavelength of the transmitted light λ to the fiber's phase birefringence Δn,

$$L_B = \frac{\lambda}{\Delta n} \tag{6.11}$$

However, the differential group delay (DGD) measured by the PSGA-101A system is related to the group birefringence Δn_g, rather than to the phase birefringence (see formula 6.12).

$$DGD = \Delta n_g\, L\, /c \tag{6.12}$$

where L is the propagation distance and c is the speed of light.
The relationship between phase and group birefringence is:

$$\Delta n_g = \Delta n - \lambda \frac{d\Delta n}{d\lambda} \tag{6.14}$$

So the beat length can be calculated from the measured DGD:

$$L_B = \frac{\lambda}{\dfrac{DGD * c}{L} + \lambda \dfrac{d\Delta n}{d\lambda}} \tag{6.15}$$

If the chromatic dispersion equation of the fiber is

$$n^2 = 1 + \frac{B_1 \lambda^2}{\lambda^2 - C_1} + \frac{B_2 \lambda^2}{\lambda^2 - C_2} + \frac{B_3 \lambda^2}{\lambda^2 - C_3}, \tag{6.16}$$

then the beat length can be calculated from $L_B = \dfrac{\lambda * y}{\dfrac{DGD * c}{L}}$ $\tag{6.17}$

where $y = 1 - \dfrac{1}{n}\left[n^2 - 1 - \left(\dfrac{B_1 \lambda^4}{(\lambda^2 - C_1)^2} + \dfrac{B_2 \lambda^4}{(\lambda^2 - C_2)^2} + \dfrac{B_3 \lambda^4}{(\lambda^2 - C_3)^2} \right) \right].$

For PM fiber, $DGD_{1310} \approx DGD_{1550}$, so the beat length at 1310 nm can be estimated from a measured value according to the following formula

$$L_{B1310} = \frac{1310}{\lambda} L_{B\lambda} \qquad (6.18)$$

Where $L_{B\lambda}$ is the measured beat length at wavelength λ.

6.7.2 Beat Length Measurement Procedure

- Select **Beat Length Measurement** from the **Measurements** menu at the top of the main interface screen (Figure 40).
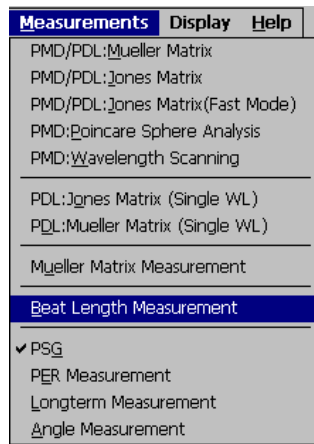
Figure 40 Beat Length Measurement selection

- After the measurement method is selected, a tunable laser setup dialog window (Figure 19) pops up. Select **Laser Type** from the pull-down menu. Standard options are internal tunable laser and Agilent tunable laser. Other tunable laser sources can be added by customer request.

- After the laser type and scanning wavelength range are set up, click the "**OK**" button to save the laser setup and bring up the beat length measurement interface (Figure 41). Since the beat length is calculated from measured DGD, the laser scan parameters should be chosen according to the expected DGD of the fiber under test.
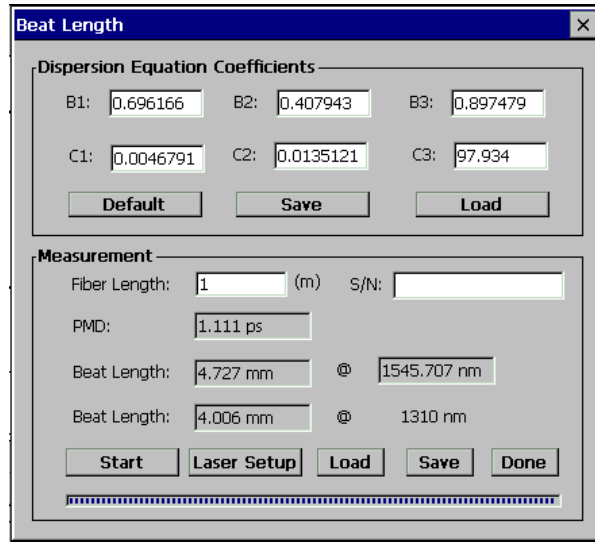
Figure 41 Beat Length Measurement Interface

- Input the length and serial number of the fiber under test. Note that the length of fiber that can be measured will be limited by the DGD measurement range corresponding to the wavelength range of the laser source (10 ps for the internal tunable laser). Click "Start" to begin measurement. The PMD of the fiber and the beat length at the center wavelength of the scanning range will be calculated and displayed. The approximate beat length at 1310nm is also calculated using equation 6.18. Once a measurement is completed, the data can be saved by clicking the "Save" button. The user will be prompted to input a file name and location for the saved data.

- The default dispersion equation (6.16) coefficients used for the calculation are those of fused silica glass. Users can change, save and load sets of dispersion coefficients for different materials to more closely match the fiber under test.

Section 7. Front Panel Control:

In addition to the user-friendly graphic display control and measurement interface, the PSGA-101A also provides control access through the front panel LCD and function keys. This feature can simplify measurements for particular applications or environments.

Figure 42 shows the front panel layout of the PSGA-101A. The ten major function keys are located under the blue LCD screen.
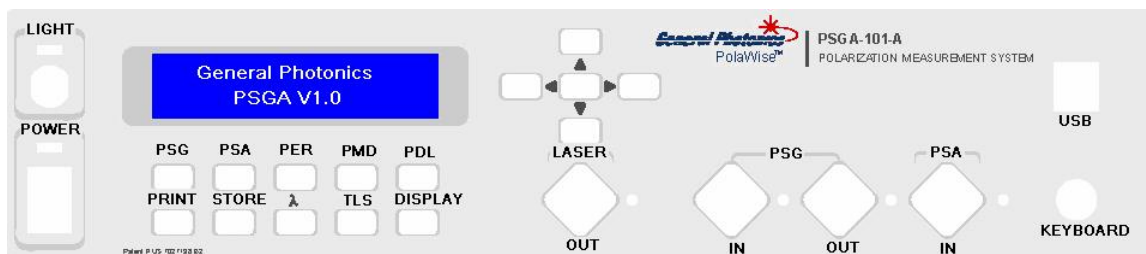
Figure 42 Front panel layout of the PSGA-101A

When the PSGA-101A is first turned on, the flip-up LCD graphic display is automatically enabled. After initialization, it shows the interface screen pictured in Figure 4. The front panel LCD display shows:
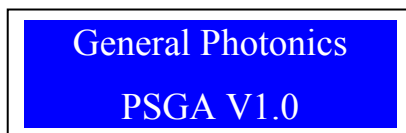
Figure 43 Front panel LCD startup screen

As long as the flip-up LCD graphic display is enabled, the front panel LCD displays the startup screen shown in Figure 43, and most of the front panel function keys are disabled. Only the "PRINT" and "DISPLAY" keys will respond.

The "DISPLAY" key toggles the flip-up LCD graphic display on and off. When it is off, the PSGA's front panel control is enabled. The PSGA accepts input from the front panel keys and displays results to the front panel LCD. When it is on, the PSGA's GUI control interface is enabled and the front panel control is disabled. In short, the, "DISPLAY" key is used to select the PSGA's user interface.

The "PRINT" key is only functional when the graphic display is enabled. When "PRINT" is pressed, the PSGA-101A will print the graphic display screen to a *.bmp file. The user will be prompted to enter a name and location for the stored file.

Front Panel Function Key Summary:

PSG: Brings up PSG control options
PSA: Brings up PSA control options
PER: Begin setup for PER measurement
PMD: Begin setup for PMD measurement
PDL: Begin setup for PDL measurement
PRINT: Prints currently displayed screen on flip-up graphic display to a bitmap file. Can only be used with graphic display enabled.
STORE: Store current settings (PSG or laser settings) or measured data (PMD or PDL) to a file.
λ: Select wavelength settings for PMD measurement.
TLS: Select laser source for PMD measurement
DISPLAY: Toggles PSGA between front panel and GUI user interfaces

▲
◄ ►: Arrow keys - used to scroll through menus or enter numerical parameters
▼

ENTER (key in center of the arrow keys): Used to select menu options or enter parameters

PSGA front panel control:
(Please see section 6 for optical connection diagrams for the various measurements.)

7.1 PSG control
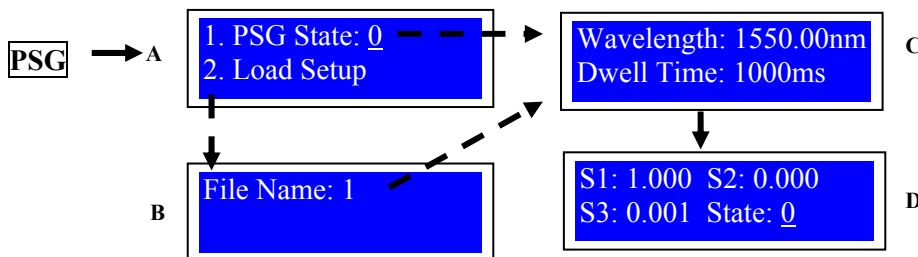
Figure 44 PSG front panel control sequence

- Press the PSG key to bring up the main PSG control menu (Figure 44A). The left arrow (◄) key moves between options 1 and 2.

- Option 1: With the "PSG State" option highlighted, the up and down arrow keys (▲▼) can be used to select the PSG output polarization state. Options are: 0°, 45°, -45°, 90°, RHC, LHC, and SCAN. Press ↵ (ENTER- center key in the arrow keypad) to go to the PSG setup interface (Figure 44C).

- Option 2: "Load Setup" is used to recall a stored settings file. With "2" on the main menu highlighted, press ↵ to select the PSG setup file to be loaded (Figure 44B). The up and down arrow keys (▲▼) are used to scroll through available file numbers, and ↵ is used to load the selected file.

- After the setup file is loaded, the interface shown in Figure 44C is displayed.

- In the setup interface (Figure 44C), the arrow keys (▲▼◄►) can be used to enter values for the wavelength of the input light and the dwell time per state for the scanning mode. After setting the values, press ↵ to execute the settings and proceed to the SOP display interface (Figure 44D).

- The SOP display interface (Figure 44D) shows the current PSG output state (0°, 45°, -45°, 90°, RHC, or LHC) and its Stokes parameters.

- The up and down arrow keys (▲▼) can be used to change the PSG output state from the SOP display interface. Options are: 0°, 45°, -45°, 90°, RHC, LHC, SCAN.

- In "Scan" mode, the PSG will scan through the states in the following sequence: 0°, 45°, -45°, 90°, LHC, RHC, using the currently set dwell time at each step.

- In Scan mode, pressing ↵ will terminate the scanning process. The output polarization will stay in the state it was in when ↵ was pressed. Pressing Enter again will restart the scan.

7.2 PSA control
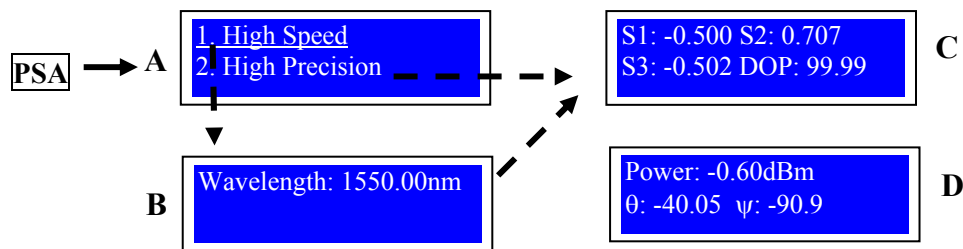
Figure 45 PSA front panel control sequence

- Press the PSA key to bring up the PSA measurement mode selection screen (Figure 45A)

- Use the up and down arrow keys (▲▼) to select "High Speed" or "High Precision" measurement mode.

  If "High Speed" is selected, the wavelength of the input light must be specified. Press ↵ to proceed to the wavelength setting screen (Figure 45B). From the screen shown in Figure 45B, use the arrow keys to set the wavelength and ↵ to accept it and proceed to a data display screen.

  If "High precision" is selected, press ↵ to proceed directly to a data display screen.

- After the wavelength is set for "High Speed" mode or after "High Precision" is selected, the first data display screen shows the current SOP (as Stokes parameters) and DOP of the input light (Figure 45C).

- The ▼ key toggles the data display to the second screen (Figure 45D) which displays the optical power, ellipticity angle θ and azimuth angle ψ. The ▲ key toggles the display back to the Stokes parameter screen.

7.3 PER measurement

Note: Only the λ scan measurement method can be used with front panel control.

A
```
PER: 20.2dB  Start
θ:     -12.1º
```

B
```
PER:  20.2dB Testing
θ:     -12.1º
```
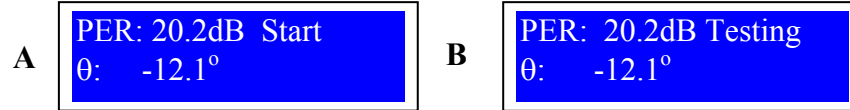
Figure 46 PER measurement front panel control sequence

- Press the PER key to bring up the PER measurement screen (Figure 46A). Any other processes currently in progress (PSG scanning, tunable laser scanning, PSA, PMD or PDL measurement) will stop. If a PSG scan was in progress, the PSG output remains in the state it was in when the "PER" key was pressed.

- Turn the laser key on the top left of the front panel to the "on" position (*the internal tunable laser must be turned on*).

- Press ↵ to begin the measurement using the λ scan method (default). While testing is in progress, the "Start" in the display will change to "Testing" (Figure 46B). When testing is complete, the measured PER and angle will be displayed.

7.4 PMD measurement

Note: Only the Jones matrix method can be used with front panel control.
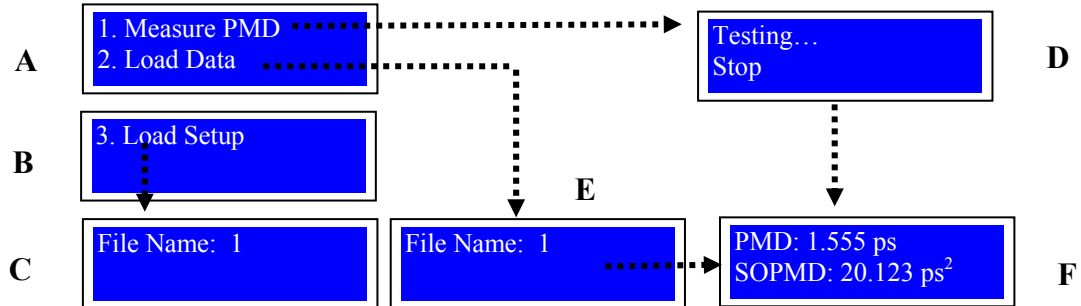
Figure 47 PMD measurement front panel control sequence

- If using the internal tunable laser, check that the laser key above the main power button is in the "on position.

- Press the PMD button to bring up the main PMD measurement menu (Figure 47A and B). Use the up and down arrow keys (▲▼) to scroll through the options ("Measure PMD", "Load Setup", or "Load Data"). Press ↵ to select the highlighted option and proceed to the next step.

- To begin a new measurement, select "Measure PMD". PMD measurement will begin using the Jones matrix method, with the current laser setup parameters (see "Load Setup" step for directions on how to change laser setup parameters). During testing, the screen shown in Figure 47D is displayed. Pressing ↵ during testing will terminate a test in progress and return the display to Figure 47A. Otherwise, after testing is complete, measurement results will be displayed (Figure 47F)

- To recall stored data from an earlier measurement, select "Load Data". After ↵ is pressed, the file selection screen (Figure 47E) is displayed. Use the up and down arrow keys (▲▼) to select the desired file number, then press ↵. The recalled measurement data will be displayed on a measurement data display screen (Figure 47F).

- To recall a stored laser and wavelength setup file, select "Load Setup" (Figure 47B). After ↵ is pressed, the file selection screen (Figure 47C) is displayed. Use the up and down arrow keys (▲▼) to select the desired file number, then press ↵ to load the selected file. (This data would be a TLS file. After it is recalled, the settings can be viewed using the "λ" and TLS buttons.) The laser and wavelength settings can also be manually set using the "λ" and TLS keys.

7.5 PDL measurement

Note: Only single-wavelength PDL measurements can be performed using front panel control.

A   B

PDL ▪▪▪▶

| Wavelength |
| 1550.00 nm |

▪▪▪▶

| PDL: 20.23 |
| Avg Times: 12   Start |
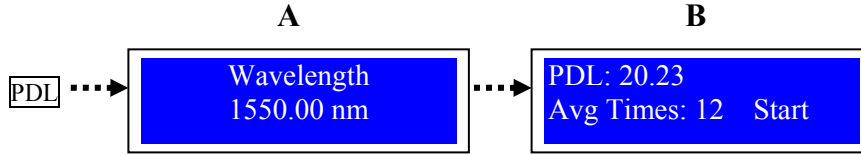
Figure 48 PDL measurement front panel control sequence

- Check that the laser key above the main power button is in the "on position.

- When the PDL key is pressed, the wavelength selection screen (Figure 48A) is displayed.

- Use the arrow keys to set the wavelength, then press ↵ to proceed to the measurement interface (Figure 48B).

- Use the arrow keys to select the number of measurements to be averaged (within the range of 1~99).

- Move cursor to **Start** using the right arrow (▶) key, then press ↵ to start the measurement.

- After the measurement is completed, the PDL value will be displayed. If any error is found during testing, the test will be terminated and the errors will be shown.

7.6 PMD measurement laser selection
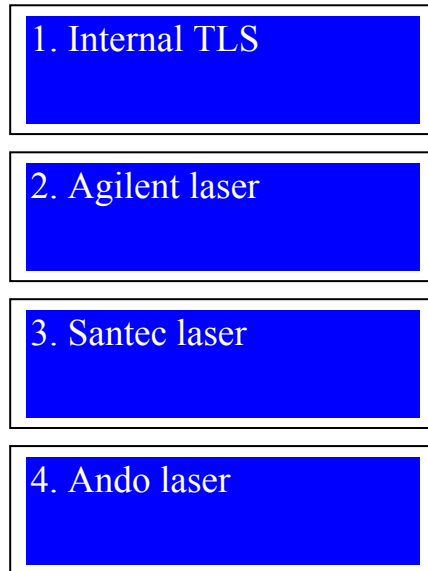
Figure 49 Laser selection screens

The TLS key is used to select the laser source used for PMD measurement.

- Go to TLS setup interface by pressing the TLS key (Figure 49).

- Use up and down arrow keys (▲▼) to select the desired laser source for PMD measurement (default is internal TLS).

7.7 Wavelength/wavelength scan setup for PMD measurement

7.7.1 Wavelength setup for the internal tunable laser
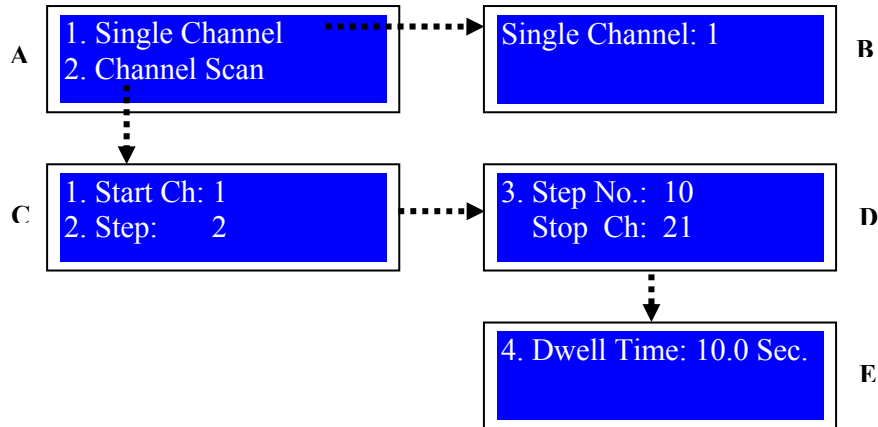
Figure 50 Internal laser source wavelength selection control sequence

- Press $\boxed{\lambda}$ to bring up the main wavelength setup selection screen (Figure 50A).

- Use the up and down arrow keys (▲▼) to select "Single Channel" setup or "Channel Scan" setup. Press ↵ to select the highlighted option.

- If "Single Channel" is selected, the display proceeds to the channel selection screen (Figure 50B). Use the up and down arrow keys (▲▼) to set the channel number, and ↵ to execute the setting.

- If "Channel Scan" is selected, the display proceeds to the first scan setup screen (Figure 50C). Use the arrow keys to set the start channel, scanning step, step number and dwell time for PMD measurement. Press ↵ to execute the setting.

7.7.2 Wavelength setup for an external tunable laser source


```
A    ┌─────────────────────────┐          ┌─────────────────────────┐   B
     │ 1. Single Wavelength    │········▶  │   Single Wavelength     │
     │ 2. Wavelength  Scan     │          │     1550.00 nm          │
     └─────────────────────────┘          └─────────────────────────┘
                 ┊
                 ▼
C    ┌─────────────────────────┐          ┌─────────────────────────┐   D
     │ 1. Start WL: 1540.00nm  │········▶  │ 3. Step No: 20          │
     │ 2. Step:       1.00nm   │          │    Stop WL: 1560nm      │
     └─────────────────────────┘          └─────────────────────────┘
                                                      ┊
                                                      ▼
                                          ┌─────────────────────────┐   E
                                          │ 4. Dwell Time: 10.0 Sec.│
                                          └─────────────────────────┘
```
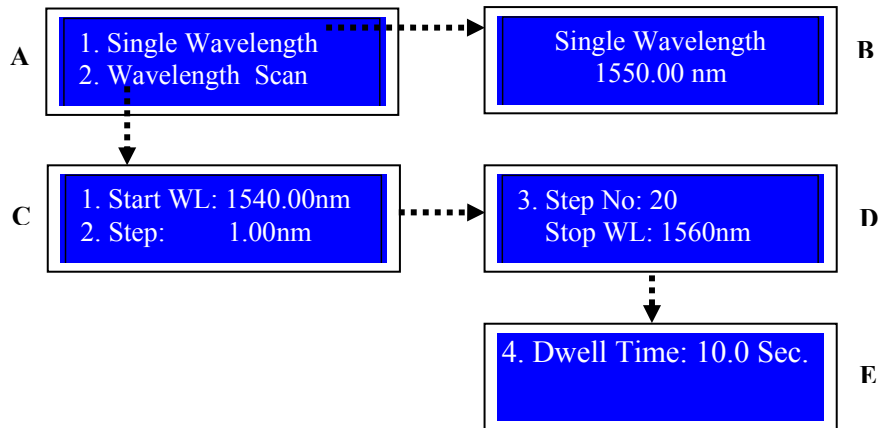
Figure 51 External laser source wavelength selection control sequence

- Press λ to bring up the main wavelength setup selection screen (Figure 51A).

- Use the up and down arrow keys (▲▼) to select "Single Wavelength" setup or "Wavelength Scan" setup. Press ↵ to select the highlighted option.

- If "Single Wavelength" is selected, the display proceeds to the wavelength selection screen (Figure 51B). Use the arrow keys to set the wavelength, and ↵ to execute the setting.

- If "Wavelength Scan" is selected, the display proceeds to the first scan setup screen (Figure 51C). Use the arrow keys to set the start wavelength, scanning step, step number and dwell time for PMD measurement. Press ↵ to execute the setting.

7.8 Measurement or setup data storage

The "Store" key is used to save current settings or measurement data to a file.
When the Store key is pressed, the file storage menu is displayed (Figure 52).

```
1. Type :PSG
2. FileName: xx 3.Save
```

Figure 52 Data storage interface

- When the file storage menu first appears, option 1 is highlighted. Use the arrow keys to select 1, 2 or 3.

- If 1 is selected, press ↵ to access the file type options. Use the up and down arrow keys (▲▼) to scroll through file type options (PSG, PDL, PMD, and TLS).

- Use the left and right arrow keys (◄►) to move to option 2, and ↵ to select it, then use the up and down arrow keys (▲▼) to change the file number xx (range is 1~99). Press ↵ to accept the file number and return to menu option selection (the cursor will move to the 2 before "FileName" on the menu.

- Use the left and right arrow keys (◄►) to move to option 3, then press ↵ to save the file xx.PSG, xx.PDL, xx.PMD or xx.TLS.

- xx.PSG is used to store the current PSG setup; xx.PMD is used to store PMD measurement results; xx.TLS is used to store the laser and wavelength setup for PMD measurement; xx.PDL is used to store PDL measurement results.

- If the file number chosen contains previously saved data, the user will be asked whether or not to overwrite the file.
  (i) Default position of cursor is "No"
  (ii) Use the left and right arrow keys (◄►) to select "Yes" or "No": If the answer is "Yes", the existing file is overwritten; otherwise, the cursor returns to option 2 to allow the user to select another number.

Section 8. Internal Tunable Laser (Optional):

To facilitate different measurements using wavelength scanning related procedures, the standard configuration of the PSGA-101A includes an internal tunable laser. The tunable laser can be used by itself as an independent light source, or in conjunction with the other PSGA modules (PSG and PSA) to perform different measurements.

To set up the internal tunable laser's operation parameters, select "**Internal TLS**" under the "**Setup**" menu in the menu bar at the top of the main control interface. The laser setup window (Figure 53) will appear. The control options are described below.
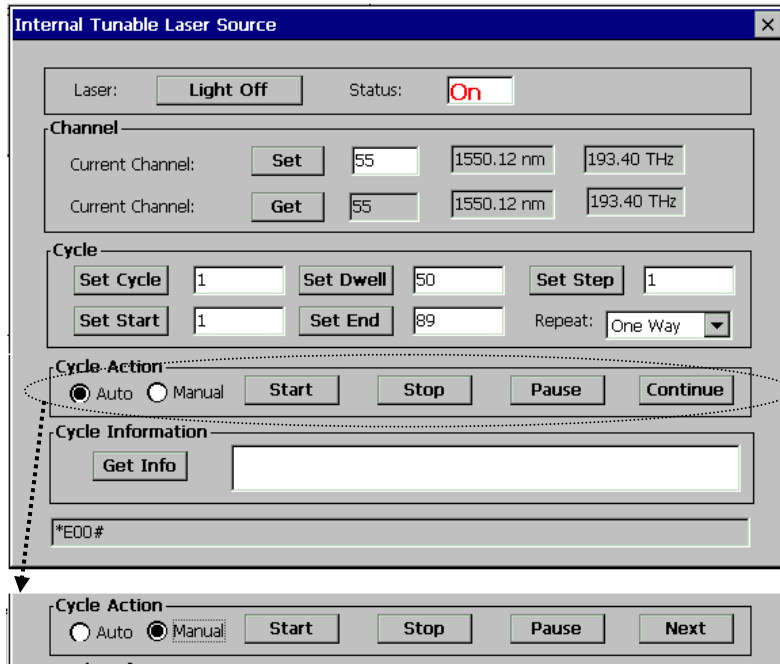
Figure 53 Internal tunable laser source setup interface

Table 3 Internal tunable laser source control options

Light On/Light Off:	Turns Laser on or off. For the laser to turn on, both the laser key above the main power switch on the front panel and the "Light On/Light Off" button in this setup window must be in the "on" position.
Current Channel Set	Sets the channel number (wavelength) of internal laser; the corresponding wavelength and frequency are shown in the text boxes to the right of the "Set" button after "Set" is clicked.
Current Channel Get	Reads the current channel (wavelength/frequency) of internal laser output.

Cycle function keys:	Used to set parameters for a wavelength scan
Set Cycle	Sets the number of times to perform the scan; range is 1-999.
Set Dwell	Sets the dwell time per state during a scan. Can only be used when cycle action is set to "auto"; nnnn is 20-3600 ms
Set Start	Sets the start channel of a sweep. nn: 1~89
Set End	Sets the end channel of a sweep. nn 1~89
Set Step	Sets the step size (number of channels per step). nn:1~89
Repeat option: One way/Two way	One way: The scan starts at the designated start wavelength and ends at the designated end wavelength. This process is repeated the number of times set in the "Set Cycle" box. Two way: A round-trip scan starting at the designated start wavelength, proceeding to the end wavelength, and then scanning back to the start wavelength. This process is repeated the number of times set in the "Set Cycle" box.
Auto Cycle Mode	Wavelength sweeps continuously according to the parameters set in the Cycle parameter box.
Manual Cycle Mode	Wavelength sweep is controlled manually
Start	Starts channel (wavelength) sweep
Stop	Stops channel(wavelength) sweep
Pause	Pauses Channel(wavelength) sweep
Continue	Continues a paused channel (wavelength) sweep
Next	In manual scan mode, tunes the channel (wavelength) to the next channel in the sequence dictated by the scan parameters set in the Cycle parameter box.
Get Info.	Displays the current scan parameters
Message Box (last line in window)	Shows laser command response codes *E00#: OK *E01#: command error *E13#: parameter setting error: the start and end channel settings are not compatible with the step size. *E14#: command conflict. For example: Start used during a scan *E15#: TLA is not ready for output. Command should be re-sent

The output wavelengths of the internal tunable laser source match the 50GHz ITU-grid. Corresponding channel numbers and wavelengths are listed in Table 4.

Table 4 Tunable laser output channels and corresponding wavelengths

Channel #	Wavelength (nm)	Channel #	Wavelength (nm)	Channel #	Wavelength (nm)
1	1528.77	31	1540.56	61	1552.52
2	1529.16	32	1540.95	62	1552.93
3	1529.55	33	1541.35	63	1553.33
4	1529.94	34	1541.75	64	1553.73
5	1530.33	35	1542.14	65	1554.13
6	1530.72	36	1542.54	66	1554.54
7	1531.12	37	1542.94	67	1554.94
8	1531.51	38	1543.33	68	1555.34
9	1531.90	39	1543.73	69	1555.75
10	1532.29	40	1544.13	70	1556.15
11	1532.68	41	1544.53	71	1556.55
12	1533.07	42	1544.92	72	1556.96
13	1533.47	43	1545.32	73	1557.36
14	1533.86	44	1545.72	74	1557.77
15	1534.25	45	1546.12	75	1558.17
16	1534.64	46	1546.52	76	1558.58
17	1535.04	47	1546.92	77	1558.98
18	1535.43	48	1547.32	78	1559.39
19	1535.82	49	1547.72	79	1559.79
20	1536.22	50	1548.11	80	1560.20
21	1536.61	51	1548.51	81	1560.61
22	1537.00	52	1548.91	82	1561.01
23	1537.40	53	1549.32	83	1561.42
24	1537.79	54	1549.72	84	1561.83
25	1538.19	55	1550.12	85	1562.23
26	1538.58	56	1550.52	86	1562.64
27	1538.98	57	1550.92	87	1563.05
28	1539.37	58	1551.32	88	1563.45
29	1539.77	59	1551.72	89	1563.86
30	1540.16	60	1552.12		

Section 9. Remote Control:

The PSGA-101A can be remote controlled through either the GPIB or ETHERNET ports on the rear panel.

9.1 GPIB Control
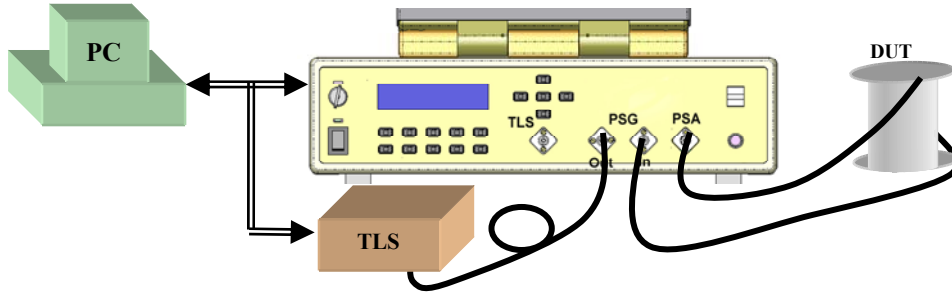
Figure 54 Configuration for GPIB control using PC

The typical configuration for GPIB control of the PSGA and an external tunable laser is shown in Figure 54. After the hardware connections are made, proceed through the following steps:

- Select **GPIB** setup from the "**Setup**" menu (Figure 55a).The GPIB setup dialog window will appear (Figure 55b and c).

a)   b)   c)
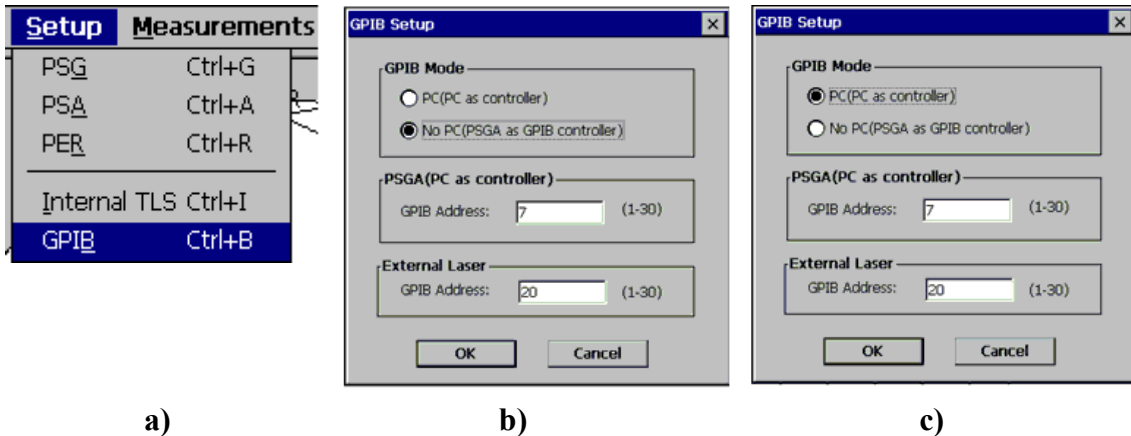
Figure 55 GPIB setup interface

- Set the GPIB addresses of the PSGA-101A and the external laser source (if using one).
- Select the GPIB mode: "PC mode" or "No PC mode".

(i) **No PC Mode (PSGA Mode):** The PSGA acts as the GPIB controller; it controls the other GPIB devices. In this mode, no other PC is connected to the PSGA-101A through a GPIB connection. Without an external PC, the PSGA can be used as a GPIB controller to control external lasers through GPIB cables. **If this mode is to be used, no external PC can be connected to the PSGA via GPIB cable; if a PC is connected, the PSGA cannot control the external laser or communicate with the PC.** The GPIB address of the PSGA is 0 (when it is used as a GPIB controller). The correct GPIB address of the external laser to be controlled must be set in the setup dialog window (Figure 55).

(ii) **PC Mode:** the remote PC functions as the GPIB controller, with the PSGA-101A as one of the GPIB devices under remote control. In this case, the user should set a GPIB address between 1 and 30 for the PSGA-101A, and the correct GPIB address for the external laser being controlled by the PSGA, in the setup dialog window (Figure 55). The GPIB driver program "IRQ.exe" should be run on the PC to support this mode (Figure 56), **otherwise**, **the PSGA cannot control the external laser to finish measurements. Please set the correct PSGA GPIB address before attempting any measurements or control.**
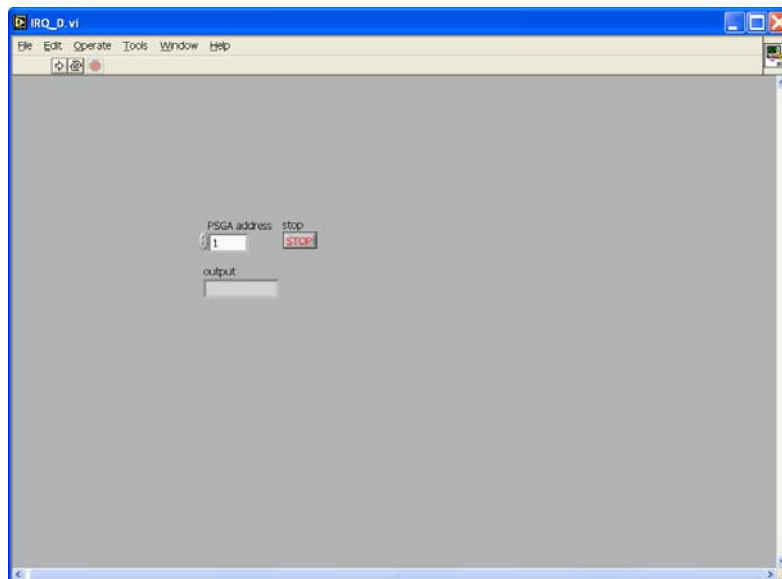
Figure 56 Control interface of IRQ.exe

After setting up the proper connections and operation modes, the user can perform different measurements using the control commands given in Sections 9.3-9.9.

9.2 Ethernet Control

The PSGA-101A uses a TCP Server/Client to implement Ethernet control. The PSGA has a TCP server which can receive requests from a TCP client and send back responses. During setup, the PSGA's Ethernet hardware connection should be in place. (There is a network socket located on the rear panel of the PSGA). Click the PCI information icon at the right bottom of the tool bar (Figure 57). The resulting network information dialog box shows the current IP address and other network information. The user can then input the PSGA's IP address in the Server IP edit box of the client program and establish the connection (Figure 58). Once the connection is set up, the user can use it to send commands to the PSGA. On the PSGA end, when a command is received, a communication interface shows up and detailed information regarding the communication type, command content and command response is returned (Figure 59).
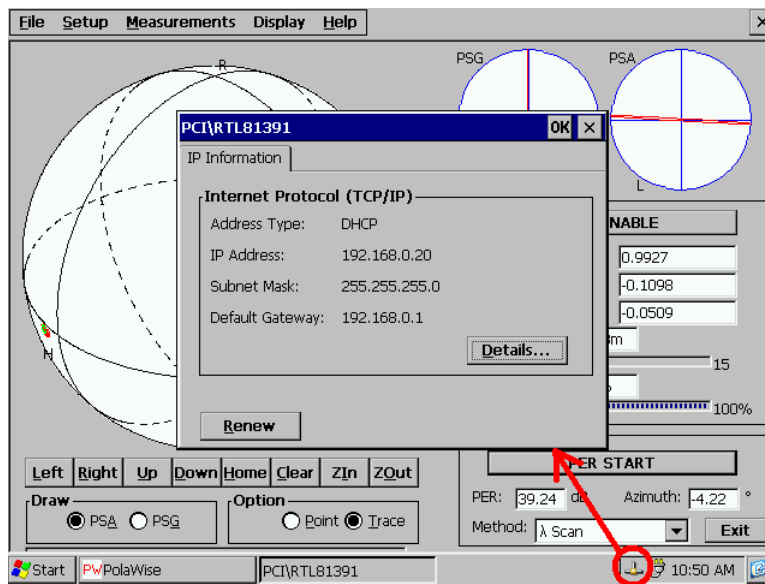
Figure 57 IP Setup
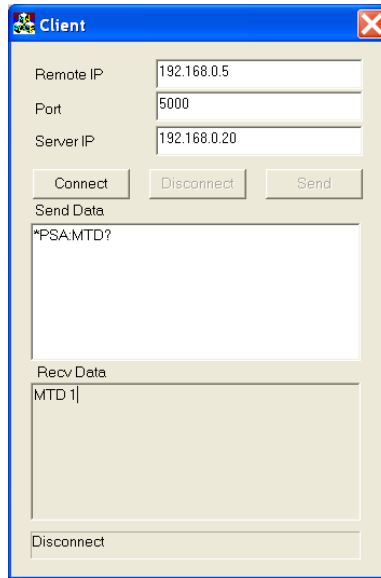
Figure 58 TCP Client
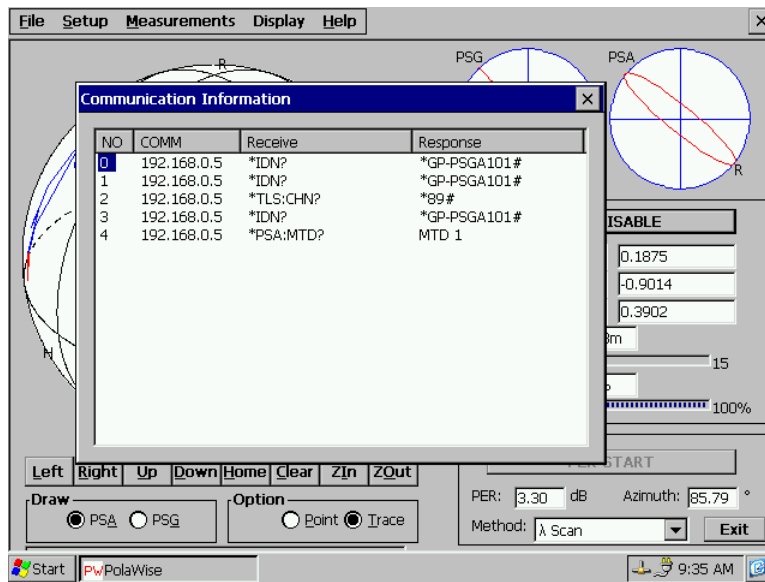
Figure 59 Communication Interface

Users can use any programming language that supports the TCP/IP (for Ethernet) or IEEE 488.2 (for GPIB) communication protocols to send commands to the PSGA-101A.

Note: For commands that include a parameter such as a wavelength, there should be exactly one space between the command body and the parameter.
For example, PSG:WAV 1500.00#.
Omitting the space or adding multiple spaces may result in an error message.

9.3 PSG GPIB/Ethernet Commands

Setup Commands

Control Command	Description	Error Response
*PSG:STA <state>#	Sets the PSG output polarization state. <state> = RHC|LHC|LHP|LVP|45|-45|SCAN Eg. PSG:STA 45# (set PSG output state to +45°)	E00, E01, E02
*PSG:DWL ff.ff#	Sets PSG dwell time (all values in sec.) Unused digits do not need to be filled. Example: PSG:DWL 1 (set dwell time to 1 sec) Range: >0.1s	E00, E01, E02 E06
*PSG:WAV ffff.ff#	Sets PSG wavelength (all values in nm) Unused digits do not need to be filled. Example: PSG:WAV 1500.00# Range: 1440nm~1620nm	E00, E01, E02, E06
*PSG:ADPOW#	Toggles 90° polarization rotator setting. Used to increase PSG output power when initial input polarization state is close to orthogonal to alignment polarizer axis.	E00, E01, E02

Status Report Commands

Report Command	Description	Returned Value	Error
*PSG:WAV?	Returns PSG wavelength	WAV ffff.ff (unit = nm) Example: WAV 1550.00	E01
*PSG:STA?	Returns current state	PSG RHC|LHC|0|90|45|-45|SCAN etc.	E01
*PSG:STK?	Returns Stokes parameters for PSG output polarization state	STK sf.fff,sf.fff,sf.fff Example: STK 1.000,-0.003,0.002	E01
*PSG:DWL?	Returns dwell time setting	Example: PSG:DWL 1.0 (unit = s)	E01

9.4 PSA GPIB/Ethernet Commands:

Setup Commands

Control Command	Description	Error Response
*PSA:ENA \<setting\>#	PSA enable/disable \<setting\> = ON | OFF Example: PSA:ENA ON#	E00 E02: if the \<setting\> parameter is omitted or is something other than ON or OFF
*PSA:MTD n #	Sets the PSA measurement mode. PSA:MTD 0# | PSA:MTD 1# 0: high speed; 1: high precision. Default: 1	E00 E02: if n is omitted or is something other than 0 or 1
*PSA:WAV ffff.ff#	Sets PSA wavelength (all values in nm) Example: PSA:WAV 1500.00# to set wavelength to 1500.00 nm Range: 1440~1620	E00,E01,E02,E06

Status Report Commands

Report Command	Description	Response	Error
*PSA:ENA?	Queries whether PSA is enabled or disabled	ENA ON|OFF	
*PSA:STK?	Returns the current measured Stokes parameters	STK sf.fff,sf.fff,sf.fff	E08,E09
*PSA:POW [dBm]|[mw]?	Returns input power	POW sff.ff dBm POW ff.fffff MW	E08,E09
*PSA:PKG [dBm]|[mw]?	Returns Power and Stokes parameters	PKG sff.fffff [DBM]|[MW], sf.fff,sf.fff,sf.fff, sf.fff (Format: Power,s1,s2,s3, DOP)	E08,E09
*PSA:DOP?	Returns DOP of input light	DOP f.fff	E08,E09
*PSA:THA?	Returns azimuth angle θ of input light	THA sff.f	E08,E09
*PSA:PHI?	Returns ellipticity angle φ of input light	PHI sff.f	E08,E09
*PSA:S1|S2|S3?	Returns Stokes parameter S1, S2 or S3	S{1|2|3} sf.fff	E08,E09
*PSA:MTD?	Returns the measurement mode	0:high speed;1: high precision	E08,E09
*PSA:WAV?	Returns current wavelength	WAV ffff.ff	

Note: Parameters or units in brackets [] are optional. If they are omitted, the default value will be used. For the commands in this table, the default unit is dBm.

9.5 PMD/PDL scan GPIB/Ethernet Commands

Setup Commands

Control Command	Description	Error

*PMD:MTD n#	Sets the PMD measurement method.
	n = measurement option:
	      0: Jones matrix eigenanalysis
	      1: PSA method
	      2: Mueller Matrix
	      3: Wavelength Scanning Method
		E00
		E02: if n is omitted or is a value other than 0, 1,2 or 3.

*PMD:TLS n#	Sets the type of tunable laser to be used for PMD measurement.
	n = laser option:
	      0: manual mode;
	      1: internal TLS;
	      2: Agilent TLS
		E00,E02,E06

*PMD:BGN#	Starts PMD measurement	E00,E70,E71,E72
*PMD:END#	Stops PMD measurement	E00
*PMD:NEX#	Begins next measurement for manual mode.	E00
*PMD:DWL ff.f#	Sets the laser delay in seconds(e.g. 10.0) This command used only for external laser. (Range: 0~99s)	E00

Status Report Commands

Report Command	Description	Response	Error
*PMD:RDY?	Queries whether PMD data are available	0: available 1: not ready Error code: see section 9.9	E08, E09, E50, E51, E52, E53, E54, E55, E56
*PMD:SCN?	For the wavelength scanning method, returns PMD values calculated from variations in s1, s2 and s3, respectively	ffff.fff,ffff.fff,ffff.fff	E50,E51,E52
*PMD:NUM?	Returns the number of wavelengths/ channels included in the measurement	mmmm	
*PMD:DGD nnnn?	Returns the nnnnth measured DGD Range: nnnn ≤ mmmm-1 (see *PMD: NUM?)	WL ffff.ff, DGD fff.fff Note: λ returned is the λ corresponding to the nnnnth measured DGD.	E06
*PMD:TWO nnnn?	Returns the nnnnth measured second order PMD. Range: nnnn ≤ mmmm-2 (see *PMD: NUM?)	WL ffff.ff SODGD ffff.fff Note: λ returned is the λ corresponding to the nnnnth measured SODGD.	E06
*PMD:PSP nnnn?	Returns the nnnnth measured PSP. Range: nnnn ≤ mmmm-1 (see *PMD: NUM?)	WL ffff.ff ,f.fff,f.fff,f.fff (λ and Stokes parameters for nnnnth PSP)	E06
*PMD: AVG?	Returns the average DGD over measured wavelength range	ffff.fff	
*PMD: RMS?	Returns the RMS DGD over measured wavelength range	ffff.fff	
*PMD:DEV?	Returns the standard deviation of DGD over measured wavelength range	ffff.fff	
*PMD:MAX?	Returns the MAX DGD over measured wavelength range	ffff.fff	
*PMD:MIN?	Returns the MIN DGD over measured wavelength range	ffff.fff	
*PMD:TWO:AVG?	Returns the RMS second order PMD over measured wavelength range.	ffff.fff	
*PMD:MTD?	Queries the PMD measurement method	0: Jones matrix eigenanalysis 1: PSA method 2: Mueller Matrix 3: Wavelength scanning	
*PMD:PDL nnnn?	Returns the nnnnth measured PDL Range: nnnn ≤ mmmm (see *PMD: NUM?)	WL ffff.ff, PDL fff.fff Note: λ returned is the λ corresponding to the nnnnth measured PDL.	E06
*PMD: PDL:AVG?	Returns the average PDL over measured wavelength range	ffff.fff	
*PMD:PDL:DEV?	Returns the standard deviation of PDL over measured wavelength range	ffff.fff	
*PMD:PDL:MAX?	Returns the MAX PDL over measured wavelength range	ffff.fff	
*PMD:PDL:MIN?	Returns the MIN PDL over measured wavelength range	ffff.fff	

9.6 PDL single wavelength measurement GPIB/Ethernet Commands

Setup Commands

Control Command	Description	Error
*PDL:MTD n#	Sets the measurement method. 0: Jones matrix method 1: Mueller matrix method	E00,E02, E04
*PDL:BGN#	Starts PDL measurement	E00
*PDL:END#	Stops PDL measurement	E00

Status Report Commands

Report Command	Description	Response	Error
*PDL:RDY?	Queries whether PDL data are available	0: available 1: not ready	E08,E09,E61, E62
*PDL?	Returns the PDL value. This command is only available in single wavelength mode.	ff.ff	E64

9.7 Wavelength Setup Commands for PMD and PDL measurement

Setup Commands

Control Command	Description	Error
	Internal Tunable Laser	
*MEA:CHN:SIN nn#	Sets laser channel to nn. Used for single wavelength PDL measurement.	E00,E02,E06
*MEA:CHN:LWR nn#	Sets the start channel for a scan	E00,E02,E06
*MEA:CHN:UPR nn#	Sets the end channel for a scan	E00,E02,E06
*MEA:CHN:STP nn#	Sets the step size (# of channels) for a scan	E00,E02,E06
	External Laser	
*MEA:WAL:SIN ffff.ff#	Sets laser wavelength to ffff.ff nm. Used for single wavelength PDL measurement.	E00,E02,E06
*MEA:WAL:LWR ffff.ff#	Sets the start wavelength for a scan	E00,E02,E06
*MEA:WAL:UPR ffff.ff#	Sets the end wavelength for a scan	E00,E02,E06
*MEA:WAL:STP ffff.ff#	Sets the wavelength step size for a scan	E00,E02,E06

Status Report Commands

Report Command	Description	Response	Error
	Internal Tunable Laser		
*MEA:CHN:SIN?	Returns current channel number (single wavelength operation)	nn	
*MEA:CHN:LWR?	Returns the start channel number	nn	
*MEA:CHN:UPR?	Returns the end channel number	nn	
*MEA:CHN:STP?	Returns the step size (# of channels)	nn	
	External Laser		
*MEA:WAL:SIN?	Returns current wavelength (in nm) (single wavelength operation)	ffff.fff	
*MEA:WAL:LWR?	Returns the start wavelength (nm)	ffff.ff	
*MEA:WAL:UPR?	Returns the end wavelength(nm)	ffff.ff	
*MEA:WAL:STP?	Returns the wavelength step size (nm)	ffff.ff	

9.8 Internal tunable laser commands

Command	Description	Response
*POW?	Returns the laser output power in dBm.	*POW 2.55#
*TLS:REG hhhhhh?	Query the TLS register; hhhhhh is the register, data1, and data2. For example, to determine the status of register 0x32 when data1 is 0x00 and data2 is 0x00, the correct command is *TLS:REG 320000?	Returns the status of register: hh hh hh hh. Refer to OIF-ITLA-MSA for the meaning of the data.
*TLS:CHN nn#	Sets the channel of the laser source. nn=0~88	*E00#: OK *E01#: undefined command *E06#:parameter out of range
*TLS:CHN?	Returns the current channel number. This command is available for sweep mode	*CHN 12# *E01#: undefined command
*TLS:FRQ?	Returns the current frequency of laser source	
*TLS:WAV?	Returns the current wavelength of laser source	
*TLS:STA n#	Switch the laser source on or off 0: laser off; 1: laser on ;	
*TLS:STA?	Queries the laser state. 0: laser off. 1: laser on; 2: laser not available	*STA 0#: laser off *STA 1#: laser on *STA 2#: laser not available
*TLS:SWP:MOD n#	Sets the sweep mode. 0: manual mode. 1: auto mode.	
*TLS:SWP:MOD?	Query the current operation mode	*MOD 0/1#
*TLS:SWP:CYC nnn#	Sets the number of scan cycles to be executed. Range:1≤ nnn ≤ 999; if nnn >999 or nnn<1, the number of cycles will be defined to be infinite (INF), and the laser will continue scanning until manually stopped. Sample commands: *TLS:SWP:CYC nnn# *TLS:SWP:CYC INF#	
*TLS:SWP:CYC?	Returns the number of scan cycles set.	*CYC 0#: cycle is infinite
*TLS:SWP:DWE nnnn#	Sets the dwell time per step for auto sweep mode Can only be used in auto mode; Range for nnnn is 20-3600 ms Sample command: *TLS:SWP:DWE 100#	
*TLS:SWP:DWE?	Returns the dwell time per step (auto sweep mode)	
*TLS:SWP:REP n#	Sets the repeat mode. N=0 or1 0: One way. Every sweep cycle starts at the start wavelength and ends at the end wavelength 1: Round trip: Each sweep cycle starts at the start wavelength, scans to the end wavelength, then scans back to the start wavelength.	

*TLS:SWP:REP?	Returns the current repeat mode.	*0#; one way *1#: round trip
*TLS:SWP:BGN nn#	Sets the start channel for a sweep. nn: 0~88 Sample commands: *TLS:SWP:BGN 0# *TLS:SWP:BGN 88#	
*TLS:SWP:BGN?	Returns the currently set sweep start channel	
*TLS:SWP:END nn#	Sets the end channel for a sweep. nn: 0~88	
*TLS:SWP:END?	Returns the currently set sweep end channel	
*TLS:SWP:STE nn#	Sets the step size (# of channels). nn:1~88	
*TLS:SWP:STE?	Returns the step size (# of channels)	
*TLS:SWP:STA n#	Stops, starts, pauses or continues a paused channel sweep Options for n: 0: stop 1:start 2: pause 3: continue	*E00#: OK *E01#: command error *E13#: parameter setting error; the start and end channels are not compatible with the step size. *E14#: commands conflict; e.g. "stop" can be used only if a scan is in progress, "start" can be used only if a scan is stopped or paused, "pause" can be used only if a scan is in progress; "continue" can be used only if a scan is paused. *E15#: TLA is not ready for output. Command should be re-sent
*TLS:SWP:STA?	Returns the sweep status. 0: Sweep is not running; 1:Sweep in progress	
*TLS:SWP:ssss#	ssss: next. In manual mode, advances to the next wavelength in the sequence.	*E00#: OK *E01#: command error *E14#: commands conflict; this command can only be used in manual sweep.
*TLS:RST#	Resets laser source- all settings are reset to default values.	
*TLS:WAV nn?	Returns the wavelength of the channel nn.	
*TLS:FRQ nn?	Returns the frequency of the channel nn	
*TLS:CHN:MAX?	Returns the number of the highest available channel.	

9.9 Error Definitions

E00	No error (State OK)
E01	Undefined Command
E02	Missing or incorrect parameter
E03	Invalid syntax found in command string
E04	string of characters too long (>buffer limit)
E05	parameter has too many digits after the decimal point
E06	parameter outside the allowed range
E07	Failed Self Test
E08	Light power too high
E09	Light power too low
E10	Incorrect operating wavelength (Outside operating wavelength range)
E11	Error loading stored values
E12	Unable to store state
E13	Parameter setting error; the start and end channels are not compatible with the step size. Response to *TLS:SWP:STA n# command
E14	Command conflicts with another command already in operation
E15	TLA is not ready for output. Command should be re-sent
E50	Wavelength scan PMD measurement failure
E51	Requested command only applies in wavelength scan mode. Current PMD measurement method is not wavelength scan method
E52	Wavelength Scan initialization failure
E53	Poincaré Sphere Analysis PMD measurement failure
E54	Mueller Matrix PMD measurement failure
E56	Jones Matrix PMD measurement failure
E60	PDL measurement initialization failure
E61	Mueller Matrix PDL measurement failure
E62	Jones Matrix PDL measurement failure
E64	Measurement mode is not single wavelength mode
E65	Measurement mode is not wavelength scanning mode
E70	Incorrect wavelength setup
E71	Incorrect channel setup
E72	Wavelength scan PMD measurement cannot use manual laser mode

Section 10. Technical Support and Factory Service Information:

10.1 Technical Support

General Photonics is committed to high quality standards and customer satisfaction. For any questions regarding the quality and use of the PSGA-101A, or future suggestions, please contact General Photonics Corporation at (909)-590-5473 (telephone) or (909)-902-5536 (fax), or by e-mail at info@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

10.2 Factory Service Information

The PSGA-101A Polarization Measurement System contains no user serviceable parts. To obtain information regarding factory service, contact General Photonics Corporation or your General Photonics representatives/distributors. Please have the following information available:

1.   Instrument model number and serial number

2.   Description of the problem.

If the instrument is to be returned to General Photonics Corporation, you will be given a RMA Number, which you should reference in your shipping documents. Please fill out a copy of the service form, located on the following page, and have the information ready when contacting General Photonics Corporation. Return the completed service form with the instrument.

Related product warranty information can be found on the second page of the user manual.

Service Form

Making Light Work Lighter

General Photonics

C o r p o r a t i o n

Name_____   Return Authorization # _____
                                                (Please obtain RMA# prior to return of item)

Company _____

Address _____   Date _____

Country _____   Phone Number _____

P.O. Number _____   FAX Number_____

Item(s) Being Returned:

Model # _____   Serial # _____

Description

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Reason for return of goods (please list any specific problems):

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