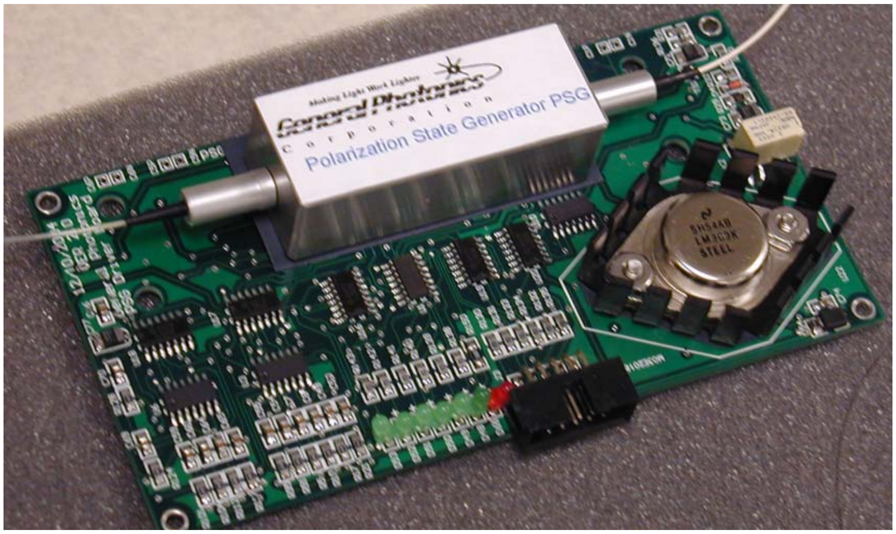
PSG-001

Fiber-optic Polarization State Generator

Operation Manual



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Section 1. Specifications:

Physical Features:

Dimensions	135 mm (L) × 70 mm (W) × 21 mm (H)
Input Fiber Type	SM or PM
Output Fiber Type	SM
Fiber Input Connector	FC/PC, FC/APC, SC/PC, or SC/APC
Fiber Output Connector	FC/PC, FC/APC, SC/PC, or SC/APC
Power On Indicator	Red LED
Operation Indicators	6 green LEDs
Control Interface	10-pin protected header
Adapter Cable	10-pin female connector with ribbon cable (for the digital I/O port control option)

Optical Characteristics:

SOP repeatability	+/-0.5 degrees on Poincare Sphere
SOP accuracy to targets	+/-5 degrees (@1550 nm)
Insertion Loss	1.2 dB (@1550 nm) [1]
Insertion loss variation	0.2 dB (typical).
Return Loss[2]	55 dB
SOP Switching Speed	250 µs
Number of Polarization States	6
Wavelength Dependent Loss (WDL)	0.3 dB (across C-band)
Transient Loss (per bit)	0.5 dB (typical)
Maximum Power	300 mW

Electrical Characteristics:

Power Supply (provided)	+12 V DC/ 1.5 A
Control Input Signals	TTL
Operating Temperature	0 °C to 50 °C
Storage Temperature	- 40 °C to 85 °C
Switching Rise Time	35 µs
Switching Fall Time	35 µs
Output/Input Delay Time	100 ns
Maximum Operation Frequency (TTL)	500Hz if all 6 bits are used

Note:

1. Insertion loss is measured when electrical power is turned on. Connector loss excluded.
2. The return loss is specified for the PSG only application. Standard modules are designed for both PSG and PSA applications, thus return loss is not specified.

Section 2. Overview:

The PSG-001 is a programmable polarization state generation device designed and developed by General Photonics Corporation. This device is capable of generating 6 distinct states of polarization (SOP) across the Poincare sphere: linear polarization states at –45°, 0°, +45°, and +90°, as well as right hand circular (RHC) and left hand circular (LHC) polarization states, relative to the axis defined by an internal linear polarizer. The actual output polarization states may be rotated due to the birefringence of the output SM fiber, so the exact SOP locations on the Poincaré sphere of the measurement system may be different from the values above. However, the angular relationship between the generated SOP locations will be the same. The 6 generated polarization states will symmetrically cover the Poincaré sphere.

The PSG-001 is a high speed polarization state generation module with high accuracy and repeatability. Typical applications include polarization analysis, optical device characterization, network characterization, nonlinear optics, light-matter interaction study, etc.

The PSG-001 module consists of an optical head and a drive circuit. The SOP of the output beam is controlled by a parallel 6-bit TTL binary command. The TTL control commands can be generated by either an electronic circuit or a computer. The parallel format assures the highest possible operation speed. There are no moving parts in the optical head. The SOP switching is achieved electronically. The average SOP switching time is about 250 μs.

A common approach for generating a TTL control signal is to use a digital I/O card installed on a personal computer (PC). In this case, a digital I/O card must be purchased either from General Photonics or from a third party and be installed in the computer.

For more general operation, users can apply the desired TTL signal sequences from any logic circuits directly to the input port of the driver board without going through personal computer control.

In this manual, the structure and operation of the PSG-001 are described in detail in Sections 3 and 4. The logic table for obtaining different SOPs is included in Appendix A, and the degenerate states are listed in Appendix B. The accuracy SOP calculation formula is given in Appendix C, while some typical questions with corresponding answers are discussed in Appendix E.

<u>Section 3. Hardware:</u>

The PSG-001 consists of two main parts: the optical module and the electronic drive board.

3.1 Optical interface

1. The optical module has two internal fiber pigtails, one for the input and the other for the output. The input pigtail can be either PM or SM fiber, while the output pigtail is usually SM fiber.

2. The input and output ports are marked on the front panel of the package.

3. Fiber connectors can either be FC/PC, FC/APC, SC/PC, or SC/APC per customer's specifications.

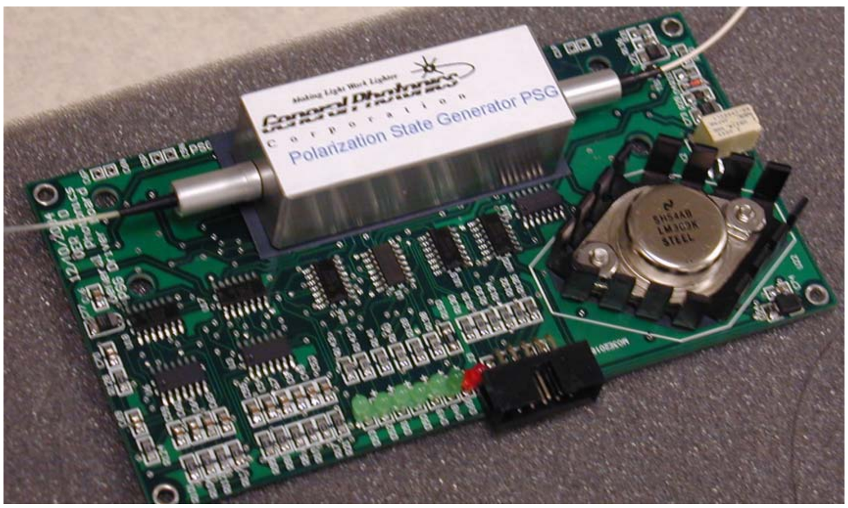

Fig. 1 Photograph of a PSG-001.

3.2 Electrical interface

The +12V power supply is provided through the 10-PIN connector (pin 1 for +12V, pin 2 for ground) do not need to be separately connected.

The TTL control signal is connected to the circuit board through the 10-pin male header on the rear panel of the enclosure.

1. The pin connection assignment is illustrated in Fig. 2. Pin 1 is +12 volts. Pins 2, 4 are connected to ground. Pins 5, 6, 7, 8, 9 and 10 are assigned to represent TTL control binary signal bits 1, 2, 3, 4, 5 and 6, respectively, where bit 6 is the most significant bit (MSB) and bit 1 is the least significant bit (LSB).

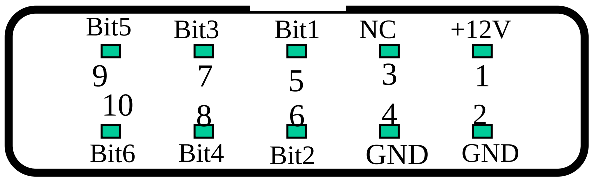

Fig. 2 Pin assignments for the electronic input header on the rear panel of the package

2. There is a red power indicator LED above the power switch on the front panel. When the external +12V DC power supply is on, this red LED should be on.

3. There are 6 green LEDs to indicate the status of the 6 control bits. A lit LED indicates a logic high ("1") while a dark LED indicates a logic low ("0") Therefore, an instruction command to the optical module can be easily identified by observing the status of the 6 LEDs. **For example, a control signal (111110) (Bit6=1 Bit5=1 Bit4=1 Bit3=1 Bit2=1 Bit1=0) will show a dark bit-1 LED, with the rest of LEDs lit. The bit-1 LED is next to the red power indicator LED.**

4. A ribbon cable with a 10-pin female connector is supplied with the module. The ribbon cable is color coded as follows:

Table 1: Connector pin assignment and ribbon cable color code

Pin number	*Color*	*Connection*
1	Black	+12V power supply
2	White	GND
3	Gray	NC
4	Purple	GND
5	Blue	Bit 1
6	Green	Bit 2
7	Yellow	Bit 3
8	Orange	Bit 4
9	Red	Bit5
10	Brown	Bit6

Section 4. Operation Instructions

4.1 Safety Information

The PSG-001 is designed for indoor use only. It is important to follow the safety procedures below:

- Turn off the power supply when making electrical connections, such as connecting the ribbon cable.
- Avoid exposure to liquid spills and excessive moisture.
- The PSG-001 board is not user serviceable.
- ***To get better stability and repeatability, an external cooling method such as using a fan, is preferred for long-term application.***

The PSG-001 can handle optical power over 300 mW. It is important to avoid looking directly into the optical output port, as this may cause damage to human eyes.

It is important to clean the fiber connectors before establishing optical connections to the PSG-001 module.
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4.2 Unpacking

Inspect the PSG-001 for any damage due to shipping or transportation. Check the packing list to make sure that all parts and accessories are present.

4.3 Getting Started

Fig. 3 illustrates a typical configuration using a PSG-001 module to generate different SOPs. The control device can be a control circuit with a 6-bit parallel output port, a computer with a parallel port (printer port), or a computer with a digital I/O card. In this setup, we assume that the input fiber pigtail of the PSG-001 is PM fiber. Polarization controller #1 aligns the laser output light polarization to the polarizer at the input of the PSG-001 for maximum throughput. This can be achieved by using this polarization controller to adjust the input polarization to maximize power at the output of the PSG-001 before connecting the rest of the setup. Polarization controller #2 is optional and is used to rotate the output polarization state to a desired point on the Poincaré sphere.

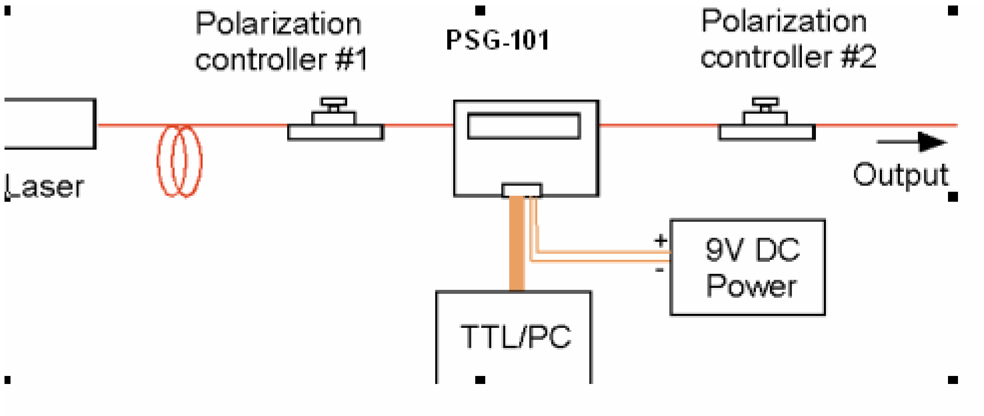

Fig. 3 A typical setup for operating a PSG-001. In this example, the 6-bit control signal is generated by a personal computer and delivered to the PSG-001 module via a digital I/O port.

Follow the steps below to prepare the PSG-001 for operation with a personal computer:

1. Connect +12V power supply to the PSG-001.

2. Connect wires corresponding to bit 1 ~ bit 6 on the ribbon cable to a digital I/O card output block. Note that 6-bit TTL control signals may also be obtained by other means.

3. Connect the ribbon cable to the PSG-001 module. Turn on the +12V DC power supply via the power switch on the front panel. The default setting is that all LEDs will be on. For best SOP repeatability, it is recommended that the PSG-001 be allowed to warm up for 20 minutes.

4. Launch control program and test TTL signals according to the logic table in Appendix A. Check whether the 6 green LEDs located on the front panel of PSG-001 are blinking when inputting TTL control signals to the module. The blinking LED indicates that logic highs (LED on) and lows (LED off) are successfully sent to the module from the controller. Otherwise, check the connection to make sure that the module is correctly connected to the computer.

5. Launch the optical signal from the input side.

6. Start to control SOP values according to the logic table listed in Appendix A. If using the sample setup in Fig. 3, set SOP to RHC polarization state (logic “000000”) and check the output polarization using a polarization analyzer. If it does not match, use polarization controller #2 to adjust the polarization to RHC polarization state. Output polarizations should now match the set SOP for all 6 SOPs.

4.4 Troubleshooting

The following table lists some possible problems and suggested solutions.

Symptom	Possible Solution
A. The device doesn't work (The six LEDs do not blink)	1. Check the red LED on the board (power). 2. If the red LED is not on, check the +12V power supply connection. 3. If the red LED is on, check the connection between the device and the computer.
B. The optical insertion loss is higher than specified value	1. Check if the +12V DC power supply is turned on or not. When DC power is not on, the optical IL will be higher. 2. Check if all fiber connectors are clean.
C. The performance of the device changes suddenly, e.g. loss increases a lot, no SOP variation.	1. Make sure there is no sudden external force on the device. 2. Check the connection between the computer and device 3. Turn off the device and wait for half an hour, then restart the device
D. Everything works fine but the SOP does not change, while the output power changes.	1. This typically indicates that the input optical source is connected to the output pigtail of the PSG-001. Exchanging the input and output pigtail connections will correct the problem.
E. Cannot access all 6 distinct polarization states	1. Check if the ribbon cable connections to the DIO block or TTL circuit are correct. 2. Check if bit 1~bit 6 are assigned correctly in control program.

Section 5. Technical Support

General Photonics is committed to high quality standards and customer satisfaction. For any questions regarding the quality and use of the PSG-001, or future suggestions, please feel free to 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 reached by mail at:

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Appendix A: SOP Logic Table

A total of 6 distinct SOP states can be generated by 6-bit digital highs and lows, as shown in the logic table below. As described previously, the logic high and low of each bit can be directly verified by inspecting the corresponding LED on the module board. LED "on" represents "1" for the logic table; LED "off" represents "0" for the logic table.

Logic Table	SOP
(000101)	State 1
(110101)	State 2
(010000)	State 3
(010101)	State 4
(010111)	State 5
(010001)	State 6

Note that the logic table presented here is not unique for PSG-001 control. It is only one of many combinations that can generate 6 distinct states. There are 64 combinations for 6-bit binary TTL code. However, there are only 6 distinct polarization states (see Appendix B). Therefore, many output SOPs are degenerate or nearly degenerate among the 64 combinations. If the user prefers to select its own TTL logic combinations, a new logic table can be obtained by monitoring output polarization states on a polarization analyzer.

Appendix B: Degenerate states vs. Logic table

State 1	State 2	State 3	State 4	State 5	State 6
000000	110000	010000	010011	010111	010001
000001	110001	011111	010101	011011	010010
000010	110010	100000	010110	011101	010100
000011	110011	101111	011001	011110	011000
000100	110100		011010	100111	100001
000101	110101		011100	101011	100010
000110	110110		100011	101101	100100
000111	110111		100101	101110	101000
001000	111000		100110		
001001	111001		101001		
001010	111010		101010		
001011	111011		101100		
001100	111100				
001101	111101				
001110	111110				
001111	111111				

Appendix C: Stokes Parameters of PSG Output

Stokes Parameters of 6-state PSG

The SOP at point A is

$$SOP_A = \begin{pmatrix} 1 \\ -\cos2\alpha\cos2\beta + \sin2\alpha\sin2\beta\cos\gamma \\ -\cos2\alpha\sin2\beta - \sin2\alpha\cos2\beta\cos\gamma \\ \sin2\alpha\sin\gamma \end{pmatrix}$$

where

$$\alpha = \sum_{n=5}^{6}(Bit_n f_n + (Bit_n - 1)g_n)$$

$$\beta = \sum_{n=1}^{4}(Bit_n f_n + (Bit_n - 1)g_n)$$

$$f_n = 22.5 + b_n + a_n(\lambda - 1550nm) + (h_1(\lambda - 1550nm) + h_2) * (T - T_0)$$

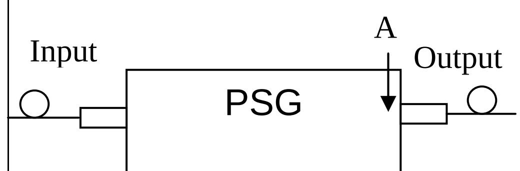
$$g_n = 22.5 + d_n + c_n(\lambda - 1550nm) + (h_1(\lambda - 1550nm) + h_2) * (T - T_0)$$

$$\gamma = \gamma_0 + h_3(T - T_0)$$

where n=1,2, …6. T is the temperature inside PSG. The temperature inside PSG is approximately equal to T_0 under the environmental temperature of 25°C. The real temperature can be determined by measuring the resistance between the eighth pair pins on optical head. The conversion between resistance and temperature is listed in Appendix D.

Bit_n is the logic state (1 or 0) of the nth control bit. For example, the Bit_n (n=6,5, …, 1) of logic (100110) are

$Bit_6=1$
$Bit_5=0$
$Bit_4=0$
$Bit_3=1$
$Bit_2=1$
$Bit_1=0$



For each PSG module, before assembling the output fiber, the Stokes parameters of all possible output polarization states are measured. The corresponding parameters can be calculated according to the testing results. We then provide these parameters for each PSG. From these parameters, customers can easily know the exact output SOPs without the output fiber according to these given parameters and above formula. Based on these determined SOPs, customers can also easily calibrate the transfer matrix of the output optical fiber or other optical components along the optical path, thus to perform accurate polarization analysis. **Please also refer to the test report for the recommendation of six logic states to generate six accurate and distinctive polarization states.**

Stokes Parameters of 5-Sate PSG

The SOP at point A is

$$SOP_A = \begin{pmatrix} 1 \\ -\cos 2\alpha \cos 2\beta + \sin 2\alpha \sin 2\beta \cos\gamma \\ -\cos 2\alpha \sin 2\beta - \sin 2\alpha \cos 2\beta \cos\gamma \\ \sin 2\alpha \sin\gamma \end{pmatrix}$$

where

$$\alpha = \sum_{n=3}^{4} (Bit_n f_n + (Bit_n - 1) g_n)$$

$$\beta = \sum_{n=1}^{2} (Bit_n f_n + (Bit_n - 1) g_n)$$

$$f_n = 22.5 + b_n + a_n(\lambda - 1550nm) + (h_1(\lambda - 1550nm) + h_2) * (T - T_0)$$

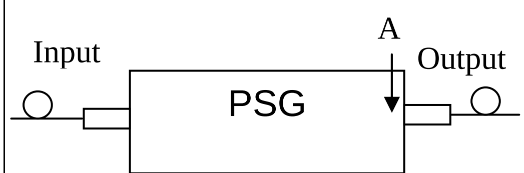
$$g_n = 22.5 + d_n + c_n(\lambda - 1550nm) + (h_1(\lambda - 1550nm) + h_2) * (T - T_0)$$

$$\gamma = \gamma_0 + h_3(T - T_0)$$

where n=1,2, …6. T is the temperature inside PSG. The temperature inside PSG is approximately equal to T_0 under the environmental temperature of 25°C. The real temperature can be determined by measuring the resistance between the eighth pair pins on optical head. The conversion between resistance and temperature is listed in Appendix D.

Bit_n is the logic state (1 or 0) of the nth control bit. For example, the Bit_n (n=4,3,2,1) of logic (1100) are

Bit_4=1
Bit_3=1
Bit_2=0
Bit_1=0



Appendix D: Thermistor, Resistance/Temperature Conversion

Temperature (°C)	Resistance (kΩ)	Temperature (°C)	Resistance (kΩ)	Temperature (°C)	Resistance (kΩ)
0	32.66	34	6.808	68	1.878
1	31.04	35	6.531	69	1.814
2	29.51	36	6.267	70	1.753
3	28.06	37	6.015	71	1.695
4	26.69	38	5.774	72	1.638
5	25.4	39	5.545	73	1.584
6	24.18	40	5.325	74	1.532
7	23.02	41	5.116	75	1.482
8	21.92	42	4.916	76	1.433
9	20.89	43	4.725	77	1.387
10	19.9	44	4.543	78	1.342
11	18.97	45	4.368	79	1.299
12	18.09	46	4.201	80	1.257
13	17.26	47	4.041	81	1.218
14	16.47	48	3.888	82	1.179
15	15.71	49	3.742	83	1.142
16	15	50	3.602	84	1.106
17	14.32	51	3.468	85	1.072
18	13.68	52	3.34	86	1.039
19	13.07	53	3.217	87	1.007
20	12.49	54	3.099	88	0.9759
21	11.94	55	2.987	89	0.9461
22	11.42	56	2.878	90	0.9174
23	10.92	57	2.775	91	0.8897
24	10.45	58	2.675	92	0.863
25	10.00	59	2.58	93	0.8372
26	9.572	60	2.488	94	0.8123
27	9.165	61	2.401	95	0.7882
28	8.777	62	2.317	96	0.765
29	8.408	63	2.236	97	0.7426
30	8.055	64	2.158	98	0.7209
31	7.721	65	2.084	99	0.7
32	7.402	66	2.012	100	0.6798
33	7.098	67	1.944		

Appendix E: Common questions

1. Questions on Degenerate States

• Will the degenerate states produce the same SOP?
A: Each state is highly repeatable, however, the degenerate states may not provide the exact same SOP, there will be a slight difference due to the imperfection of optical components used inside.

• Is the logic table valid for different devices?
A: Yes. The same logic operation on different devices will always generate the same (slightly different) output states by the device itself, although the output SMF will disturb (adding another transfer function) the output SOP.

• Will the degenerate states have the same wavelength dependence?
A: Without the output SMF, the wavelength dependence for the degenerate states will be the same in terms of the slope between the variation angle and the wavelength. Unfortunately, this won't hold when SMF is attached. Thus the slope values for all the states will be provided for each device.

2. Questions in Orthogonality

• Will the orthogonality remains at different wavelengths?
A: This depends on different states. Some states do keep the orthogonality (slight variation), some do not (normally in linear relationship to the wavelength).

• How could we know the variation of orthogonalities for different combinations of states?
A: Normally there will be six typical states recommended on the test report for each device, however, there may be some other states that have better performance in terms of orthogonality, General Photonics may provide the detailed report on that for each device per customers' request.

• How about the other relationship (e.g. 45-degree)?
A: Similarly, this relationship may also change with wavelength (normally in linear).

• What's the reason of this variation?
A: The real physical reason is the wavelength dependence of MO polarization rotators.

3. Others

• Which logic table should we use?
A: Please refer the logic table listed on the test report. The user manual only lists several typical ones.

• Why our measurement results are different from the test report?
A: There may be several reasons. (i) the coordination system is different; Note that all the states are relative in different coordination systems although their relationship keeps constant. (ii) the control logic may be in the reversed order; (iii) The angle we calculated in the test report is the real physical angle between states (half of that on the Poincare sphere).

• Can we improve the output accuracy or perform some kind of calibration?
A: Using the matrix calculation for several chosen states (even in the case of SMF output), higher output accuracy or calibration may be realized.

• **What's the difference between 5-state generator and 6-state generator?**

A: General Photonics provides two versions of polarization state generators, i.e. 5-state and 6-state. The difference between these two versions is the number of magneto-optics (MO) switches inside the devices. The user may take a look at the paper published by our researchers on Optics Letter (June, 2005) about the details. Since the operation procedure is almost the same to both, we did not include the descriptions about 5-state generator. If the user has any question about that, please feel free to contact our company.