Operation Manual

Thorlabs Blueline™ Series

Modular Polarization Measurement System

PAT 9000 B

Polarimeter
ER-Meter
PDL-Meter
PMD-Meter

2003

THORLABS GmbH

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We aim to develop and deliver the best solution for your fiber optic test and measurement application. To reach this goal, we need your suggestions on how our products can be improved further. Please let us know your proposals and critics. We are looking forward to hearing from you.
On the windows displayed by the PAT 9000B and in the stored data log files you may find the name PROFILE. PROFILE was the name of the manufacturer before it was acquired by Thorlabs and renamed Thorlabs GmbH.

Thorlabs GmbH

This operation manual contains specific information on how to operate the Modular Polarization Measurement System PAT 9000B. A general description is followed by explanations of how to operate the unit manually. You will also find information about remote control via the IEEE 488 computer interface.

☝Attention☝

This manual contains "WARNINGS" and "ATTENTION" label in this form, to indicate dangers for persons or possible damage of equipment.

Please read these advises carefully!

NOTE

This manual also contains "NOTES" and "HINTS" written in this form.

1 General information

1.1 General description

The polarization measurement system PAT 9000B by *Thorlabs GmbH* is a universal modular measurement system for polarization analysis, characterization of optical signals and components with respect to polarization dependent losses (PDL) and polarization mode dispersion (PMD).
The mainframe is a 586 Pentium®.-based unit with an integrated TFT monitor and a GPIB/IEEE 488 interface. Connectors for keyboard, mouse and external monitor are provided.
The mainframe PAT 9000B can be furnished with up to three different modules of the 9000 series. Wideband tunable semiconductor lasers with external cavities of different manufacturers can also be controlled via the GPIB/IEEE 488 interface.
The PAT 9000B by *Thorlabs GmbH* is optimally suited for:

- **Polarization analysis of signals and components (fiber guided or free space)**
- **Long term analysis of polarization effects**
- **Analysis of extinction ratio in polarization maintaining fibers or laser-to-fiber coupling**
- **Analysis of birefringence and absorption of optical components**
- **Precise measurement of polarization dependent losses or gains (PDL/PDG)**
- **Polarization mode dispersion (PMD) measurement with different techniques even on already installed fibers**
- **Recording of wavelength and time dependency of PDL and PMD**
- **High resolution measurements on narrowband optical components**
- **External Jones-Matrix measurement**

The polarimeter module PAN 9300 NIR (950 ... 1160 nm), the polarimeter module PAN 9300 FIR (1200 ... 1700 nm) and the polarizer modules POL 9320 NIR (960 ... 1160 nm) and POL 9320 FIR (1200 … 1700 nm) are available.
The PAT 9000B automatically recognizes the inserted modules and activates them.
The mainframe is operated under the Windows®98 operating system. The user controls all software via keyboard or mouse. The integrated TFT color display or an external VGA monitor serve as display.
If an external cavity laser is used together with the PAT 9000B, both units must be connected via the GPIB/IEEE 488 interface before turning them on.

All measured data may be stored on the built-in hard disc in ASCII-format. Since the PAT 9000B is a 586 based unit, the PAT 9000B can also be used for further processing of the measured data with any commercially available software running under MS-DOS or MS Windows®.

☝ Attention ☝

Changing the configuration of the computer software or running certain software programs may lead to a failure of the measurement system!

If difficulties occur please contact our Thorlabs technical hotline.

NOTE

For software configuration problems see also your Windows® 98 manual.

1.2 Software License

Thorlabs GmbH warrants that the SOFTWARE included in this product will perform in substantial accordance with the documentation. *Thorlabs GmbH* grants to the original end user of its product a non-exclusive worldwide license to operate the software installed therein. This license shall be transferred to any person or entity which subsequently acquires lawful ownership of the product.

This license shall be limited to using the software for contemplated operation of *Thorlabs GmbH's* products. This license does not permit any end user to (a) modify or adapt Thorlabs GmbH's software or to merge it into another program (b) reverse engineer, disassemble, or otherwise attempt to discover *Thorlabs GmbH's* software source code or (c) sub license or otherwise transfer *Thorlabs GmbH's* software for any use other than operating the product originally purchased from *Thorlabs GmbH*.

1.3 Safety instructions

Prior to operate the PAT 9000B you should read this chapter to avoid damage to the unit or connected circuits as well as endangerment of persons. The safety instructions given herein must be strictly adhered to at any time.

☝ Attention ☝

To avoid potential hazards, use this product only as specified!

Before applying power to your PAT 9000B system, make sure that the protective conductor of the 3 conductor mains power cord is correctly connected to the protective earth contact of the socket outlet!
Improper grounding could cause electric shock with health damage or even death!

Modules may only be installed or uninstalled with the mainframe being switched off!

All modules must be fixed with all screws provided for this purpose.

Modules of the 9000 series must only be operated in the mainframe PAT 9000B.

All modules must only be operated with duly shielded connection cables.

Only with written consent of Thorlabs GmbH changes of single components may be carried out or components not supplied by Thorlabs GmbH be used.

This precision device is only dispatchable if duly packed into the complete original packaging including the plastic form parts. If necessary, ask for a replacement package.

☝ Attention ☝

The laser modules used with the PAT 9000B can deliver up to several mW of invisible laser radiation!

When operated improperly, this can cause severe eye and health damage!
Make sure to strictly pay attention to the safety recommendations of the appropriate laser safety class!
This laser safety class is marked on your external laser source used!
Never switch on the laser with connectors left open.

☝ Attention ☝

Mobile telephones, cellular phones or other radio transmitters are not to be used within the range of three meters of this unit since the electromagnetic field intensity may then exceed the maximum allowed disturbance values according to EN 50 082-1.

The unit must not be operated in explosion endangered environments or under wet/damp conditions.
Do not operate the system with suspected failures. If you suspect there is a damage to this product, have it inspected by qualified service peronnel.

☝ Warning ☝

Don't interchange FC/PC (non-angled) with FC/APC (angled) connectors which are used with some of our modules

NOTE

To guarantee a safe operation of the PAT 9000B take care not to cover any of the ventilation slots in the housing nor the ventilation fan air inlet at the rear panel!

1.4 Warranty

Thorlabs GmbH warrants material and production of the PAT 9000B mainframe for a period of 24 months starting with the date of shipment. During this warranty period *Thorlabs GmbH* will see to defaults by repair or by exchange if these are entitled to warranty.
For warranty repairs or service the unit must be sent back to *Thorlabs GmbH (Germany)* or to a place determined by *Thorlabs GmbH*. The customer will carry the shipping costs to *Thorlabs GmbH,* in case of warranty repairs *Thorlabs GmbH* will carry the shipping costs back to the customer.
If no warranty repair is applicable the customer also has to carry the costs for back shipment.
In case of shipment from outside EU, duties, taxes etc. which should arise have to be carried by the customer
Thorlabs GmbH warrants the hard- and software determined by *Thorlabs GmbH* for this unit to operate fault-free provided that they are handled according to our requirements. However, *Thorlabs GmbH* does not warrant a fault free and uninterrupted operation of the unit, of the soft- or firmware for special applications nor this instruction manual to be error free. *Thorlabs GmbH* is not liable for consequential damages.

Restriction of warranty

The warranty mentioned before does not cover errors and defects being the result of improper treatment, software or interface not supplied by us, modification, misuse or operation outside the defined ambient conditions stated by us or unauthorized maintenance.
Further claims will not be consented to and will not be acknowledged. *Thorlabs GmbH* does explicitly not warrant the usability or the economical use for certain cases of application.
Thorlabs GmbH reserves the right to change this instruction manual or the technical data of the described unit at any time.

1.5 Technical data

(The technical data are valid at 23 ± 5°C and 45 ±15% rel. humidity)

Chassis	**PAT 9000B**
Number of slots	3
Processor	Pentium® class or compatible
Drives	> 2GB HD, 3.5" floppy disc
Printer interface	LPT1
IEEE 488 interface	24 pin IEEE 488
Ports	3 analog outputs, ext. VGA monitor, mouse, keyboard
Line voltage (widerange)	100 V -240 V ±10%
Line frequency	50 … 60 Hz
Supply mains	Overvoltage Category II (Cat II)
Power consumption (max.)	75 VA
Operating temperature	10 … 40 °C
Storage temperature	-30 ... 70 °C
Max. operation altitude	3000m above sea level
Max. air humidity	80% up to 31°C, decreasing to 50% at 40 °C
Operation	Indoor use only, Pollution degree 2
Installation Category	CAT II
Dimensions (W x H x D) [1)]	449 x 132 x 419 mm^3
Weight [2)]	< 10 kg

[1)] dimensions of chassis without feet, including PAN head

[2)] including POL 9320 and PAN 9300

PAN 9300 NIR/FIR

Wavelength Range	PAN 9300 NIR: 960 ... 1160 nm
	PAN 9300 FIR: 1200 ... 1700 nm
Speed	standard mode: 33/sec
	turbo mode: 200/sec [1)]
Input power range	-70 ... +8 dBm
Active area of photodiode	7 mm²
Optical attenuator option[2)]	abt. 10 dB
	abt.17 dB
Input port FO Connector	FC [3)]
free space operation	≥ 3mm ∅ aperture
PAT 9000B slot width	1
Dimensions of the optical head [4)]	W x H x D: 48 x 60.5 x 139 mm³

POL 9320 NIR/FIR

Wavelength range	
POL 9320NIR	960 … 1160 nm
POL 9320FIR	1200 … 1700 nm
Insertion loss	< 1.5 dB [5)]
Return loss	> 30 dB
Extinction ratio	> 50 dB
Step size resolution	0.18°
Rotation range	0 … 179.82°
PAT 9000B slot width	1
Optical Connectors	FC/APC

1) Option SW TURBO required

2) PAT 9000B calibration parameters factors are dependent on the attenuator setting; when ordered together with the PAT 9000B the factory calibration is done with the attenuator.

3) the receptacle accepts FC/PC or FC/APC connectors due to internal free space propagation

4) removable from module; optional extension cable required for remote operation

5) for optimal aligned input polarization

Supported Tunable Laser Sources [1)]

ANDO	series AQ 4320 A/D, AQ 4321 A/D
Anritsu	MG 9637 A, MG 9638 A (all types), MG 9541A
Agilent	Agilent 8164A, 81640A, 81642A, 81680A, 81682A, HP 8167 / 8168 / 8164
New Focus	series 6200 (all types)
NetTest	Series TUNICS (all types)

SOP and DOP Measurements

Input power range	-70 ... +8 dBm
Accuracy of the elevation angle[2)]	< 0.25°[3) 4)]
Accuracy of the ellipticity angle[2)]	< 0.25° [3)]
Accuracy of the normalized Stokes components S_1, S_2, S_3	< 0.005[3) 4)]
Accuracy of the degree of polarization (DOP)	± 2% f.s.[5)]

PDL and PDG Measurements	**Jones-Matrix Eigenanalysis**
PDL measurement range	0 … 50 dB
Repeatability	± 0.02 dB [6)]
Dynamic range	> 55 dB [7)]
Measurement time	> 0.5 s

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1) ECL lasers from other manufacturers on request

2) elevation angle is defined as the inclination angle of the major axis of the polarization ellipse to the horizontal axis. the ellipticity angle is given as arctan(b/a) with b the length of the minor axis and a the length of major axis of the polarization ellipse

3) for any SOP with –30° < ellipticity < 30°

4) typically a factor of 2 less accuracy in turbo mode

5) for Pin ≥ - 40 dBm at 1550nm, w/o optical attenuator; for other wavelengths guaranteed by design

6) for PDL < 3 dB

7) for P_{in} ≥ 0 dBm @ input port of POL 9320

PMD Measurement	**Jones-Matrix Eigenanalysis**
DGD measurement range	
1310nm	0.001ps … 280ps
1550nm[1]	0.001ps … 400ps
Repeatability	< 0.01ps [2]
Max. insertion loss of DUT[3]	55 dB
Typ. measuring time [4]	
1 / 100 data points	2s / 100s

PMD measurement	**Arc-angle method**
DGD measurement range	
1310nm	0.001ps … 280ps
1550nm [1]	0.001ps … 400ps
Repeatability	< 0.01ps [2]
Max. insertion loss of DUT [4]	60 dB
Typ. measuring time [5]	1s / 50s for 1 / 100 data points

PMD measurement	**3-Stokes parameter wavelength scanning method**
DGD measurement range	
1310nm	0.050ps … 280ps
1550nm [1]	0.050ps … 400ps
Repeatability	< 0.05ps[5]
Max. insertion loss of DUT [4]	60 dB
Typ. measuring time[6]	1s / 50s for 1 / 100 data points

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[1] the maximal measurable DGD is limited by the smallest possible wavelength step. The given values are for a 10 pm step size.

[2] for PMD <0.3 ps

[3] at $P_{in} \geq 1$ mW

[4] if the scan speed of the laser is not a limiting factor

[5] at 100 nm scanning range

[6] if the scan speed of the laser is not a limiting factor

1.6 Order codes and accessories

With the PAT 9000B are delivered:
a 3-wire mains cable with protective conductor
a computer keyboard and a mouse
this operation manual
Below list shows the order codes of the modules available at the time being. Please visit the Thorlabs web page www.thorlabs.com for the latest issue on order codes:

PAT9000B	Mainframe, Modular Controller Unit with integrated TFT Display, 3 slots for Modules of the 9000 Series, Keyboard and Mouse, IEEE 488, basic Software and Ethernet Interface included in the Mainframe
PAT9000F	Measurement Package for Fiber based PMD and PDL measurements in the range 1200-1700 nm. Includes: PAT 9000B, PAN 9300FIR, POL 9320FIR, DGD Reference, Software SW PMD, SW PDL WL, SW DRV.
PAT9000N	Measurement Package for Component measurements PMD and PDL in the range 1200-1700 nm. Includes: PAT 9000F, Software SW NBC, SW Turbo, SW PAN ER.
PAT9000P1	Polarimeter Measurement Package in the range 1200-1700 nm. Includes: PAT 9000B, PAN 9300FIR, PAN EXT, Software SW Turbo, SW PAN ER.
PAT9000P2	Polarimeter Measurement Package in the range 960-1160 nm. Includes: PAT 9000B, PAN 9300NIR, PAN EXT, Software SW Turbo, SW PAN ER.
Rack19-32	19 Inch Mounting Kit for PAT 9000B

SWTURBO	Turbo Mode with 200 Measurements/s enabled
SWPANER	Software to measure the Extinction Ratio of PM Fibers and Components
SWPDLWL	Add-On Software to measure the PDL Wavelength Dependency (Tunable Laser Source required) [1)]

[1)] requires a POL 9320 for JME

SWPMD	PMD Analysis Software. Basic Module for 3-Stokes-Pameter-Wavelength-Scanning, ARC Angle (PSP) and Jones-Matrix-Eigenanalysis (JME) [1)]
SWPMDEXT/JM	PMD Analysis Add-On to measure deployed fibers with all ECL sources sustained by the PAT: Measurement according to the Jones-Matrix method. Two PAT 9000B Mainframes required. [1)]
SWDRV	Software Driver for all supported external ECL Laser Sources
SWDRVAGI [1)]	Software Driver for external ECL Laser Source Agilent / Hewlett-Packard Agilent 8164A, 81640A, 81642A, 81680A, 81682A, 81689A HP 8167 / 8168 / 8164
SWDRVANDO[1)]	Software Driver for external ECL Laser Source ANDOQ4320 A/D, AQ4321 A/D
SWDRVANR [1)]	Software Driver for external ECL Laser Source Anritsu MG 9637 A / 9638 A (all types) and MG9541A
SWDRVNF [1)]	Software Driver for external ECL Laser Source New Focus Series 6200 (all types)
SWDRVTUNICS [1)]	Software Driver for external ECL Laser Source NetTest TUNICS (all types)

PAN9300FIR	Polarimeter for the Wavelength Range from 1200 nm … 1700 nm, removable Optical Head, Open Beam Input, FC receptacle for any FC/PC or FC/APC connector
PAN9300NIR	Polarimeter for the Wavelength Range from 960 nm … 1160 nm, removable Optical Head, Open Beam Input, FC receptacle for any FC/PC or FC/APC connector
PANATT10	Attenuator, approx. 10 dB (>10 dB) @1550 nm (980nm)
PANATT17	Attenuator, approx. 17 dB (>17 dB) @ 1550 nm (980 nm)
PANEXT	Extension Cable to operate the Optical Head outside the module PAN 9300, 1.5 m
POL9320FIR	Polarizer Module for PDL/PMD Measurements with automatic setting of linear Polarization, Wavelength Range 1200 nm … 1700 nm, FC/APC Connector

[1)] requires SW PMD

POL9320NIR	Polarizer Module for PDL/PMD Measurements with automatic setting of linear Polarization, Wavelength Range 960 nm … 1160 nm, FC/APC Connector
DGDREFERENCE	Module with PMF Reference Fiber with Plot DGD vs. Wavelength, FC/APC Connectors

NOTE:

Add-ons to the PMD analysis software can be combined individually.

2 Operation

This chapter describes the operation of the mainframe of the modular polarization measurement system PAT 9000B, of the polarimeter modules PAN9300NIR, PAN9300FIR, the polarizer modules POL9320NIR and POL9320FIR, as well as the corresponding software PAT.EXE for WINDOWS®.

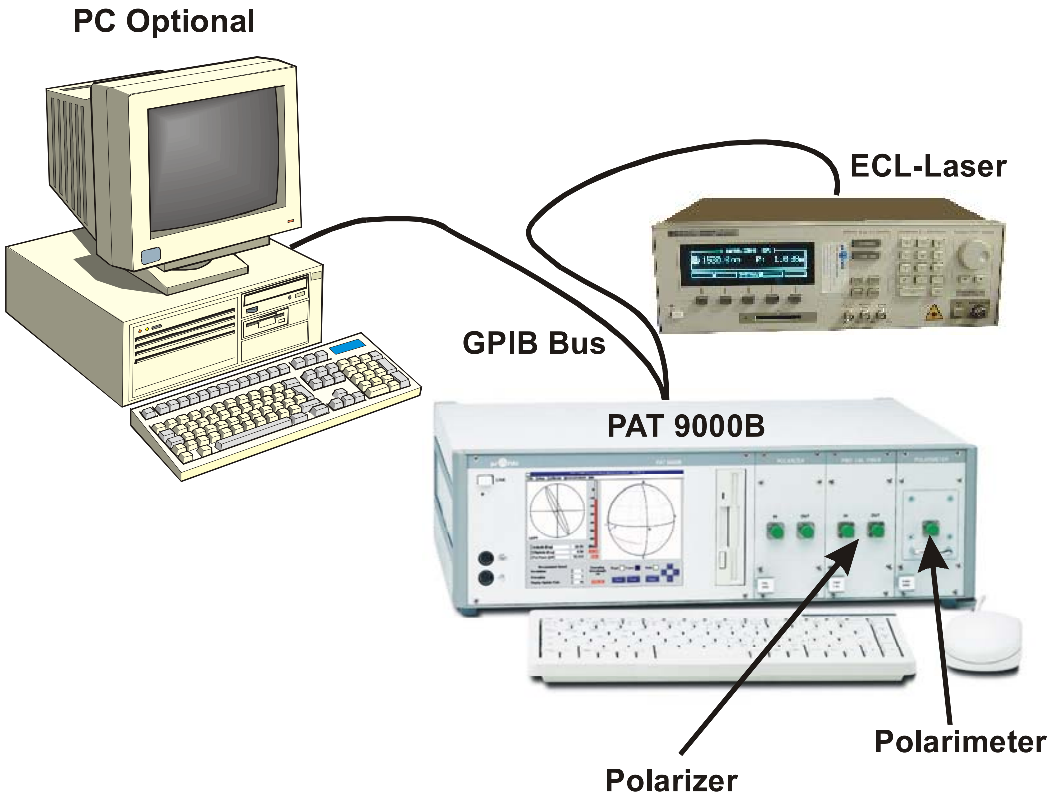

Figure 1 The PAT 9000B, typical set-up with optional PC

2.1 PAT 9000B Mainframe

2.1.1 Operating elements and connectors of the mainframe

The 19" mainframe PAT 9000B can house up to three modules of the 9000 series. It is possible to use modules of the same type or different modules. All modules are operated via keyboard, mouse or the interface of the mainframe.

Figure 2 shows the front panel of a PAT 9000B with a polarimeter module PAN 9300 and two blind covers.

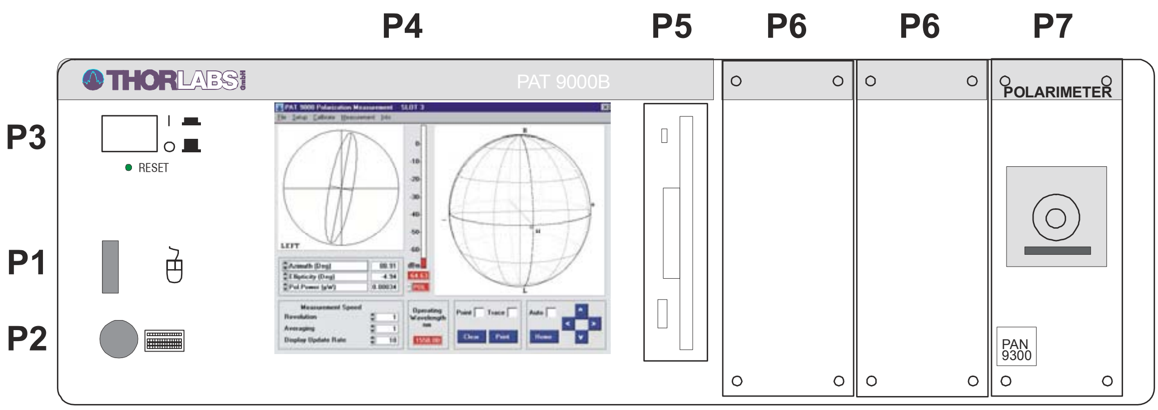

Figure 2 Front panel of the mainframe PAT 9000B

P1 Jack for USB mouse
P2 Jack for PC keyboard
P3 Mains switch
P4 VGA LCD screen (TFT color)
P5 3½" –floppy disk
P6 2 empty slots for modules of the 9000 series
P7 3rd slot here with PAN 9300 module

Assignment of the module slots:

SLOT 1 left slot
SLOT 2 middle slot
SLOT 3 right slot

The rear panel of the mainframe PAT 9000B is shown in Figure 3.

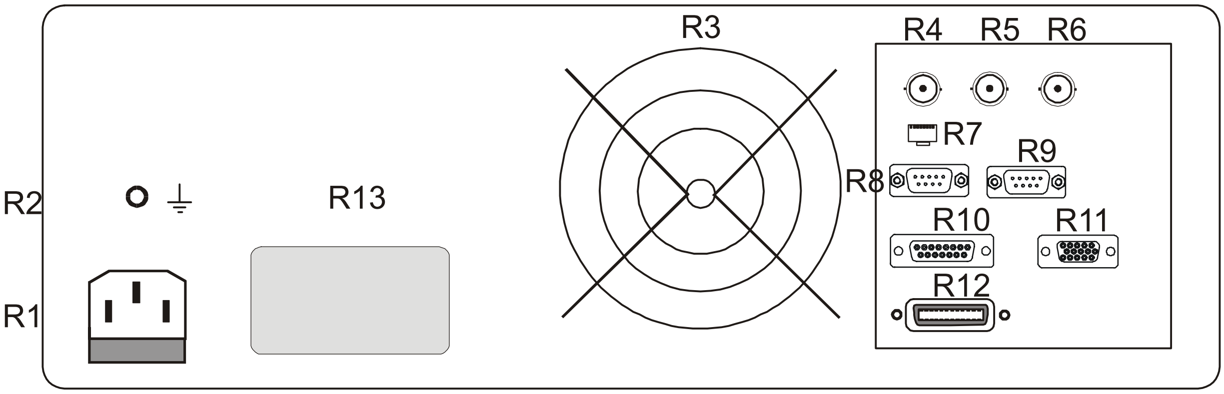

Figure 3 Rear panel of the mainframe PAT 9000B

R1	Line connector with fuse holder
R2	Chassis socket for grounding
R3	Fan air inlet
R4 ... R6	3 analogue outputs (BNC) for the 3 chosen measurement parameters (0 … 10 V)
R7	100 MHz, 8-pin RJ45 Network Connector
R8	9-pin D-SUB jack for COM 1 interface
R9	9-pin D-SUB jack for COM 2 interface
R10	25-pin D-SUB jack for LPT 1 interface
R11	15-pin high density -SUB jack for an external VGA monitor
R12	24-pin jack for IEEE 488 interface
R13	Product label indicating Voltage range, power consumtion and fuse

2.1.2 Operating instructions

☝Attention☝

**Prior to first operation: Please check properly if your line voltage corresponds to one of the specified line voltage-ranges of the PAT 9000B denoted on the identification plate on the rear panel!
The unit selects the appropriate range automatically.**

Insert the desired modules into the slots and tighten all screws properly

☝Attention☝

**Do not insert or change plug-in modules with the system turned on!
This could result in severe damages to mainframe or module.**

The optical head of the polarimeter module has to be inserted into the polarimeter module or must be connected via the optional extension cable PAN-EXT to the PAN module.

☝Attention☝

When no power is applied to the PAT, please remove the optical input signal to the PAN! Otherwise a burn-in effect could occur and damage the waveplate, which is not rotating then.

When using a tunable laser source with external cavity connect this unit by means of a GPIB connection cable to the GPIB/IEEE 488 interface of the PAT 9000B prior to switching on both units.
If the PAT 9000B itself is to be controlled via the GPIB/IEEE 488 interface, please connect the PC to the PAT 9000B by means of a GPIB cable.
After turning on, the PAT 9000B starts the operating system WINDOWS-98® and the program "PAT.EXE".

The software supplied with the PAT 9000B consists mainly of the following files:

- PAT.EXE Main measurement program for WINDOWS 98 ®
- PAT.UIR File for graphic performance
- PAT_CODE.CFG Password file for software options
- PAT_GPIB.INI Configuration data set for the GPIB/IEEE 488 interface
- HP-DAT.CFG Configuration data set for the tunable laser HP 8167/8168

- TUNI-DAT.CFG Configuration data set for the tunable laser Tunics PR/BT
- INTU_DAT.CFG Configuration data set for the tunable laser INTUN
- ANRI_DAT.CFG Configuration data set for the tunable laser ANRITSU MG 9637 A / 9638 A
- ANRITSU9541A.INI Configuration data set for the tunable laser ANRITSU MG9541A
- ANDO_DAT.CFG Configuration data set for the tunable laser ANDO
- THORLABS.ICO Icon file of *Thorlabs* applications

These files are already installed on the hard disc in directory C:\PAT.
You may make a safety copy on floppy disk of these files.

Further data sets and device drivers to operate the PAT 9000B are installed in directory C:\WINDOWS.

After program start the PAT 9000B checks the configuration of the modules and displays them as shown in Figure 4.
SLOT 1 indicates the left, SLOT 2 the middle and SLOT 3 the right slot.

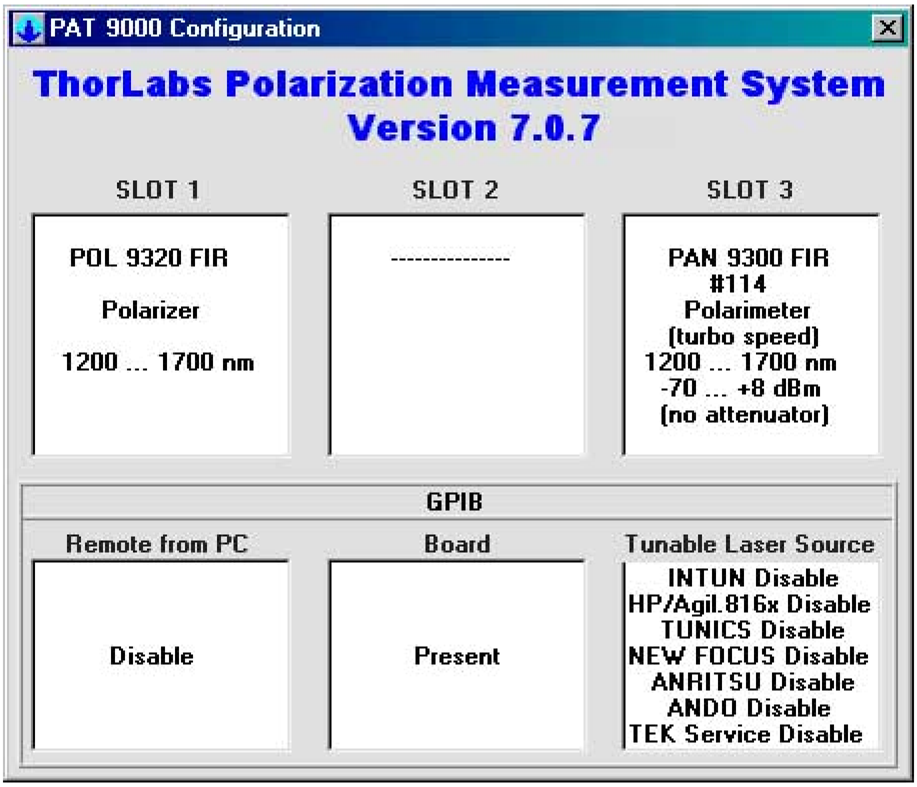

Figure 4 Display of the PAT 9000B configuration

If a polarimeter module PAN 9300NIR or PAN 9300FIR is used (as shown), it is activated and starts displaying the measured values. Calibration data for this module are read directly from the optical head. A possible attenuator is also indicated.

NOTE

When using more than one module of the same type always the module with the smallest slot number is activated first.
Use the menu points:
Select PAN MODULE or Select POL MODULE
in the set-up menu to change module-activation

Each polarizer module POL 9320 is activated with it's basic settings when initialized. After each program start the internal polarization controller starts at the default position.
The lower part of the screen 'PAT 9000B Configuration' informs about the possibilities of the GPIB/IEEE 488 interface. You can see whether the GPIB/IEEE 488 interface card is installed (board = present), whether a data transfer to a PC is possible (remote from PC = enable) and whether a tunable external laser source can be controlled.
All GPIB/IEEE 488 interface connections must be done with a GPIB cable before switching on the instruments.
For PMD measurements one of all available laser sources must be the active PMD laser, i.e. this laser is intended for wavelength tuning in PMD measurements.
The default setting is done according the following hierarchy:

- HP/Agilent 816x
- Tunics PR/BT
- New Focus 6200
- Anritsu MG9637/8A, MG9541A
- Ando

2.1.3 Operating the mainframe with the program PAT.EXE

After starting the program and initializing the modules the main screen is built up.
It can be seen on the internal TFT display or/and on the externally connected VGA monitor.
Here the measurement results of the active polarimeter module are displayed graphically and numerically.

Operation via mouse

You can activate the graphical dialog boxes by mouse click and edit the input.
Double clicking marks the whole input line and overwrites it by the next input

Keyboard operation

You also can use the PC keyboard for editing. Select the dialog boxes with the TAB key (forward) or the SHIFT-TAB combination keys (backward).To toggle between two selections use the '↑' or '↓ keys ', to activate them hit <ENTER>.
When entering numbers with decimal point use a real decimal point, no commata!

The menu

The second line on the screen is the menu line.:

Select a menu point by mouse click or by pressing the ALT key together with the underlined letter of the menu point.
The drop down menus give the following options:

File

Print Panel	Prints the main screen
Quit	Terminates the program

Set-up

Wavelength	Setting the desired wavelength
Parameter Selection	Selecting parameters for the numerical display and long-term analysis
Power Low Level	Determine a minimum level of necessary power
Laser wait time	Define wait time after laser adjustment
Select PAN Module	Select one of several polarimeter modules
Select POL Module	Select one of several polarizer modules
Select PMD Laser	Select the active laser for PMD measurement
Show POL Panel	Display the polarimeter panel
Show INTUN Panel	Display the INTUN panel
Show HP/Agilent 816x Panel	Display the HP laser panel
Show TUNICS Panel	Display the Tunics laser panel
Show NEW FOCUS Panel	Display New Focus laser panel
Show ANRITSU Panel	Display ANRITSU laser panel
Show ANDO Panel	Display ANDO laser panel
Show software options	Displays all available / installed software options
GPIB Configuration	Configuration of GPIB/IEEE 488 interface

Calibrate	**User specific calibration of:**
Dark current	Dark current of detector
Circular calibration	Internal angle diversity at circular polarization
Wave plate calibration	Delay angle of wave plate
Power calibration	Power display
Offset Azimuth	Set correction angle for the azimuth
Load user calibration	Load user specific calibration values
Save user calibration	Store user specific calibration values

Measurement

Display photocurrent	Display the photocurrent of the internal detector
Long term analysis	Long-term analysis of selectable values
PM Fiber Extinction Ratio	Alignment characterization of polarization maintaining fibers
Jones Matrix / PDL	
>Jones Matrix / PDL	Measures the Jones-Matrix and displays the polarization dependent loss (PDL)
>PDL vs. Wavelength	Measures the wavelength dependency of the PDL
PMD	PMD measurement according to the
>Jones matrix eigenanalysis	Jones-Matrix analysis
>HiRes WDM components (Jones matrix)	High resolution Jones matrix analysis for narrowband components
>JONES with distant laser – Transmitter	Jones matrix method on installed fibers (2nd PAT controls ECL and acts as transmitter)
>JONES with distant laser – Receiver	Jones matrix method on installed fibers (PAT acts as receiver)
>Arc angle method	Arc-angle method
>3 Stokes Parameter	3-Stokes-parameter-wavelength-scanning method

Info

Show program info displays program version and copyright

Figure 5 Program Info

The menus are described in detail in the following sections.

NOTE

To obtain precise results, the correct wavelength of the measured radiation must be set in the menu 'Set-up / Wavelength'. The current wavelength setting is shown in the lower part of the main screen.

2.2 Activation of the different software options.

All available software options are already installed on your PAT 9000B system. They must be activated individually by a password supplied by *Thorlabs GmbH* after purchase of the software option. The different passwords are only valid for the individual PAT system and the individual optical head. They are stored in the password file "PAT_CODE.CFG".

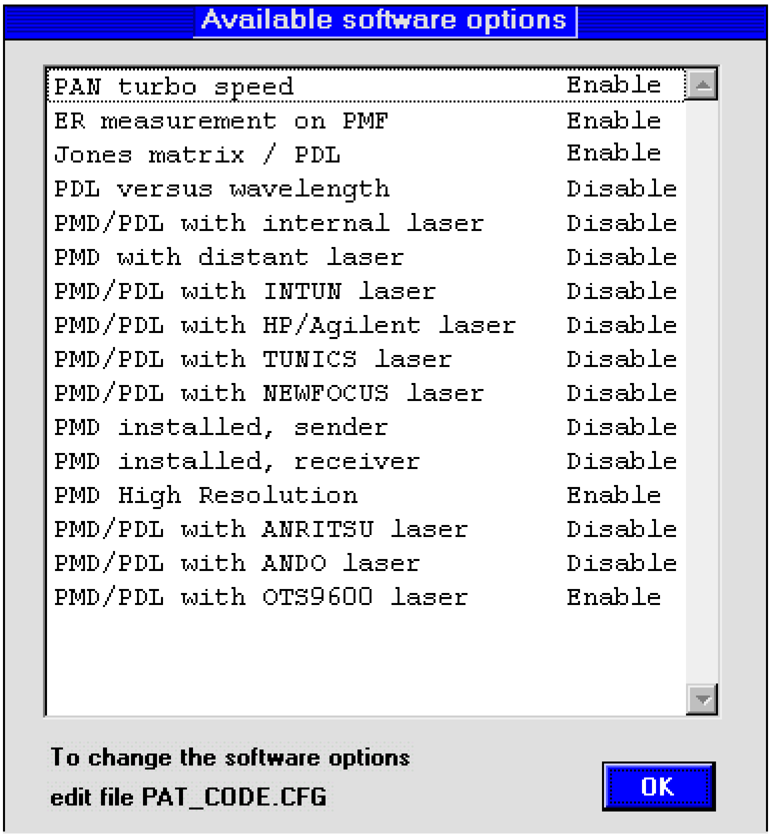

Figure 6 Display the installed software options

The menu item 'Setup/Show software option' shows as in Fig 6 which software options are enabled in your system.

NOTE

If you have more than one PAT, you can enter the passwords of both units in each of the configuration files. You can exchange then the different PAN heads between the units without locking the software options.

To install a new password on your PAT 9000B please use the following procedure:

- Shut down the PAT.EXE program
- Start the supplied editor program "NOTEPAD.EXE" in the "Programs / accessories" folder (or double-click on the file "C:\PAT\PAT_CODE.CFG" in the windows explorer)
- Open the password file "PAT_CODE.CFG". (If not yet present just enter the passwords, one below the other, in an empty file and save it afterwards under the name "C:\PAT\PAT_CODE.CFG").
- You may want to make a copy of the original PAT_CODE.CFG by storing it under the name PAT_CODE.OLD to the same directory. Then reopen PAT_CODE.CFG.
- You see all installed passwords (6 digit numbers).
- Add the new password <u>below</u> the existing ones (one line for each password!)
- Store the file "PAT_CODE.CFG" and close the editor (do not change the filename nor the directory!)
- Restart your PAT.EXE program
- Now the new function is available

2.3 Polarization analysis with the PAN 9300 module

The optical head of the polarimeter module PAN 9300 enables polarization analysis in free space set-up's as well as for fiber guided light.
The PAN 9300 is supplied with a fiber optic FC receptacle with internal collimator, which can be used with FC/PC and FC/APC connectors. This receptacle can also hold an input attenuator to extend the power range of the system (optional).
For free space measurements the receptacle can be removed easily. The light beam should enter the aperture of the PAN module perpendicular to the front panel of the optical head. The waist should be below 3 mm to guarantee that all light reaches the detector. The active area of the photodiode is 7 mm^2 (IR).

☝Attention☝

When the PAT 9000B is switched off, please make sure that no laser power is applied to the PAN module to avoid a burn-in effect!

The complete optical head can be removed from the PAN 9300 module for remote operation and integrated in external experimental set-ups. The head is connected to the PAN module by the extension cable "PAN EXT" (optional).
The bottom of the optical head is the reference plane for 0° horizontal polarization.

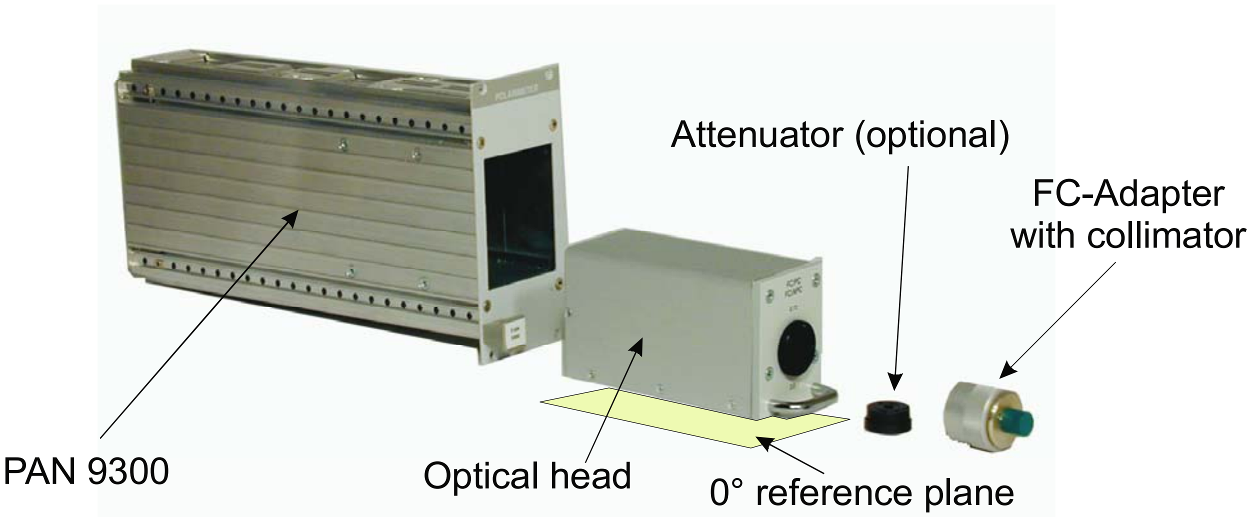

Figure 7 PAN 9300 head assembly

NOTE

Please make sure you're using a high quality FC/PC or FC/APC connector. The connector must fit into the FC adaptor. Bad connectors with a damaged fiber end surface can lead to significant measurement errors!

2.3.1 Setting the operating wavelength

The polarimeter module uses a rotating λ/4-waveplate and delivers wavelength-depending results since the birefringence of the wave plate depends on the wavelength.
Activate the menu 'Set-up / Wavelength' and set the precise wavelength (Figure 8). Coarse settings like 1310 or 1550 nm are not sufficient for top accuracy!

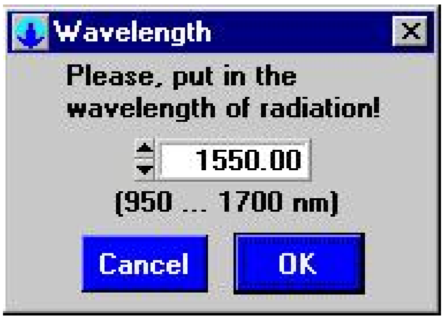

Figure 8 Setting the wavelength

The wavelength of the laser radiation has to be set as precise as possible. Under certain conditions the PAT 9000B recognizes automatically an incorrect wavelength. In these cases the error message

' Wavelength incorrect or recalibration required '.

will appear.
You then should check the set wavelength.

IMPORTANT NOTE

A basic condition for high accuracy polarization measurements is a as close as possible agreement between actual and set wavelength!

2.3.2 Selection of polarization parameters

Three of fifteen parameters can be read out numerically to the main screen below the polarization ellipse. The three parameters can be selected on the main screen or from the menu 'Set-up / Parameter Selection'. The selected values are also updated during long-term analysis.

In the menu 'Set-up / Parameter Selection' the selection becomes valid with an 'OK' mouse click.

NOTE

Exactly three parameters have to be marked in the menu

'Set-up / Parameter Selection'.

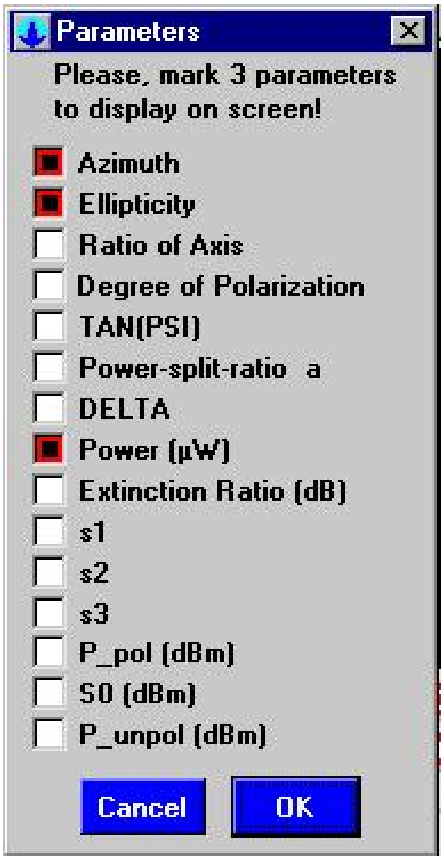

Figure 9 Selection of parameters

You can chose three of the following parameters:

Parameter	Meaning	Range
Azimuth	elevation angle θ with regard to the internal 0° reference plane	$-90° \leq \theta \leq +90°$
Ellipticity	ellipticity angle η	$-45° \leq \eta \leq +45°$
Ratio of axes	ratio of axes tan$\lvert\eta\rvert$	$0 \leq \tan\lvert\eta\rvert \leq 1$
Degree of polarization	degree of polarization DOP	$0 \leq$ DOP ≤ 100 %
TAN (PSI)	tan Ψ	$0 \leq \tan\Psi \leq 1$
Power-split-ratio a	power split ratio a	$0 \leq a \leq 1$
DELTA Δ	phase difference Δ	$-180° \leq \Delta \leq 180°$
Power (µW)	polarized power P_{pol}	
	In AC mode	$P_{pol} \leq 6.3$ mW
	In DC mode	$P_{pol} \leq 2.5$ mW
Extinction Ratio	extinction ratio ER	$-\infty$ dB $\leq$ ER $\leq$ 0dB
s_1	normalized Stokes parameter s_1	$-1 \leq s_1 \leq 1$
s_2	normalized Stokes parameter s_2	$-1 \leq s_2 \leq 1$
s_3	normalized Stokes parameter s_3	$-1 \leq s_3 \leq 1$
P_pol (dBm)	polarized power in dBm	≤8 dBm
S0 (dBm)	total optical power in dBm	≤8 dBm
P_unpol (dBm)	unpolarized power in dBm	≤8 dBm

The elevation angle (**azimuth**), ellipticity angle and ratio of axes refer directly to the polarization ellipse (see Fig. 10). The degree of polarization is the ratio of polarized optical power to the total power (polarized and non-polarized).

TanΨ is the field intensity in y-direction divided by the field intensity in x-direction (E_y/E_x).

The **power-split-ratio a** is the quotient of polarized power in x-direction and total polarized power ($E_x^2/(E_x^2 + E_y^2)$).

DELTA Δ is the phase difference between x- and y-mode ($\Delta=\phi_y-\phi_x$).

"**Power**" shows the power of the polarized light in µW. With a low degree of polarization the total optical power may be considerably higher. Choose "S0" to display the total optical power in dBm.

The **extinction ratio** (ER) is the axis ratio of the polarization ellipse in logarithmic notation.

S1,S2 and S3 denominate the three normalized Stokes-Parameters corresponding to the axes of the Poincaré sphere.

P_pol, S0 and **P_unpol** display the polarized optical power, the sum of polarized and unpolarized power (total power) and the unpolarized power in dBm.

All parameters can also be selected on the main screen. Clicking on the parameter to be changed will give a drop-down menu with all possible selections.
You can use also the small arrow keys besides the parameters to scroll up or down through the parameter list.

2.3.3 Set-up of the main screen

The main screen in Figure 10 shows different graphical and numerical representations of the measured results.
On the left side the polarization ellipse is shown, on the right the Poincaré sphere and in between the optical power is shown as bar graph. You can select the bar graph to show either the polarized part of the light ("POL") or the unpolarized part ("UNP") or the sum of both ("SUM"). Click on the small window below the bar graph (depicted here as "POL") to select the power display.

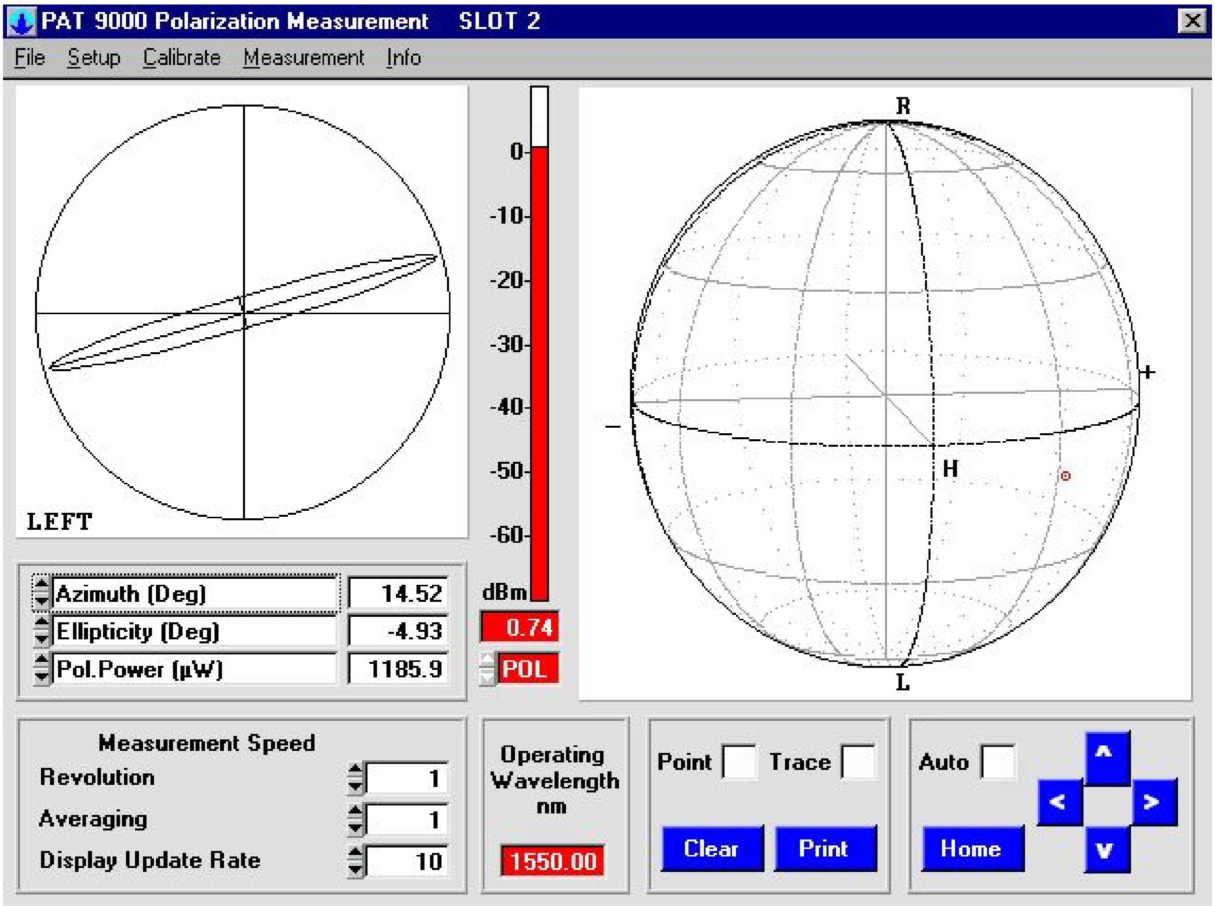

Figure 10 Main screen for polarization analysis

2.3.3.1 Polarization ellipse

The polarization ellipse is a graphical representation of the state of polarization at the polarimeter input. The polarization ellipse is defined by the elevation angle θ (azimuth) and the ellipticity angle η (ellipticity). The ellipse represents the trace of the top of the electrical field vector.

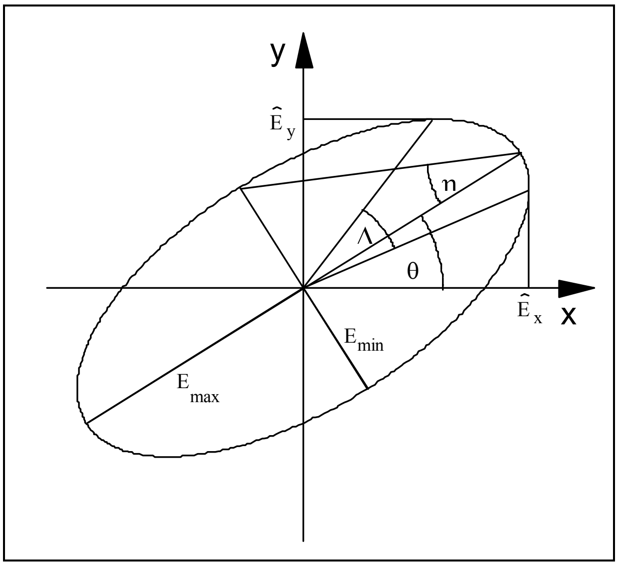

Figure 11 Polarization ellipse

The direction of rotation (right/left) of the polarization is also displayed. The (virtual) observer looks towards the light source.
Definition of right and left handed polarization: In a right handed coordinate system x, y and z where the light wave propagates in the z direction the helical motion of the tip of electrical field vector can be visualized with a right hand whose thumb is showing in the propagation direction and whose finger curl into the same direction as the rotation of the field. This definition yields a clockwise rotation of the field vector tip through the ellipse when viewed from a position looking into the light beam. For left handed light the left hand must be used and the rotation is counter clockwise on the ellipse.

2.3.3.2 Poincaré sphere

The azimuth and ellipticity angles of the polarization ellipse can be mapped uniquely onto spherical coordinates with 2 θ corresponding to the latitude and 2 η to the altitude position (see Fig. 11). Please not the factor of 2 involved in the mapping. Each point on the Poincaré sphere describes a defined state of polarization.

The equator plane represents all linear states of polarization. The two poles represent the states of circular polarization (right/left). All other points on the upper (lower) half sphere correspond to elliptical polarization's with right (left) handed rotation.

Short	**Polarization**	θ	η
H	linear, horizontal	0°	0°
+	linear +45°	+45°	0°
V	linear, vertical	±90°	0°
-	linear -45°	-45°	0°
R	right circular	-	+45°
L	left circular	-	-45°

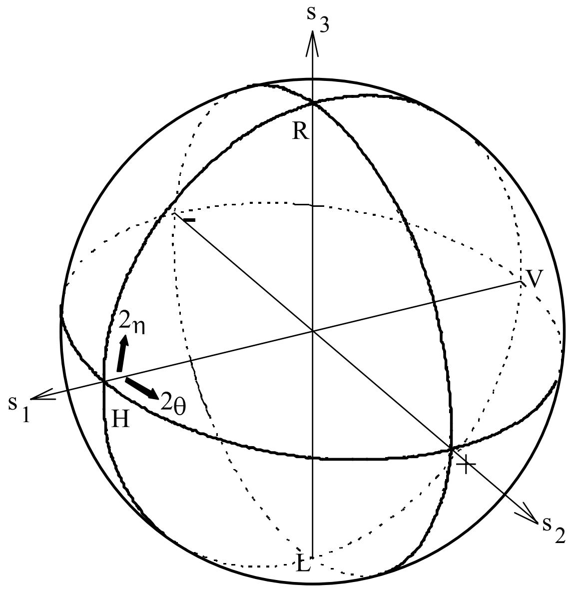

Figure 12 Poincaré sphere

The Cartesian coordinates of any point on the Poincaré sphere represent the corresponding three normalized Stokes Parameters s_1, s_2 and s_3.

The state of polarization is shown as a point on the Poincaré sphere. If this point lays on the visible front part of the Poincaré sphere it is represented in red color. If the point is on the rear of the sphere, it is in blue color.

NOTE

Points on the front part of the sphere are shown red, points on the rear part are blue!

The time dependency of polarization variations can be shown on the Poincaré sphere. Click '**Point**' and all measured states of polarization vs. time are stored as colored dots. Click '**Trace**' to connect all points by a colored line (red = front, blue =back).

Clicking again to '**Point**' or '**Trace**' switches these mode off again, however, the points or the trace will remain visible.

Clicking '**Clear**' clears the trace. If you click '**Print**', only the display of the Poincaré sphere is printed. If you want to have the total screen content printed use 'Print Panel' in the menu 'File' provided that the printer is installed properly under WINDOWS-98®.
(In the Windows®-98 menu "Start / Settings / Printers" you can choose between installed printers or install a new printer with "Add Printer". You don't need the installation CD because all installation files are stored on the PAT hard disk).
The Poincaré sphere can be rotated to any desired view position by means of the arrow keys below the sphere. If '**Auto**' is clicked, the sphere rotates automatically for best visibility of measured points. Clicking '**Home**' will return the Poincaré sphere back to its default position.

NOTE

Rotation of the sphere will clear all previously displayed points or traces!

2.3.3.3 Power display

Between the polarization ellipse and the Poincaré sphere a bar graph shows the power of the polarized, unpolarized or polarized plus unpolarized light in logarithmic scaling. This kind of display turns out to be useful for adjustment to minimum or maximum alignment. The refresh frequency of the bar graph can be set in the dialog box 'Display Update Rate'.
➔ (Refer to chapter 2.3.4, "Measurement speed" on page 34)
The optical power is also shown as numerical value in dBm at the bottom of the bar graph. The window below selects the kind of display: "POL"=polarized power, "UNP"=unpolarized, "SUM"=sum of both.

2.3.3.4 Numerical display

The polarization results are shown numerically below the polarization ellipse. Three parameters can be displayed. The desired parameters are selected from a total of 15
➔ (Refer to chapter 2.3.2, "Selection of polarization parameters" on page 27)

2.3.3.5 Wavelength

The wavelength window shows the set wavelength entered in the menu "Setup / Wavelength". You can not change the wavelength in the main screen window.

2.3.3.6 Quitting the program

Click on the menu item 'File / Quit' or press the key combination ALT+F4 to quit the program “PAT.EXE”.
You can also quit by clicking the upper right corner "X" of the window.

☝Attention☝

If you want to stop measurement please don't switch off the PAT 9000B with Windows®-98 still running. This will cause problems when restarting the system.

First shut down Windows®-98 in the "START" menu.

2.3.4 Measurement speed control

In the lower left corner of the main screen are dialog boxes to control the measurement speed and the display update rate. The user may change the pre-set values by mouse or keyboard.
Just click on the presently set number and select another value from the appearing list. You may also click to the small arrow keys beside each dialog box for increase or decrease of the values.

Revolution[1)]: The settings '½', '1’, '2’, '4’, '8’ or '16' define the number of λ/4-waveplate revolutions used for a single measurement. The length of the recorded photocurrent signal is doubled every time the setting increases. (For every polarization state the photocurrent exhibits a specific periodic pattern which is evaluated by a Fourier analysis (see Figure 14) . Each photocurrent sample gives an azimuth and ellipticity angle.) The lower the setting the faster the measurement. But especially with low light power the selection of a higher value is recommended because noise and fluctuations will be reduced. If external light from line operated light sources can affect the optical input the fastest setting '½’ should be avoided. To ensure a maximum measurement speed the polarization ellipse is not displayed in the fastest setting '½' (default is '1').

[1)] unfavorable settings of "revolution" and "averaging" may turn the system very slow.

Averaging[1]): The settings '1', '2', '4', '8' or '16' declare the number of averaged azimuth and ellipticity samples. For precise measurements, for example PDL or PMD measurements of fiber optic components the averaging should be increased. Thus the measurement accuracy is increased whereas the measurement speed is reduced (default is '1').

Display update rate:

'1', '5', '10' or '20' sets the refresh rate for the numerical displays and the bar graph update for optical power on the main screen. The set rate indicates after how many graphical updates of the polarization ellipse and Poincaré sphere the numerical readout is refreshed. This improves the readability of numerical values (default is '10').

[1]) unfavorable settings of "revolution" and "averaging" may turn the system very slow.

2.3.5 Selecting the polarimeter modules

If several PAN 9300 modules are used in the mainframe PAT 9000B, only one of them can be active. The active PAN 9300 module is controlled via the main screen with its menus and does all polarization measurements.
Select menu 'Set-up / Select PAN Module'. The following screen appears:

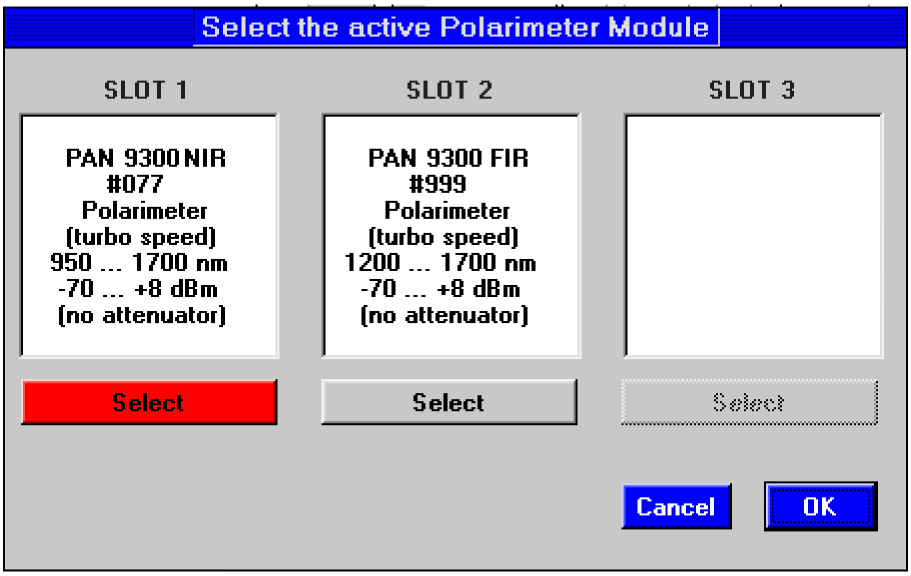

Figure 13 Screen to activate one of several polarimeter modules

Activate the corresponding polarimeter module by clicking '**Select**'.
'**OK**' clears the screen.
All following settings, calibrations and measurements refer to the active polarimeter module.

2.3.6 Operating principle of the polarimeter module PAN 9300

Several methods are known for polarization analysis. The polarimeter module PAN 9300 uses the principle of a rotating λ/4-waveplate. The rotating λ/4-waveplate converts the fixed input polarization into a temporal varying polarization, synchronized with the revolution of the wave plate. A linear polarizer behind yields a periodical optical signal which is detected by a photodiode. The oscillating photocurrent can be displayed in a window.

Select menu 'Measurement / Display Photocurrent'. The screen (Figure 14) shows the time behavior of the photocurrent for a fixed input polarization state. By means of a discrete Fourier analysis (DFT) amplitudes and phases of the signal spectrum are calculated. This numerical basis allows to calculate the state and degree of the polarization (SOP and DOP).

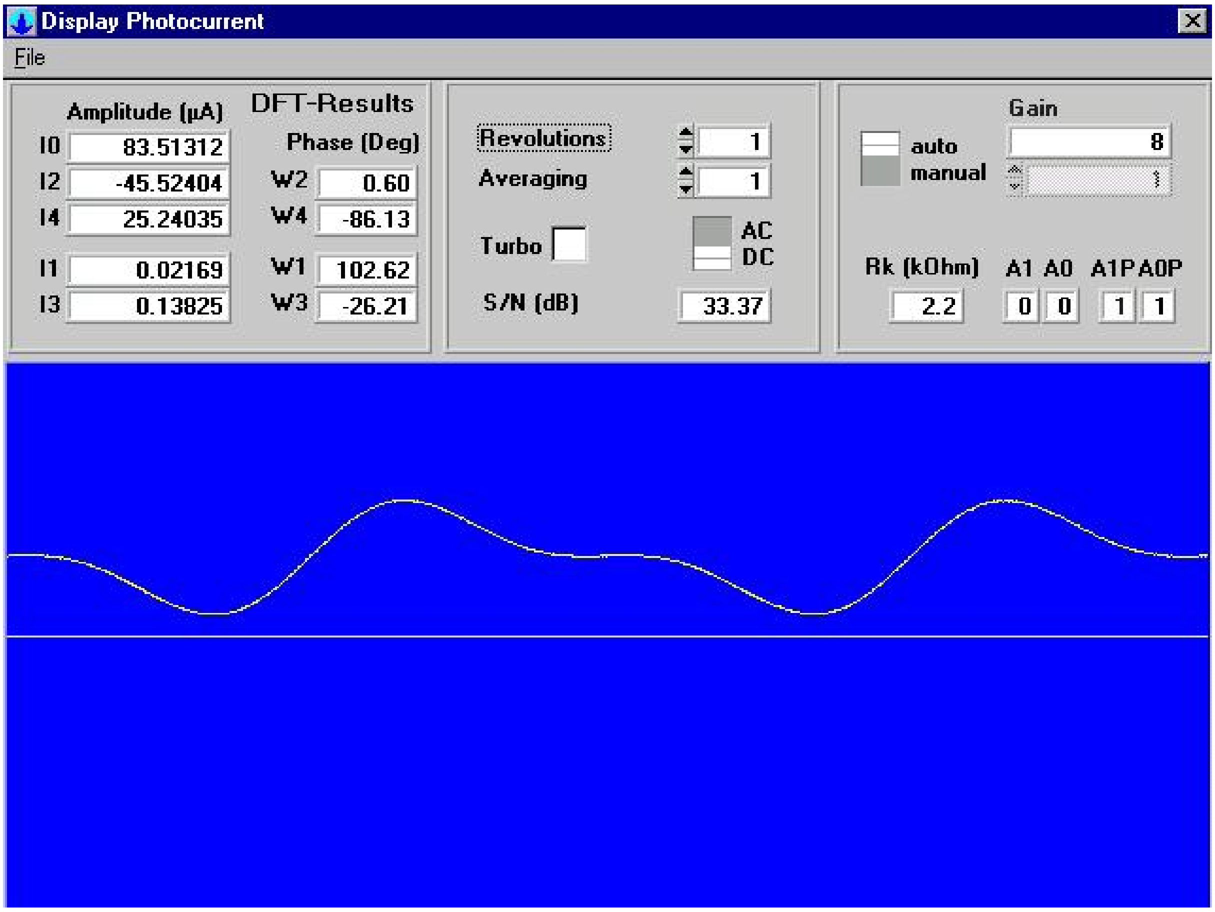

Figure 14 Displaying the time behavior of the photocurrent

NOTE

Exact polarization measurements are only possible if the displayed photocurrent shows no additional fluctuations, breakdowns in amplitude or other interference's. If such disturbances occur please check the fibers, the connectors and especially the light source used. Also stray light from artificial light sources (50 [100] or 60 [120] Hz) may lead to such fluctuations.

NOTE

Repeated short breakdowns in photocurrent at a certain x-position (peak near to zero) often indicates some dirt in the polarimeter module. In this case you should clean the module.

☝Warning☝

Do not try to clean the polarimeter module inside neither with dry or wet tissue materials!
Please only use dry and cleaned low compressed air!

Too much noise at low optical powers also reduces the measurement accuracy. This can be improved by increasing the number of revolutions used ('Revolution').
The display fields I_0 to I_4 show the calculated amplitudes of the spectrum, the fields W_1 to W_4 the corresponding phases.
The value S/N denotes the signal-to-noise ratio in dB. S/N ratios below 25 dB decrease the measurement accuracy of the polarimeter.

NOTE

An unsuitable S/N ratio may be the result of an increase of the amplitude ‘I1’ compared to ‘I2’ and ‘I4’. This often indicates light from line operated light sources (100 or 120 Hz) penetrating the optical input.
In this case please shield the optical input.

2.3.7 Long-term polarization analysis

By Selecting 'Measurement / Long term analysis' you will see the screen in Figure 15.

Long-term analysis allows to record up to 30000 measurement values (per parameter) in user-definable time steps. 1000 measurement values can be displayed in one diagram.

Enter the desired settings for 'Revolution' and 'Averaging' in the main screen to make them valid for long-term analysis.

➔ (Refer to chapter 2.3.4, "Measurement speed" on page 34).

The three diagrams show the time behavior of the three selected parameters. You can choose them for example in the menu 'Set-up / Parameter Selection'. You can select 3 from a total of 15 parameters.

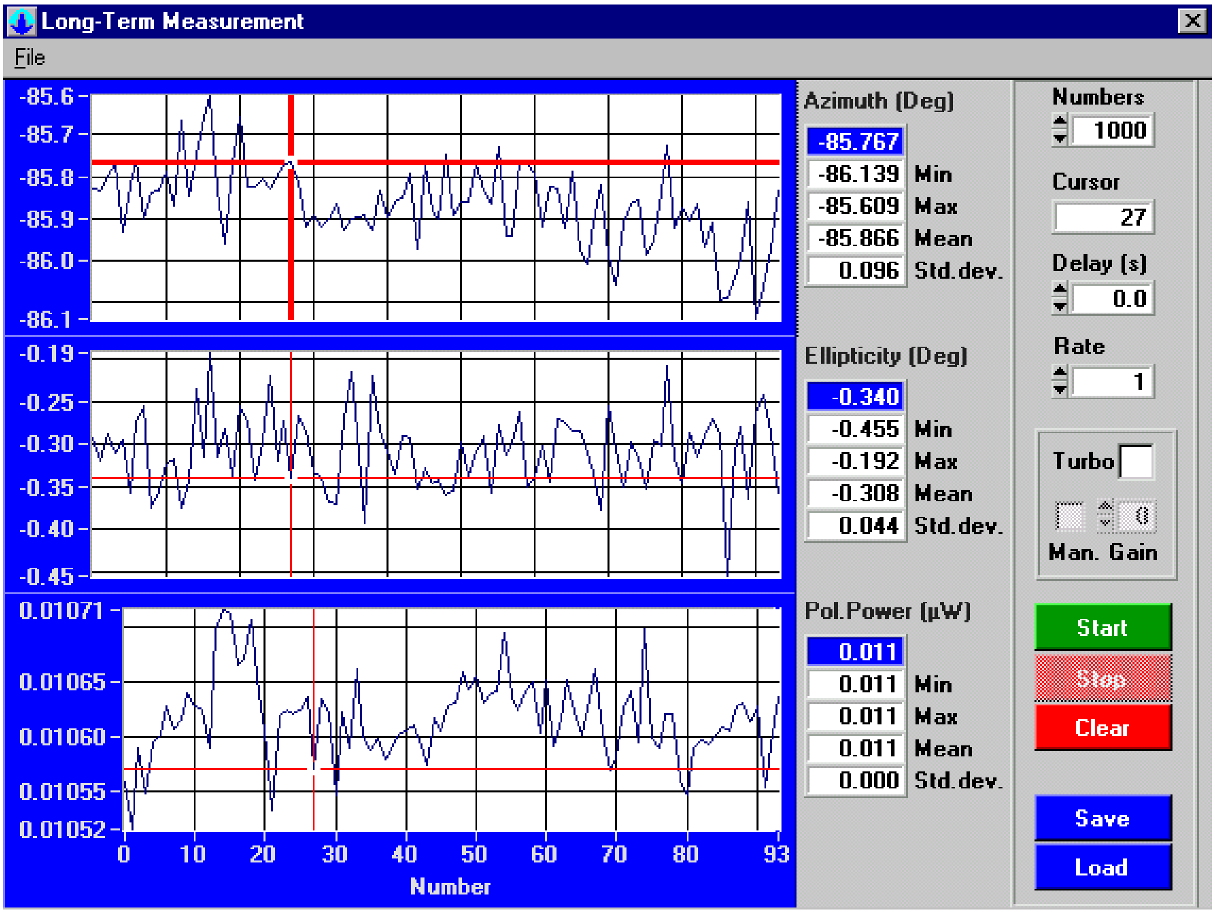

Figure 15 Long-term analysis of 3 parameters

You can either use the mouse pointer or the cursor keys to scroll through your measured values.

'Numbers' Declares the number of measuring points to be recorded. The diagrams can display a maximum of 1000 points each only. To display the following values the diagrams are cleared automatically and the display re-starts automatically with the next 1000 samples.

'Counter' Displays the number of already registered points in a running measurement. When all measurements are finished the text 'Counter' is replaced by 'Cursor', the positions of the three cursors are displayed in the diagrams. An input to this field puts all cursors on the corresponding position in the data set with respect to time.

'Delay (s)' Defines the time interval between the measurements. The setting is in seconds and fractions of seconds. The program uses the PC clock and therefore can only provide the corresponding accuracy and precision. The chosen time interval can not be valid if the required measuring time (refer to Revolution / Averaging) is longer than the 'Delay' setting.

'Rate' Determines the update rate of the three diagrams. Fast measurements are only possible with a high setting value for 'Rate'.

'Turbo' Press the button to enable the TURBO mode. The motor will speed up. Please wait several seconds for stabilizing.

The value of 'numbers' is restricted to 1000 in this mode because all data from the polarimeter are stored directly to the memory. 1000 polarization values will take 5 seconds with 200 meas./second.

After data acquisition is finished, polarization results will be calculated and displayed.

'Man.' Only valid in TURBO mode. Allows the amplifier gain to be set to manual. Since the measurements are done at a certain gain (which is fixed before), power fluctuations (mainly peaks) may overload the amplifier. An error message 'Optical Power is too high or varying. Use manual gain setting!' appears.

'Gain' Used to set a manual gain setting during the whole measurement. Valid values range from 0 (lowest gain for high power) to 19 (highest gain for lower power). Note, that too high power overload the amplifier and leads to an error, too low power increase measurement errors and a warning appears.

'Start' Starts recording measurement values.

'Stop' Stops recording measurement values and displays those previously measured.

'Clear' Clears all diagrams.

'Save' Enables storing of measured values in ASCII-format in a file 'NAME.DAT' on floppy- or hard disk. The user determines a directory and enters a file name with extension '.DAT'. The file content can be looked at with any text editor and can be processed further with corresponding software.
If the file name already exists, you can decide whether the new measured values are to be added to the existing file or whether the file may be overwritten.

'Load' Loads already stored data from hard disk or floppy-disk and displays them again.
The diagrams display a maximum of 1000 measured values even if the data file contains more values.

The data files have the following format:

```
5      Measurements,  Date: 11-06-2002
Azimuth (Deg),  Ellipticity (Deg),  Power (µW),
    15.105         -0.7265           20.309       12:29:50
    16.047          1.6397           20.294       12:29:51
```

The date is given in American notation: month-day-year. Column one to three show the three selected polarization parameters. The fourth column stores the acquisition time.

To the right of each diagram the selected parameter, the values marked with the cursor and some data statistics are shown. The minimum, maximum, average value and standard deviation are displayed.

Quit the screen 'Long-Term Measurement' by clicking on the upper right corner
'X', on menu item 'File / Close Panel' or with the key combination Alt-F4.

2.3.7.1 Long-term polarization analysis, turbo mode

The turbo mode (option) allows a higher measurement rate than in standard mode. The number of revolutions of the wave plate is increased from 33/s to 100/s in the optical head of the polarimeter.

NOTE

Averaging measured values by "revolution" or "averaging" is not possible in turbo mode

➔ (refer to chapter 2.3.4)

MODE	Standard	Turbo
Revolutions of the wave plate	33/s	100/s
Revolution = 2	8 measurements/s	./.
Revolution = 1 (standard)	16 measurements/s	./.
Revolution = ½	33 measurements/s	200 measurements/s

A measurement value is calculated every half revolution of the wave plate, thus enabling a measurement rate of 200/s results. A measurement refers to a single set of polarization angles (azimuth and ellipticity) and all related parameters. Since there is no time left to calculate and display the polarization data the measured data of photodiode current are stored and processed afterwards. Thus as "single shot measurement" up to 5 seconds can be recorded, corresponding to 1000 polarization measurements.

How to handle the turbo mode:

- All 1 ... 1000 measurements are made with fixed photocurrent amplification.
- If only minor power fluctuations can be expected in these 0 ... 5 s you can work with the automatic amplification adjustment procedure (default set-up).
- If power fluctuations occur while recording you may get an "overload" error. Then repeat the measurement with the amplification set manually:
- Press the key "Man" and select an amplification factor between 0 and 19 in the field "Gain". The amplification with automatic scaling is the default setting.
- To increase the dynamic range for expected higher power levels reduce the amplification.
- A too low gain setting reduces accuracy and may lead to warnings like "Low power (5%). Increase manual gain".
- The highest accuracy is reached in standard mode.

- Using turbo mode means an increase of rotation frequency. It will take a few seconds to stabilize the rotation speed of the wave plate.
- The Lifetime of the optical head is not affected by using turbo mode.

You can activate the turbo mode in the menus ‘Measurement / Long term analysis‘, or in ‘Measurement / Display photocurrent‘ and via the IEEE 488 interface. For all other measurements (e.g. ER, PDL and PMD) the unit automatically returns to standard mode.
Because the display refresh rate is not sufficient for the turbo mode, the data are only displayed after the data acquisition is completed.

2.3.8 User calibration of the polarimeter module PAN 9300

To guarantee utmost accuracy the polarimeter module PAN 9300 is calibrated by *Thorlabs GmbH* at several wavelengths. The calibration data are stored in the optical head and are read out automatically with each start of the program “PAT.EXE”.
The menu 'Calibrate' offers in addition the possibility to do a user calibration to achieve maximum accuracy. For calibration a stable laser source with known wavelength and a manual polarization controller, (e.g. “Lefèvre-loops or Mickey ears”), are required to set defined states of polarization.
The experimental set-up for a user calibration is shown in Figure 16.

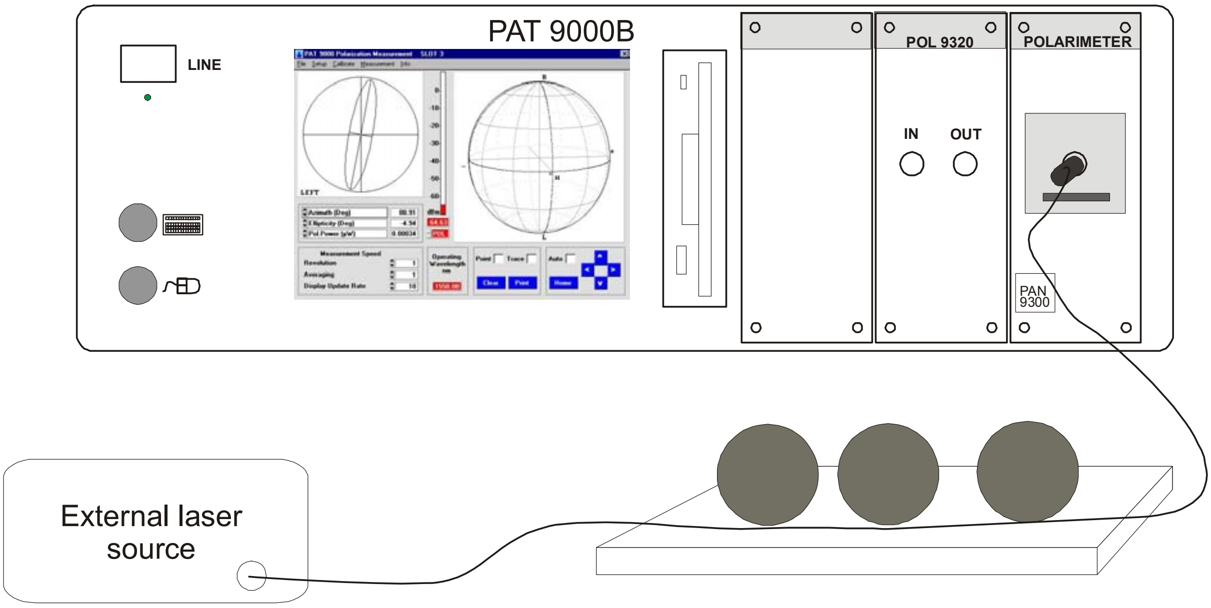

Figure 16 Set-up for calibrating the polarimeter module

Prior to calibration the wavelength of the laser source used has to be entered with an accuracy of at least 0.1 nm in the menu 'Set-up / Wavelength' (Figure 8).
The next steps are (in this order):

1. 'Calibrate / Dark current'
2. 'Calibrate / Circular calibration'
3. 'Calibrate / Wave plate calibration'
4. 'Calibrate / Power calibration'
5. ‘Calibrate / Offset Azimuth’

2.3.8.1 'Calibrate / Dark current'

'Calibrate / Dark current' measures the dark current of the detector inside the polarimeter. The optical input must be completely shut off to avoid influences of disturbing light sources. A protection cap is definitively not sufficient! Connect a fiber to the optical input of the polarimeter and cover the other end with a protection cap. Click 'OK'. The dark current is measured and automatically subtracted in all following measurements.

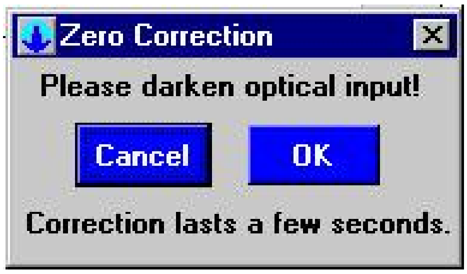

Figure 17 correction for the intrinsic dark current

2.3.8.2 'Calibrate / Circular calibration'

Before activating the item 'Calibrate / Circular Correction' set an almost circular polarization with a polarization controller. It does not matter whether right or left circular polarized.

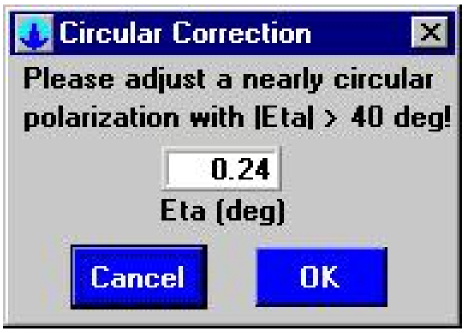

Figure 18 Calibrating at circular polarization

Now click 'OK'. The PAT 9000B measures and corrects an internal angle offset in the optical head.

2.3.8.3 'Calibrate / Wave plate calibration'

Now, the retardation angle of the rotating λ/4-waveplate is calibrated, measured and stored with the help of the degree of polarization (DOP) of the used light source.
Select the degree of polarization to be displayed in the menu 'Set-up / Parameter Selection'.
Use the polarization controller to set an almost vertical polarization and read the measured degree of polarization. With a DFB laser a DOP ≈ 99.0 % is typical.
Now adjust for a horizontal polarization and compare the two DOP values. In case of different DOPs for horizontal and vertical polarizations select the menu 'Calibrate / Wave plate calibration', hit 'YES' and enter the DOP value obtained with vertical polarization.

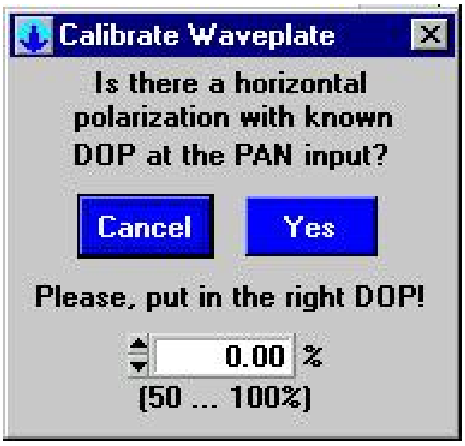

Figure 19 Calibrating the retardation of the wave plate with DOP

2.3.8.4 'Calibrate / Power calibration'

In the factory the polarimeter is calibrated for the correct optical power measurement with a calibrated external power meter. Additional calibration may be required if e.g. the input coupling at the optical head has changed or if you use the optional attenuators..
Measure the optical power of your light source with an external calibrated power meter. Then couple the total power into the polarimeter and activate the menu item 'Calibrate / Power Calibration'. Replace the displayed power by the externally measured one.

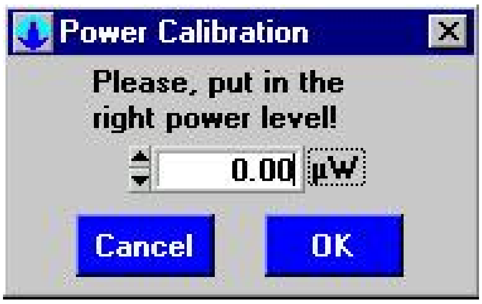

Figure 20 Calibrating the polarized optical power

NOTE

The power detected by the optical head is the polarized part of the total power. Therefore a light source with DOP > 99.9% must be used. If you use the optional optical attenuators, please keep in mind that they are wavelength dependent. Calibrate the power at your desired operation wavelength.

2.3.8.5 'Setup / Offset Azimuth'

In the menu 'Set-up / Offset Azimuth' you can rotate the 0° reference plane of the optical head to fit it best to your measurement set-up.

Figure 21 Setting the Offset Azimuth

The default offset angle is set for a horizontal linear polarization pointing parallel to the bottom of the optical head to yield an elevation angle readout of θ =0.0°.

2.3.8.6 'Calibrate / Load User Calibration'

In this menu user specific calibration data can be loaded and activated from user specific data files with extension ".SET".

2.3.8.7 'Calibrate / Save User Calibration'

User specific calibrations only remain valid for the actual program session. Switching off your PAT 9000B means loss of these data! Therefore you can store the changed calibration data to disk in the menu 'Calibrate / Save User Calibration'. The calibration data are stored in a file *.SET (default name is PAN.SET). Select a name (e.g. CAL_1310.SET).

NOTE

When the program is restarted the default calibration data of the optical head are loaded first. To use your own calibration data, use 'Load User Calibration'.

2.3.9 Defining the low power threshold

If you want that the PAT 9000B detects measurements (polarization, PDL, PMD) with too low optical power levels, select menu 'Set-up / Power Low Level'. Enter the minimum acceptable power level in dBm (Figure 22).

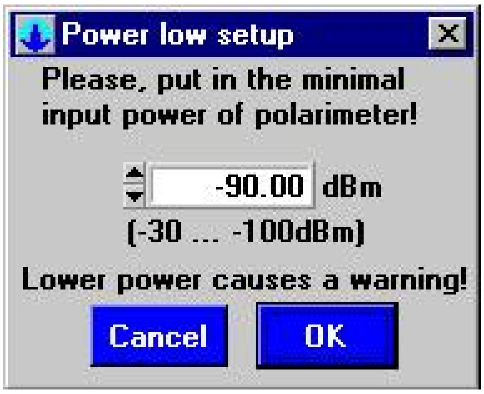

Figure 22 Setting the detection threshold for low power condition

If the polarized optical power falls below this threshold the measurement is stopped and a warning occurs. Eliminate the reason for the low power level and restart your measurement. All values measured up to then are still available and can e.g. be stored.

If you don't want to use a power threshold or don't want the low power warnings, set a power limit of -100 dBm (which will never be reached) or click on "Ignore further warnings".

Figure 23 Options for handling the low power warning

2.4 The polarizer module POL 9320

2.4.1 Selecting the polarizer modules

If several POL 9320 modules are installed in the PAT 9000B, the module with the lowest slot number becomes the active module by the initialization during the boot of PAT.EXE.

This default setting can be changed :

Select menu ‘ Set-up / Select POL Module’. The following screen appears:

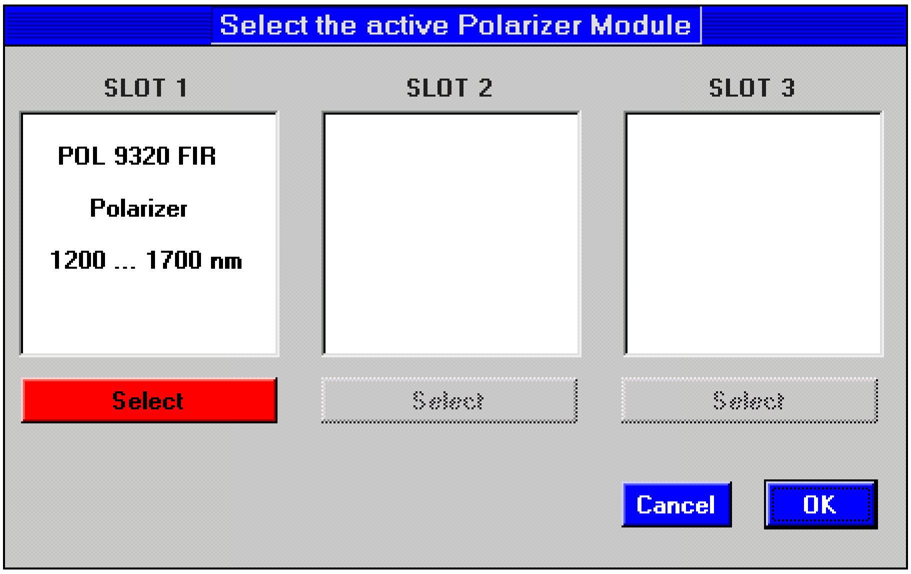

Figure 24 Screen to select the active polarizer module

Activate the corresponding module by clicking ‘Select ‘. ‘OK’ makes the setting valid and exits the screen.

All following inputs and measurements refer to the now activated polarizer module.

2.4.2 Set-up of the POL 9320 module

Incoming light is collimated and launched through a high quality and high extinction ratio linear polarizer. The polarizer has an extinction ratio of better than 50 dB in the wavelength range 1200 to 1700 nm (POL 9320 FIR) or 960 to 1160 nm (POL 9320 NIR).
The polarizer can be rotated stepwise from 0.00 to 179.82°. The minimum stepsize is 0.18°.
The polarizer module POL 9320 is always required for Jones-Matrix-, PDL-, or Jones-Matrix-PMD measurements. In these cases the polarizer module is automatically controlled by the PAT 9000B.
For special purposes it is also possible to control the polarizer POL 9320 by keyboard and mouse. E.g. it is possible to generate highly linear polarization states at the polarizer position as reference location for customized measurement applications. Of course the polarizer can be operated via GPIB commands for remote control.

2.4.3 Controlling the POL module

'Set-up / Show POL Panel' will display a window for manual control of the polarizer module (Figure 25). If several POL modules are installed in the PAT 9000B you should activate the desired module in advance with 'Set-up / Select POL Module'
➔ (refer to Figure 24).

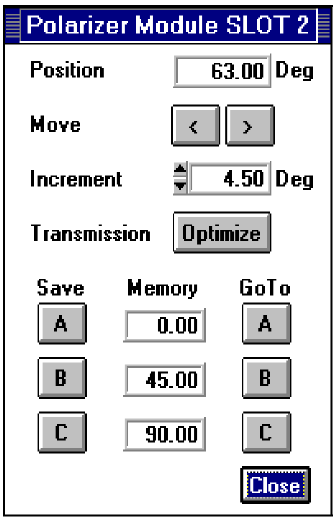

Figure 25 Window for manual control of the polarizer module

The dialog box ‘**Position**’ shows the current angle of the polarizer. The angle corresponds to the azimuth angle of the linear polarization state You can access a new position by entering a numerical value. Values outside the valid range are replaced by the lowest/highest possible values. Values not matching to the 0.18° grid of the stepper motor are replaced by the next possible one.
You can step up/down with the keys ‘**<**‘ and ‘**>**‘.The dialog box ‘**Increment**’ sets the step size in degrees.

By clicking ‘**Optimize**’ the polarizer position with the lowest attenuation through the polarizer and the connected DUTs is searched and accessed. Therefore a light source must be connected to the input of the POL 9320 and the active polarimeter module PAN 9300 must be connected. This is helpful for optimal power launch through a DUT. The reason for non-optimal launch conditions are the polarization rotations which occur in the patchcord connecting the laser with the POL 9320 card and the polarimetric behavior of the DUT.

The keys ‘**Save A,B,C**’ store the present position in A, B or C memory variables.

With ‘**Memory**’ you can read back these positions or/and set them directly.

‘**GoTo A,B,C**’ jumps to the stored setting.
While working in the POL window the main screen remains active so that you can observe direct impacts on the polarization and power parameters simultaneously.

‘**Close**’ exits the window for the polarizer module.

2.5 External tunable laser sources

For high quality PMD measurements laser sources with a wide tuning range are mandatory. Especially for the determination of low PMD/DGD values or the examination of short fiber sections large wavelength steps are necessary. To meet these requirements the PAT 9000B can control via the IEEE 488 interface tunable laser sources (semiconductor lasers with external cavity) which are commercially offered from different manufacturers.

The PAT software can interface to the external cavity lasers HP8167A®, HP8168A®, HP81640A, HP81642A and HP81680A ... HP81689A from Hewlett Packard/Agilent, the NetTest/Photonetics PR and BT models, the New Focus laser series 6200, the ANRITSU lasers MG 9637 A, MG 9638 A and MG 9541A, the ANDO lasers AQ 4320 A, AQ 4321A, AQ 4320D and AQ 4321D.

The corresponding drivers must be ordered individually.

➔ Please have a look at our homepage for new laser drivers added to this list.

For technical data and operation advices refer to the corresponding manuals of the laser sources.

The PAT 9000B offers various SW programs to measure e.g. PDL(λ), PMD and DGD(λ) as a function of wavelength. These programs control the tunable laser sources automatically. You can set a **Laser wait time** from the main menu to allow the laser or your optical set-up to stabilize after a wavelength change command has been sent to the tunable laser. The PAT 9000B will delay the execution of the following commands by the specified amount of time .

This '**Laser wait time**' is entered in the 'Setup' menu.

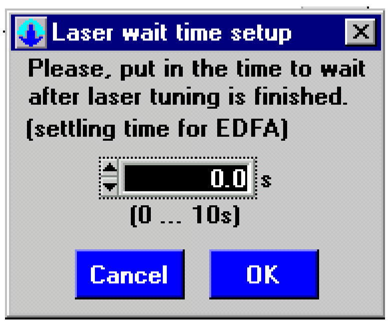

Figure 26 Setting a laser wait time

Every laser sources can be controlled manually as well. This is described in the next sections for each tunable laser source. The control features differ slightly for the different models.

2.5.1 Controlling the HP8167/8 ® external cavity laser

Select 'Set-up / Show HP8167/8 Panel'. The following window appears:

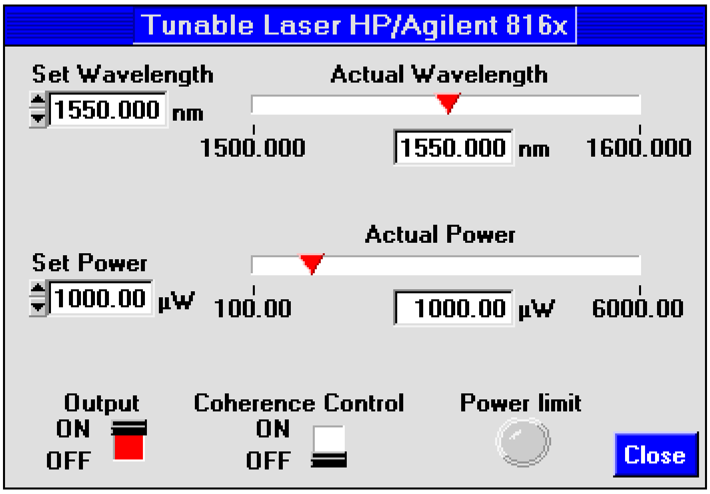

Figure 27 Control window for external Hewlett Packard lasers

You can adjust laser wavelength and laser power.
Enter the desired power in the field '**Set Power**'. The allowed setting range depends on the model. You also can adjust the power with the small arrows in the field 'Set Power' in 100 µW steps. Values outside the limits are replaced by the allowed minimum or maximum values.

The '**Coherence Control**'-button allows the spreading of the laser linewidth by more than a factor of 100. Check the manual of the tunable laser for the linewidth specification with Coherence Control on and off. In optical set-ups containing several reflection planes (e.g. glass-air-transitions) a larger linewidth may be suitable since then interference effects are avoided and more precise measurements will result.

'**Output**' activates the laser.

'**Actual Power**' displays the present power.

You can enter the laser wavelength directly in the field ‘**Set Wavelength**’ or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.

The present wavelength of the laser is shown in the field ‘**Actual Wavelength**’. It also shows the range limits for the wavelength.

Pressing ‘**Close**’ exits this window.

If the desired power exceeds the maximum achievable power at some wavelength the LED ‘**Power limit**’ will light up.

2.5.2 Controlling the NetTest Tunics external cavity laser

Select 'Set-up / Show TUNICS Panel'. The following window appears:

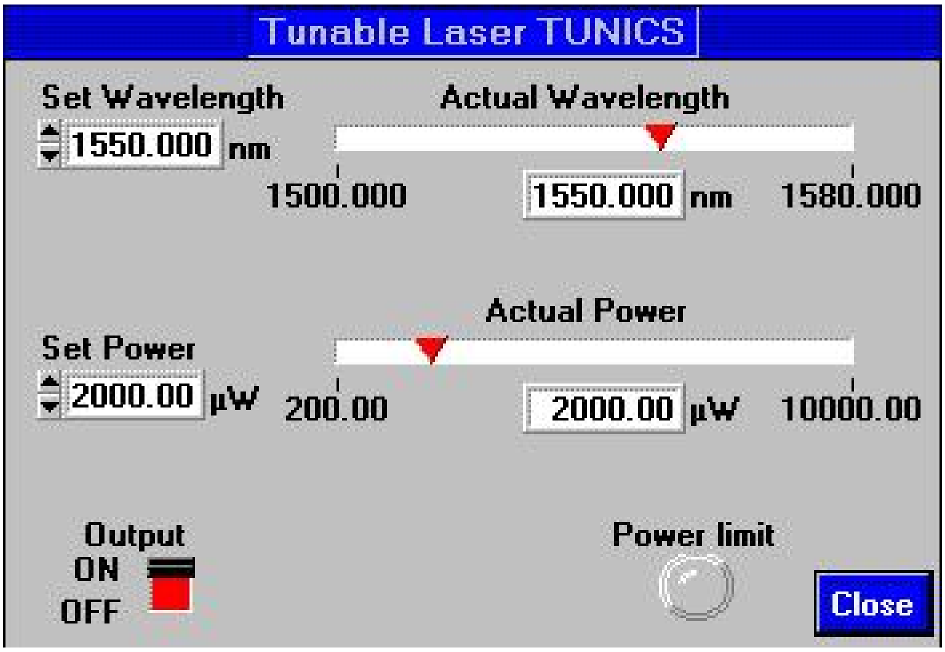

Figure 28 Control window for an external NetTest TUNICS laser

You can adjust laser wavelength and laser power.
Enter the desired power in the field '**Set Power**'. The allowed setting range depends on the model. You also can adjust the power with the small arrows in the field 'Set Power' in 100 µW steps. Values outside the limits are replaced by the allowed minimum or maximum values.

'**Output**' activates the laser. '**Actual Power**' displays the present power.
You can enter the laser wavelength directly in the field '**Set Wavelength**' or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.

The present wavelength of the laser is shown in the field '**Actual Wavelength**'. It also shows the setting range limits for the wavelength.

Pressing '**Close**' exits this window.

If the desired power exceeds the maximum achievable power at some wavelengths the LED '**Power limit**' will light up.

2.5.3 Controlling the New Focus external cavity laser

Select 'Set-up / Show NEW FOCUS Panel'. The following window appears:

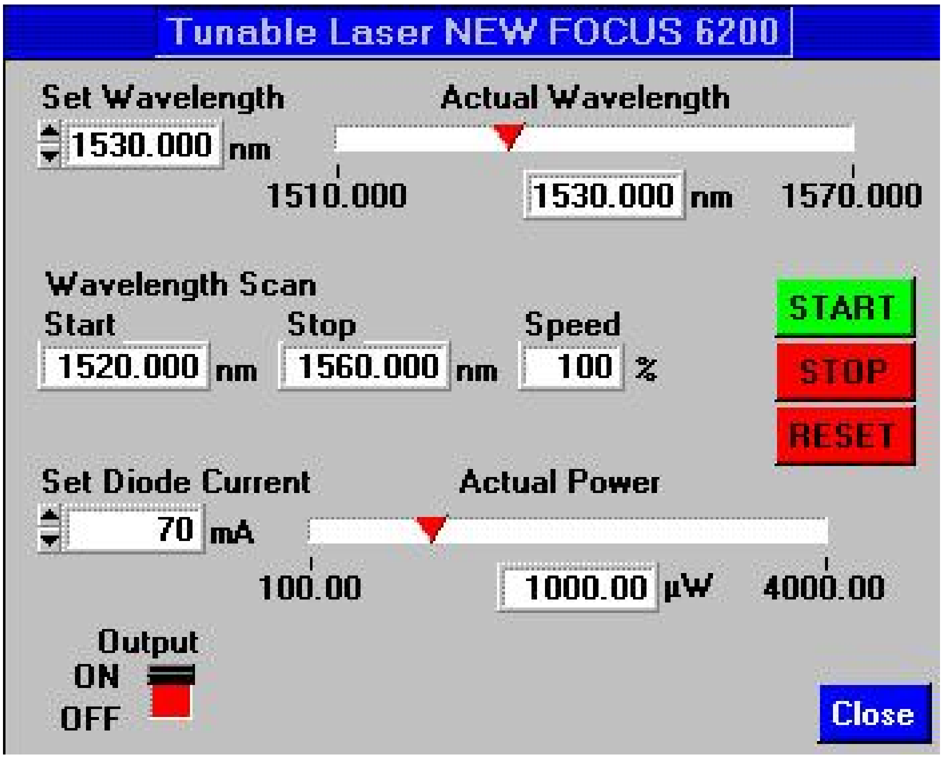

Figure 29 Control window for an external NEW FOCUS laser

You can adjust the laser wavelength and the laser current, but not directly the laser power.
Enter the desired laser current in the field '**Set Diode Current**'. The allowed setting range depends on the model. You also can adjust the current with the small arrows in the field 'Set Diode Current' in 5mA steps. The resulting output power is displayed as '**Actual Power**'.
'**Output**' activates the laser.
You can enter the laser wavelength directly in the field '**Set Wavelength**' or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.
The present wavelength of the laser is shown in the field '**Actual Wavelength**'. It also shows the setting range limits for the wavelength.
You can perform a wavelength sweep by setting the values for start and stop wavelengths and the desired tuning speed in percent of the maximum speed. '**Start**' activates the tuning until '**Stop**' is pressed or the stop wavelength is reached. '**Reset**' takes the wavelength back to the start wavelength.
Pressing '**Close**' exits this window.

2.5.4 Controlling the Anritsu MG9637/8A® external cavity laser

Select ‘Set-up / Show ANRITSU Panel’. The following window appears:

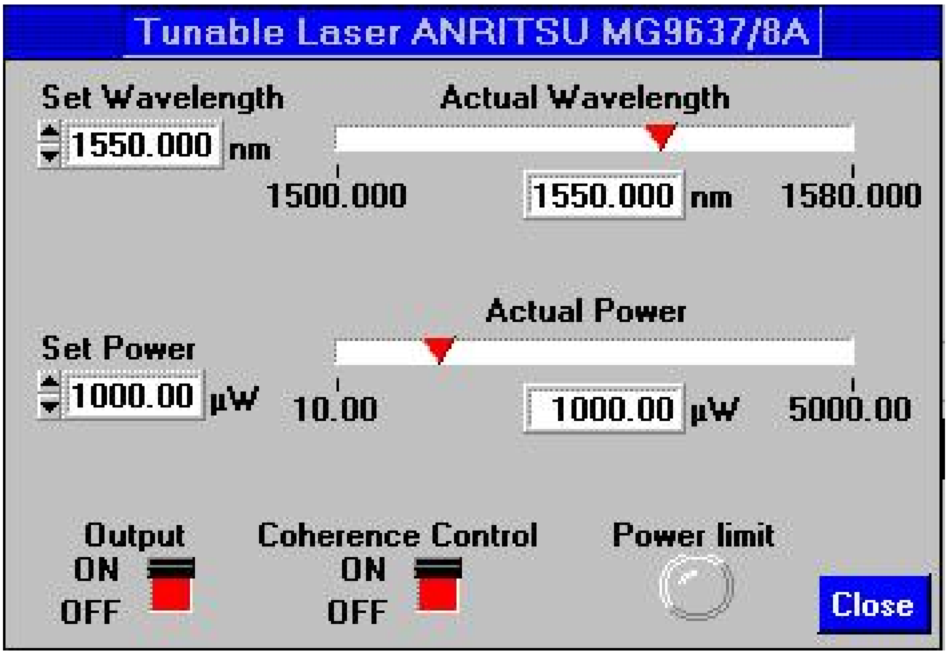

Figure 30 Control window for external lasers Anritsu MG9637/8A

You can adjust laser wavelength and laser power.

Enter the desired power in the field ‘**Set Power**’. The allowed setting range depends on the model. You also can adjust the power with the small arrows in the field ‘Set Power’ in 100 µW steps. Values outside the limits are replaced by the allowed minimum or maximum values.

The ‘**Coherence Control**’-button allows the spreading of the laser linewidth by more than a factor of 100. Check the manual of the tunable laser for the linewidth specification with Coherence Control on and off. In optical set-ups containing several reflection planes (e.g. glass-air-transitions) a larger linewidth may be advisable since then interference effects are avoided and more precise measurements will result.

‘**Output**’ activates the laser. ‘**Actual Power**’ displays the present power.

You can enter the laser wavelength directly in the field ‘**Set Wavelength**’ or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.

The present wavelength of the laser is shown in the field ‘**Actual Wavelength**’. It also shows the setting range limits for wavelength.

Pressing ‘**Close**’ exits this window.

If the desired power exceeds the maximum achievable power at some wavelengths the LED ‘**Power limit**’ will light up.

2.5.5 Controlling the Anritsu MG9541A® external cavity laser

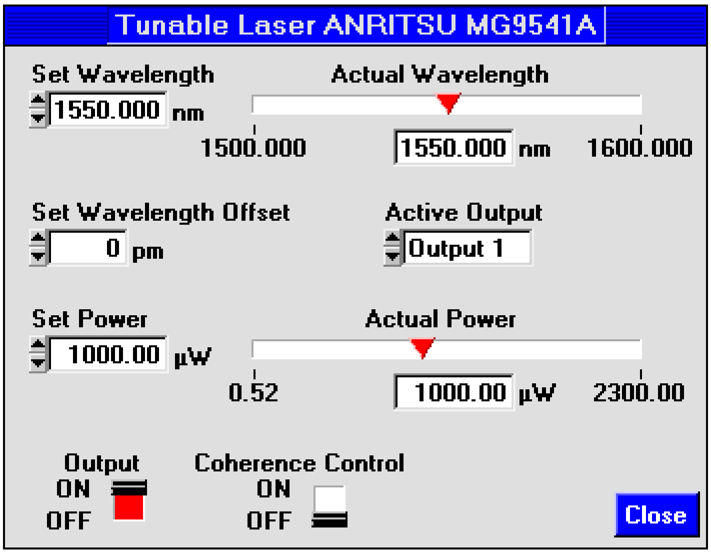

Figure 31 Control window for external lasers Anritsu MG9541A

You can adjust laser wavelength, laser power, a wavelength offset and select one of the possible 3 outputs.

Enter the desired power in the field ‘**Set Power**’. You also can adjust the power with the small arrows in the field ‘Set Power’ in 100 µW steps. Values outside the limits are replaced by the allowed minimum or maximum values.

The ‘**Coherence Control**’-button allows the spreading of the laser linewidth by more than a factor of 100. Check the manual of the tunable laser for the linewidth specification with Coherence Control on and off. In optical set-ups containing several reflection planes (e.g. glass-air-transitions) a larger linewidth may be advisable since then interference effects are avoided and more precise measurements will result.

‘**Output**’ activates the laser.

‘**Actual Power**’ displays the present power.

You can enter the laser wavelength directly in the field ‘**Set Wavelength**’ or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.

The present wavelength of the laser is shown in the field '**Actual Wavelength**'. It also shows the setting range limits for wavelength.

'**Wavelength Offset'** allows to input a laser internal wavelength offset (± 0.4 nm) to adjust the system for highest wavelength precision.

Pressing '**Close**' exits this window.

If the desired power exceeds the maximum achievable power at some wavelengths the LED '**Power limit**' will light up.

'Active Output' allows to select one of the three possible laser outputs.

2.5.5.1 Selecting one of multiple Anritsu outputs as default

If you want the PAT 9000B to use a specific laser output of the MG 9541A as default, you must give this information by editing the 'ANRITSU9541A.INI' file.

Start the supplied editor program "NOTEPAD.EXE" in the "Programs / accessories" folder (or double-click on the file "C:\PAT\ANRITSU9541A.INI" in the windows explorer)

Now you can enter the output number of the laser which shall be used by the PAT.

e.g.:

```
[OUTPUT NUMBER]
OUTPUT_NUMBER = 1
```

Save the file and restart your PAT.EXE.

2.5.6 Controlling the ANDO AQ4320A/B/D® and AQ4321A/D® laser

Select 'Set-up / Show ANDO Panel'. The following window appears:

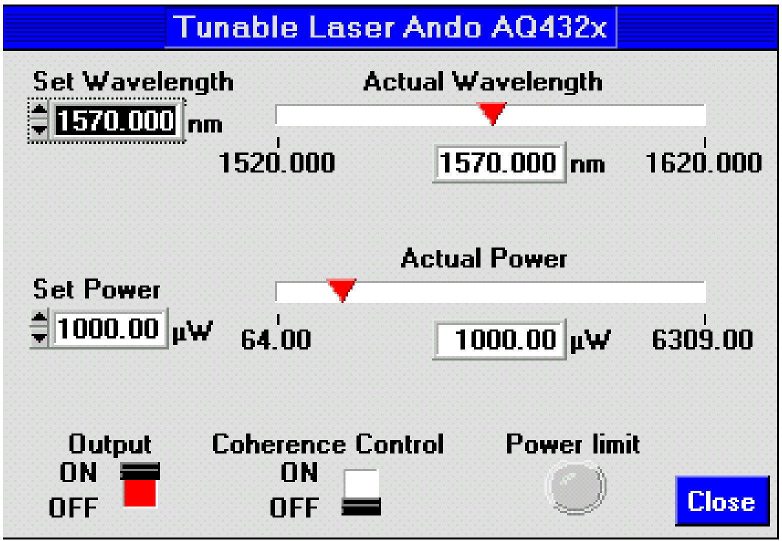

Figure 32 Control panel of the Ando AQ4321A/D® external cavity laser

You can adjust laser wavelength and laser power.
Enter the desired power in the field '**Set Power**'. The allowed setting range depends on the model. You also can adjust the power with the small arrows in the field 'Set Power' in 100 µW steps. Values outside the limits are replaced by the allowed minimum or maximum values.
The '**Coherence Control**'-button allows the spreading of the laser linewidth by more than a factor of 100. Check the manual of the tunable laser for the linewidth specification with Coherence Control on and off. In optical set-ups containing several reflection planes (e.g. glass-air-transitions) a larger linewidth may be advisable since then interference effects are avoided and more precise measurements will result.
'**Output**' activates the laser. '**Actual Power**' displays the present power.
You can enter the laser wavelength directly in the field '**Set Wavelength**' or change it with the arrow keys in 1 nm steps. Values outside the limits will be replaced by the allowed minimum or maximum values.
The present wavelength of the laser is shown in the field '**Actual Wavelength**'. It also shows the setting range limits for wavelength.
Pressing '**Close**' exits this window.
If the desired power exceeds the maximum achievable power at some wavelengths the LED '**Power limit**' will light up.

Selecting the tunable laser for PMD/PDL measurements

The software of the PAT 9000B is able to control a variety of tunable lasers for PMD or wavelength dependent PDL measurements. These sources are external lasers controlled via IEEE 488 interface.

Prior to starting one of the different PMD measurements you must select one of the different PMD laser sources.

The appropriate screen is automatically displayed when you select a menu point which needs a tunable laser.

The menu point 'Set-up / Select PMD Laser' offers the same option. The following screen appears:

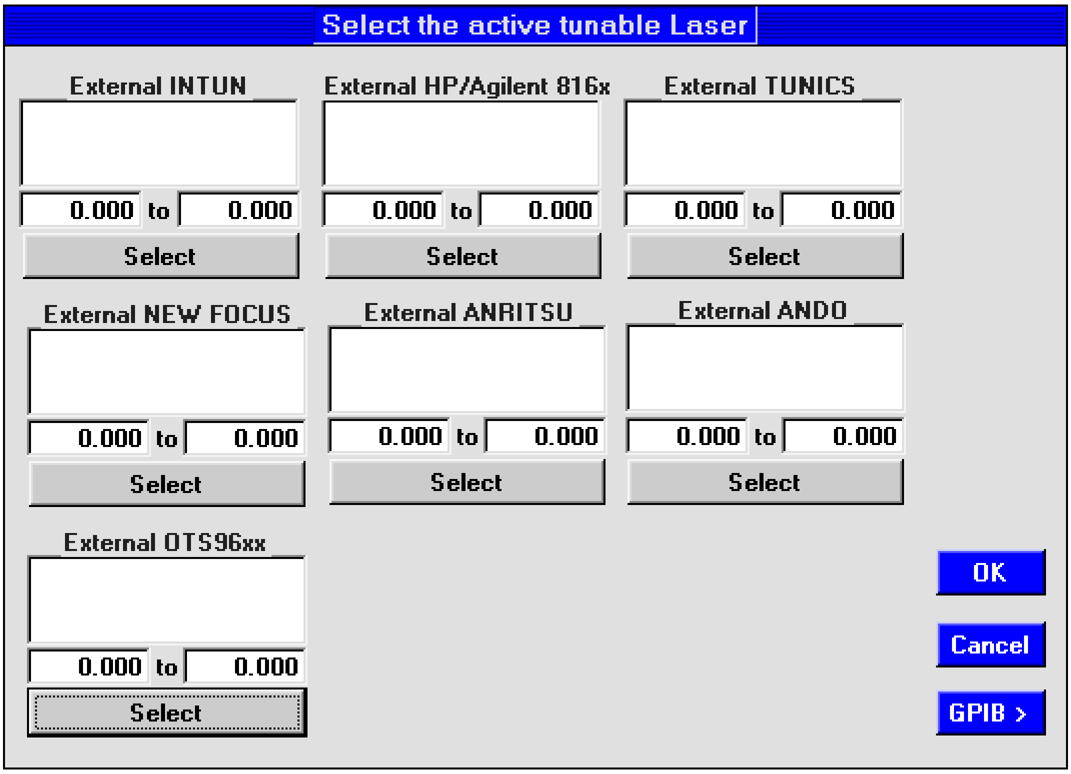

Figure 33 Selection window for the active laser source

Pressing one of the '**Select**' buttons activates the corresponding externally connected tunable laser by the IEEE 488 bus.

Confirm the setting with '**OK'** and close the screen. '**Cancel'** will exit the window with the previous setting unchanged.

'**GPIB**>' takes you to the GPIB configuration panel. This allows you to change the GPIB address and other settings.

➔ (refer to section 3.2.1)

All subsequent measurements (PMD or the wavelength dependency of the PDL) are done with the now activated Laser.
For PMD measurements the external lasers are set to a power of 1 mW. If you want to do PMD measurements with different power levels, open the corresponding laser window e.g. with 'Set-up / Show INTUN Panel' and enter a new power level.

2.6 Extinction Ratio measurement on PM fibers

2.6.1 Definition of terms

The term extinction ratio (ER) can have two slightly different meanings depending on the context: polarization ellipse and/or combination with PM fiber

The extinction ratio of a polarization state expresses the ratio of the length of the minor axis to the length of the major axis of the current polarization ellipse in dB. Sometimes the reverse ratio is taken also.

At the exit of a PM fibers the size of polarization ellipse depends on the phase difference between the x and y component and this results from the length of the PM fiber. The form of the ellipse will of course change when the measurement plane is shifted back or forth. Of interest is however only the specific polarization state where the ellipse is maximally elliptic (maximally expanded in the direction of the minor axis). The then calculated ratio (of the length of the axes) is referred to as the Extinction ratio (ER) for PM-fibers

$$ER = 10\log\frac{P_{MainAxis1}}{P_{MainAxis2}} = 20\log\frac{L\arg eEllipse - halfaxis}{SmallEllipse - halfaxis} = 20\log\frac{1}{\tan|\eta|}_{\max}$$

NOTE

ER is also used to characterize the modulation depth of lasers.
There is no relation to the ER in PM fibers.

The ER expresses the ability of a PM fiber to maintain the launched linear polarization state when optimally aligned with one of the PM axes without cross coupling to the other orthogonal PM axis. It is a crosstalk specification. If the ER is poor then either the PM fiber has a poor polarization preserving capability (or enhanced mode coupling) or the alignment into the PM fiber is non-optimal.

A PM fiber preserves the linear polarization state of the input only if the launched polarization state at the input is linearly polarized and perfectly aligned with one of the principal PM axes (polarization eigenstates). If both principal axes are excited with some light they propagate independently through the fiber, each keeping it's linear polarization state when measured individually and always staying orthogonal to each other. However, due to the birefringence of the PM fiber the phase shift between the two axes continuously changes. This phase shift will yield different polarization ellipses at each measurement location along the fiber. The accumulated phase shift at the fiber exit obviously depends on the wavelength of the light source and the length of the PM fiber and the fiber birefringence. By changing either one the polarization ellipse will be changed. This is the basis for the optimal alignment of a PM fiber to a laser chip or to second PM fiber.

Measuring method

For ER measurement the fiber must be "stressed" during data acquisition by

- either mechanically "pulling" the fiber
- or heating the fiber
- or changing the wavelength.

During the stress application the polarization at the exit of the fiber is recorded with the polarimeter PAN 9300. If there is a non-optimal launch condition (misalignment) or a poor fiber the polarization will trace a circle on the Poincaré sphere due to the stress. The diameter of the circle is obviously a measure for the extinction ratio. The smaller the circle the higher is the ER.

An intermediate non polarization maintaining optical element like a patchcord will normally map the expected linear output polarization state to an elliptical polarization state off the equatorial plane in the Poincaré sphere. However this is not an obstacle for the measurement since the circle is only repositioned bur not resized.

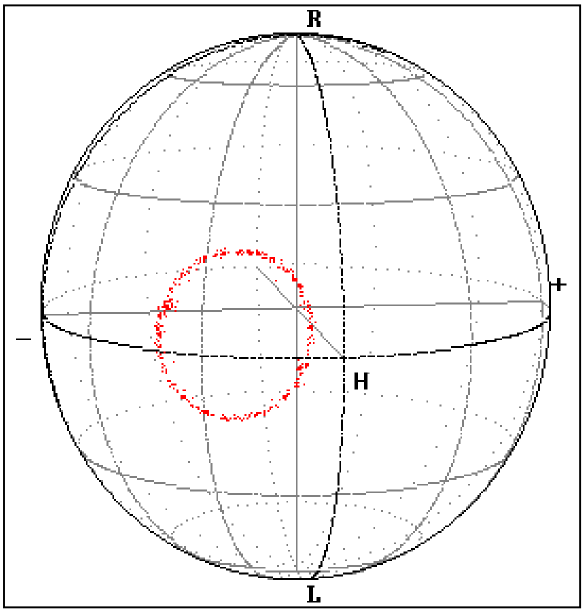

Figure 34 Polarization's at the end of the stressed PM fiber

The smaller the circle the better the polarization preserving capability of the fiber.

Possible error sources

If linear polarized light is fed in the PM fiber not coinciding with a main axis or slightly elliptical light, the polarization at the output will be elliptical even in case of an ideal

fiber. The diameter of the circle measured while stressing the fiber will then be too large - the fiber is rated worse than it is.
If the launched light does not have a high degree of polarization then always both principal axes are excited and there is a limit to the ER which is due to the degree of polarization. Improve your set in this case by inserting a high quality linear polarizer (like the POL 9320) into the set-up.

2.6.2 Measurement set-up

The measurement set-up is shown in Figure 35.

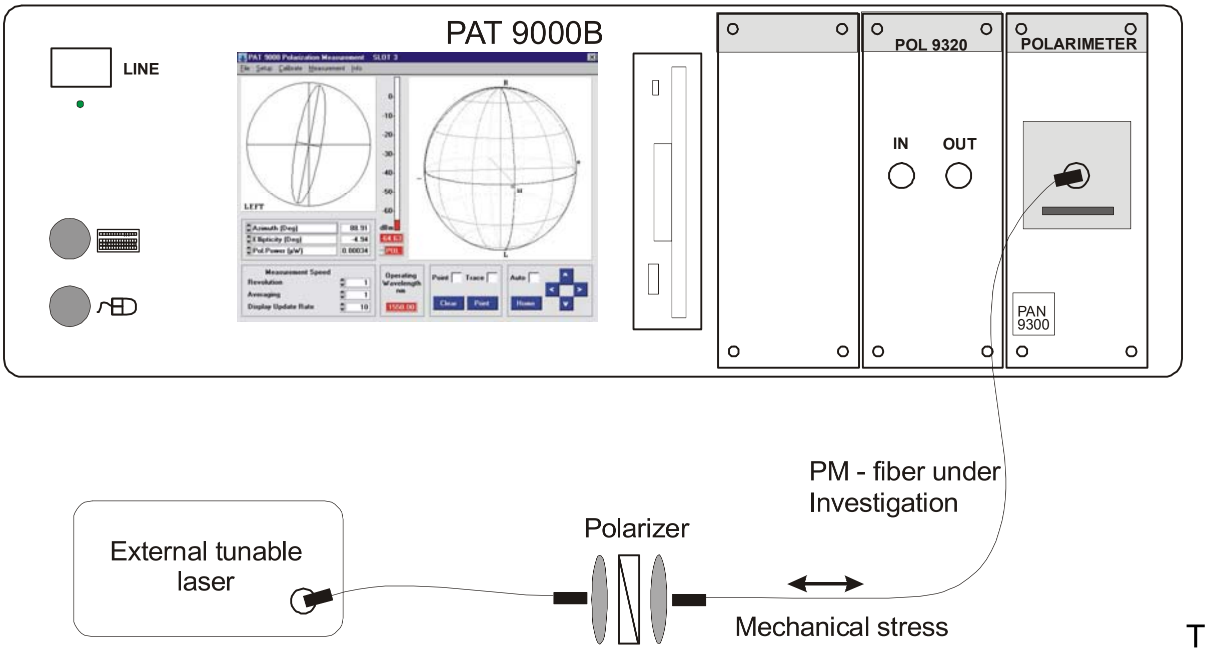

Figure 35 Set-up for extinction ratio measurements

The linear polarized light is fed into the PM fiber in the region marked ‘Polarizer’. This may be (as in the drawing) a feeding optic, the focusing optic of a laser with PM pigtail or a connection between two PM fibers.
The measured parameter ER refers to the PM fiber directly connected to the polarimeter input.
The most simple measurement technique is to find the maximum expansion of the polarization ellipse compared to the ideal linear state. Since this expansion is depending on the fiber stress, a lot of values have to be recorded while the fiber is "stressed" (pulled or a wavelength scan is performed).
This technique requires highest accuracy in the measurement of the ellipticity angle.
With a very high ER (>30 dB corresponding to almost linear states) the setup is prone to measurement inaccuracies.

To mitigate this issue the PAT 9000B uses an optimized algorithm. The recorded values during fiber stressing are used to fit a circle on the Poincaré sphere. The radius of the circle expressed in degrees is representative for the maximum expansion of the polarization ellipse.

Only the relative polarization measurement accuracy determines the ER measurement error since the shift of the circle to any position on the Poincaré sphere is irrelevant as long as the size of the circle remains unchanged. Errors resulting e.g. from poorly or angle polished fibers have no influence. ER measurements of up to more than 70 dB are thus possible.

Only the ER of the stressed fiber segment is measured. Even non PM fibers connected in series, do not influence the result.

As mentioned tuning the wavelength would also lead to a circle on the Poincaré sphere if there is nonideal alignment or a poor PM fiber. However, often a very large tuning range is required to get a full circle.

2.6.3 Measurement procedure

Select the menu item 'Measurement / PM Fiber Extinction Ratio'. The screen shown in Figure 36 opens.

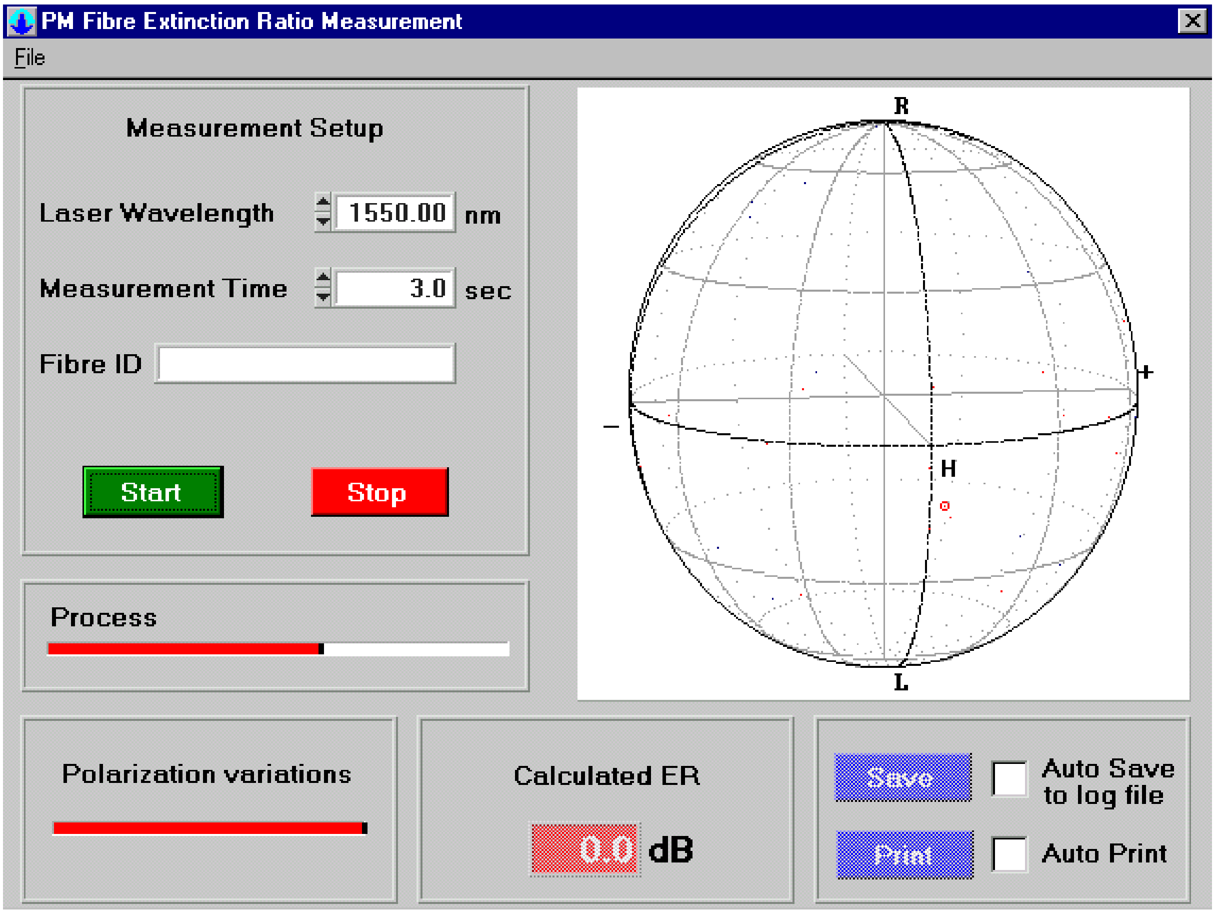

Figure 36 Screen for ER measurements

Laser Wavelength

Enter the wavelength of the laser used in nm.

Measurement Time

Apply a stress for 1-10 s in which the measurement values are recorded from the polarimeter. A short measurement time accelerates the total procedure but decreases measurement accuracy. If the number of registered values is too small or unfavorably distributed, an error message will occur.

The measurement time should be long enough for the fiber to be stressed sufficiently.

Fiber-ID

You can enter a 20 character string for identification of the device under test in protocol files.

Start

Press ‘Start’ and immediately begin to pull and relax the fiber. This should not be done too fast but with continually increasing and decreasing strength (approx. three times to and fro).

The bar graph „Polarization variations“ in the lower left corner shows the distance of two sequential measurements on the Poincaré sphere (20° = full scale). The fiber should not be stressed so fast that the full scale is reached.

A time scale in the middle of the screen indicates the time left (0..100%).

NOTE

If you want to learn more about the effect of the fiber stress go to the main menu with the Poincaré sphere and watch the polarization changes while you stress the fiber. It is helpful if you checkmark the boxes ‘Auto’ and ‘Points’. During the stress period the points should form a circle. The diameter of the circles is a measure for the ER.

After the end of the measurement the PAT software calculates the ER in several steps:

- It calculates the center of the circle from the average of all measured Stokes-parameters with a least square fit.
- It Removes erratic values unsuitable for the circle approximation (measurement errors)
- It re-optimizes iteratively the central point
- It calculates the ER from the mean distance of center point and the valid measurement points.

To ensure error-free measurements, before, during and after the measurement time some checks are carried out from which the following error messages may result:

Message	**Cause**
Optical power exceeds upper limit!	Optical power to high.
Optical power lower limit!	For ER measurements the optical power must be greater than -50 dBm
Wavelength incorrect or recalibration required!	Wavelength is set incorrectly or PAN optical head is incorrectly calibrated

<u>If these errors occur the measurement procedure is stopped immediately.</u>

Insufficient measured points	the number of measured points is too small or the measurement time is too short
Measured points not suitable for ER	no reasonable fit of the measured points to a circle is possible, repeat measurement
Not sufficient fiber stress	It's not a full circle, repeat measurement with more fiber stress

Warning	**Cause**
Measured PM fiber shows not the typical behavior	only poor circle approximation possible
Eigenmodes of measured PM fiber are not strictly linear	Center of circle to far away from the equator, polarization influencing elements in series to PM fiber

Result

Finally displays the calculated Extinction Ratio in dB.

NOTE

No result will be shown if errors have occurred!

Save

Stores the measured results in detail in a file "NAME.ER" with the following structure:

```
PAT9000 PM-Fiber Extinction-Ratio-Measurement   Thorlabs
Date: 11-06-2002    Time: 17:30:21

[SETUP]
WAVELENGTH    [nm]: 1550.00
TIME           [s]:       3

[FIBER]
FIBER_ID          : fiber004

[ER_DATA]
ER_AVG        [dB]:   22.90
```

Print

Prints the measured results in detail on the printer selected under WINDOWS® 98.

Auto Save

With **Auto Save** activated the results are automatically stored in the log-file **ER_MEAS.LOG**. The latest valid result is added in short form.

The format of the File ER_MEAS.LOG:

```
Thorlabs PAT 9000B  09-02-1999  15:19:47  WAVE[nm]=1550.50  TIME[s]= 3  ID=fibre001  ER[dB]= 32.81
Thorlabs PAT 9000B  09-02-1999  15:20:07  WAVE[nm]=1550.50  TIME[s]= 3  ID=fibre002  ER[dB]= 34.02
Thorlabs PAT 9000B  09-02-1999  15:20:11  WAVE[nm]=1550.50  TIME[s]= 3  ID=fibre003  ER[dB]= 31.85
```

Auto Print

Auto Print activated will automatically print the last valid measurement.

2.7 PDL measurement

The mainframe PAT 9000B with the modules PAN 9300 and POL 9320 allows an easy and comfortable measurement of polarization depending losses PDL or gains PDG.
Polarization dependent losses (PDL) of optical components are defined as maximum attenuation differences in the device under test when exposed to all possible polarization states (SOP).
The modules PAN 9300NIR and POL 9320NIR enable measurements in the 960 to 1160 nm wavelength range, the PAN 9300FIR and POL 9320FIR in the range 1200 … 1700 nm.
As light source a tunable semiconductor lasers with external cavity or any other stabilized laser source are suitable.

Measurement principle

The polarization dependent loss or gain is calculated from the Jones matrix of the device under test. The complex 2x2 Jones-Matrix allows a complete description of the polarization behavior of the test object, as long as the involved light beam is completely polarized
The Jones matrix is completely determined by three succeeding polarization measurements in which only linear input polarization states are required. Figure 37 demonstrates the procedure:

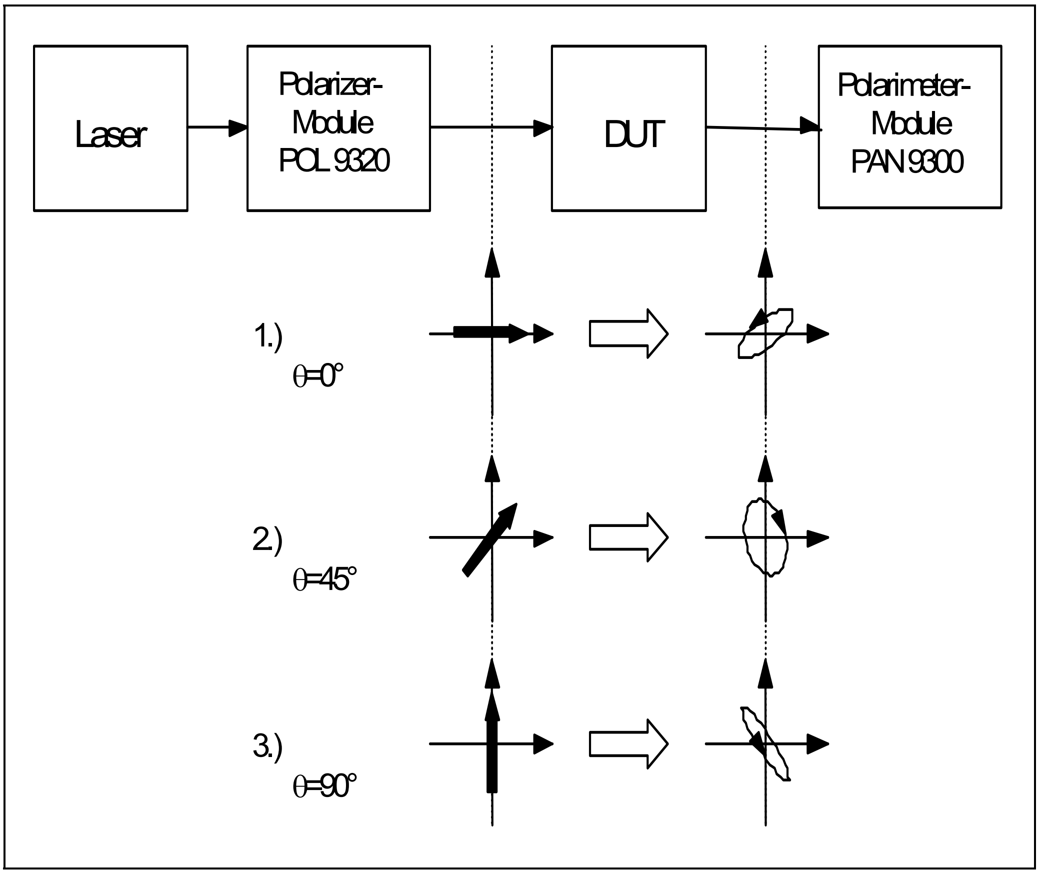

Figure 37 PDL measurements with the Jones matrix determination

The polarizer module generates sequentially three linear states of polarization, in 0°, 45° and 90°. The device under test transforms these input polarizations into three different output polarizations depending on its optical properties. The polarizer module PAN 9300 measures the output polarization states of the light.
The PDL software module calculates the corresponding Jones matrix and its eigenvalues and its eigenstates as well as the so called singular values of the Jones matrix. From the ratio of the singular values of the Jones Matrix the PDL of the device under test can be determined (see application note for more details).

2.7.1 Measurement set-up

Connect the laser source to the input of the polarizer module POL9320 with a single-mode fiber with FC/APC connectors at both ends.

NOTE

To guarantee low back reflections into the laser cavity the optical ports of the polarizer module are equipped with FC/APC connectors .

Connect the optical output of the POL 9320 to the device under test (DUT) and the output of the device under test to the optical input of the polarimeter module PAN 9300.

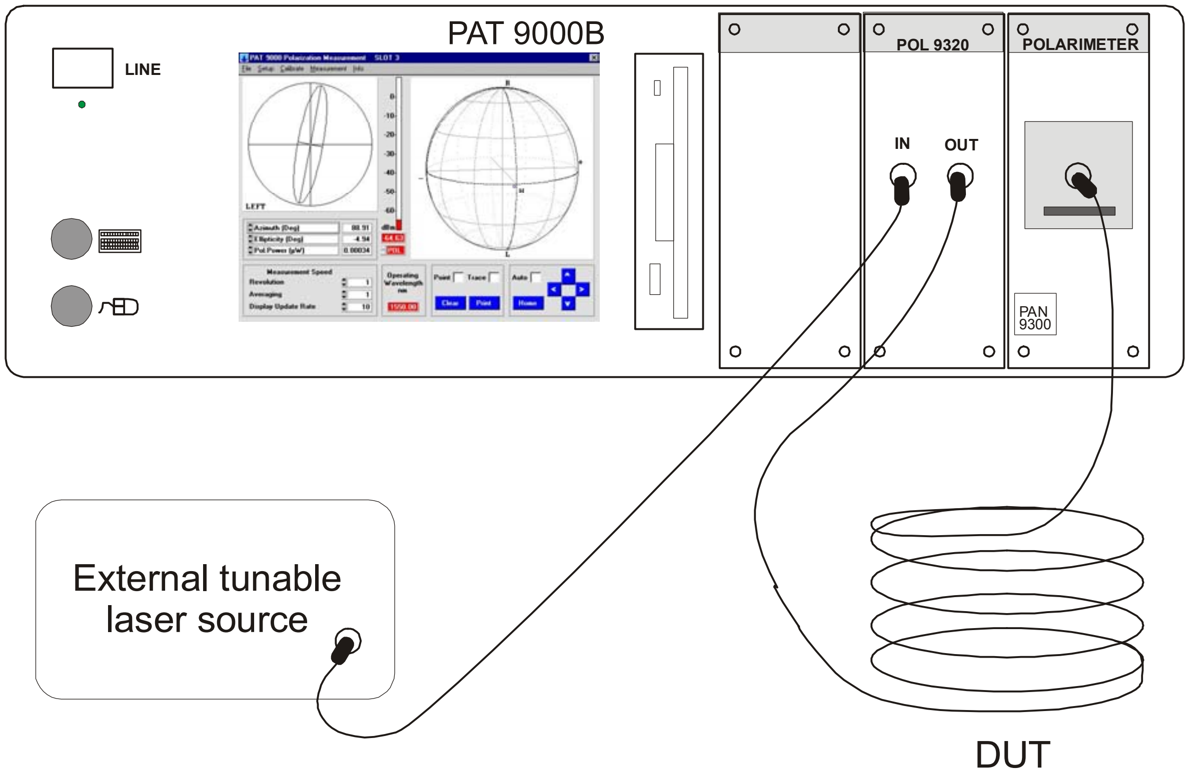

Figure 38 PDL measurement set-up

When making PDL measurements make sure that all fibers are tightly fixed and relaxed. Every movement or vibration will affect the polarization of the light wave and increase the measurement error.
The whole set-up should rest on a stable surface.

2.7.2 Measurement procedure

Establish the measurement set-up as in Figure 38.
To guarantee exact PDL measurements, make sure that the wavelength entered in the menu 'Set-up / Wavelength' corresponds to the wavelength of the used laser source.
➔ (refer to section 2.3.1)

Select the menu 'Measurement / Jones Matrix/PDL '. The following screen appears:

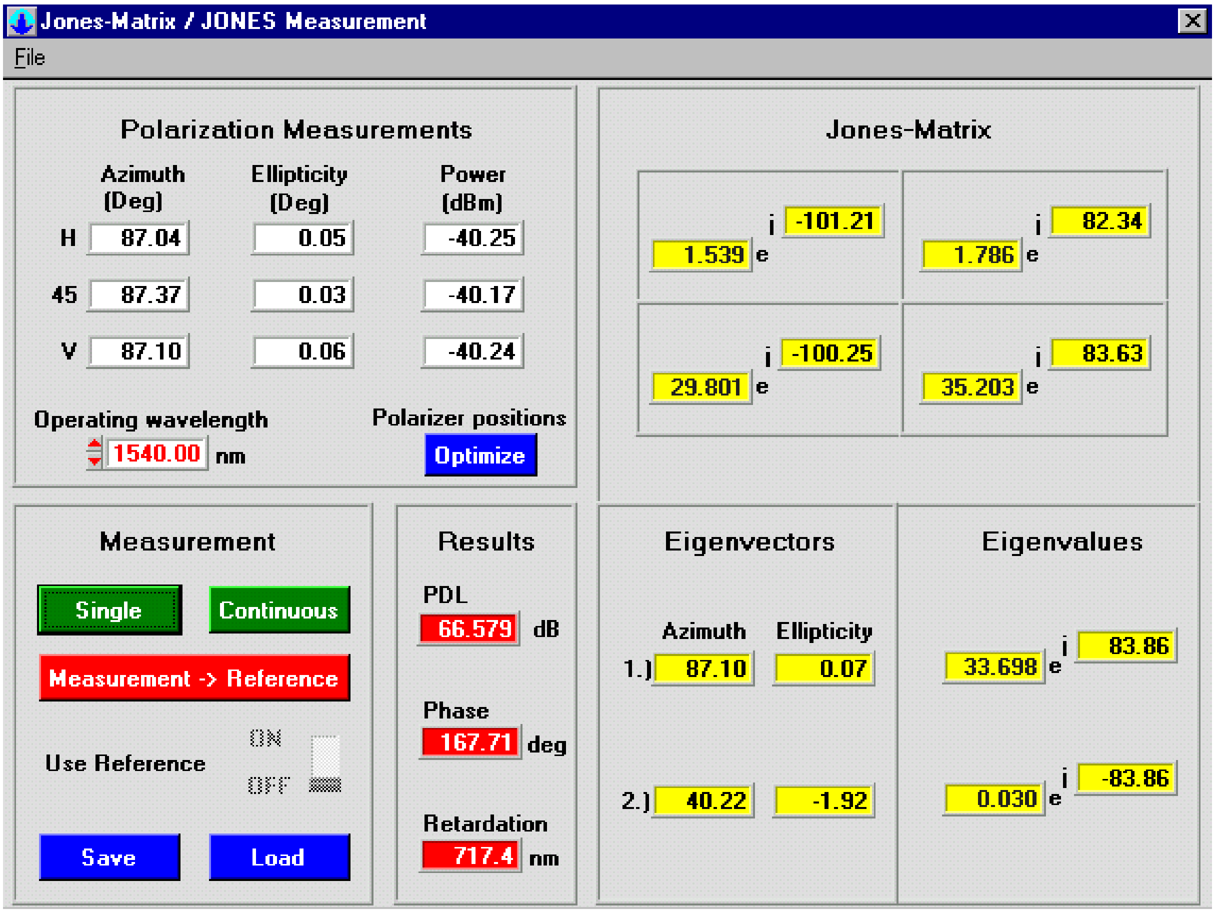

Figure 39 Screen display of PDL measurement

Along with the PDL value the Jones matrix of the device under test, the polarization eigenvectors and the eigenvalues of the Jones matrix are shown.
In the upper left corner the results of the three polarization measurements with the parameters elevation angle θ (azimuth) and ellipticity angle η are displayed.
H, 45 and V stand for the three linear polarization states generated in the polarizer module POL 9320 during the PDL measurement.
Next to these the corresponding measured optical powers are shown. The power values are only used for monitoring purposes, not for further calculations. However, they indicate whether one of the polarimeter positions unfavorably blocks the input light and would possibly lead to increased errors.
For sensitive measurements these power values should differ only slightly (< 3 dB). Automatic optimization for highest average power on all 3 settings can be activated by clicking the field 'Optimize'.
From the measured three polarization states the 2x2 Jones matrix is determined. Its four complex components are displayed in the form $|\text{modulus}| * e^{j * \text{phase angle in degrees}}$.
The matrix is normalized such that its determinant equals '1'.

The word 'phase' (in degrees) gives the phase difference between the two eigenpolarizations in the range from -180° ... +180°. The phase is multi-valued, i.e. the actual phase difference can differ by a multiple of ± 360°.
The polarization dependent loss (PDL) of an optical component is defined as the maximum loss difference of a device under test when tested with any possible state of polarization. The maximum or minimum loss at specific polarization states called PDL axis and its orthogonal state. The PDL axis is also determined by the singular value decomposition of the Jones matrix.

NOTE

The eigenvalues of the Jones matrix are different from the singular values of the Jones matrix and they do not lead to the PDL value. The eigenstates determine those polarization states which remain unchanged by the DUT. However, the eigenstates are in general not identical to those polarization states that give the maximal and minimal attenuation. These polarization states which determine the PDL are called the PDL axis and its orthogonal state. They must be calculated from the singular value decomposition of Jones matrix. Refer to the application note for details.

The singular value decomposition SVD is a very powerful mathematical algorithm from matrix algebra to determine maximum and minimum bounds for matrices.
The section 'Results' displays the polarization dependent loss (= PDL) in dB resulting from the ratio of the singular values of the Jones Matrix.
The eigenvectors of the Jones matrix are shown as elevation angle θ (Azimuth) and ellipticity angle η. The eigenvectors identify the eigenpolarizations of the device under test, i.e. those states of polarization that are passing without any changes. For optical systems which show only birefringence but no PDL, both polarization's are orthogonal to each other and the Jones Matrix is unitary (the complex-conjugate, transpose of the Jones matrix is identical to the inverse of the Jones matrix).

2.7.3 Reference measurement

Each optical component between the polarizer in the POL 9320 module and the optical input of the polarimeter module must be considered as a part of the "device under test". This includes the optical elements in the polarizer module itself, the patchcords as well as the FC/APC connector on the output port of the POL 9320. The small increase of the PDL due to the patchcords can be eliminated by a reference measurement.

Use the measurement set-up shown in Figure 38.

The essential step is to bridge the DUT for a reference set-up. Either a reference DUT with no PDL can be included for the DUT in the set-up or the output port of the polarizer POL 9320 card can be connected directly to the input of the polarimeter module.

Click '**Optimize**'. The loss caused by the polarizer is automatically minimized and an even distribution of transmitted power for the two polarization states 0° and 90° is achieved.

The measured PDL should ideally read now '0.00 dB'. In practice, differences of some '0.01 dB' may occur.

Activate the field **'Measurement->Reference**'. The Jones matrix of the reference set-up (without DUT) is now measured, automatically inverted and stored as reference.

With every following measurement the inverted reference matrix is multiplied with the current determined Jones matrix. For a test repeat the measurement for the reference set-up. With no changes made in the set-up, the result of this multiplication is the unity matrix with the two eigenvalues = '1' and the indicated PDL should read '0.00 dB'. Should the PDL value be unstable make sure that all fibers are in tranquil position or use a more stable laser source.

Insert the device under test between the output of the POL 9320 and the input of the polarimeter module, for instance by splicing. The PDL value now measured takes into account the PDL by the reference set-up. It characterizes the polarization dependency of the device under test alone. The polarization dependent loss of the environment is eliminated using the reference measurement.

Obviously if the reference set-up is changed even slightly while the DUT is inserted into the set-up then the reference Jones matrix will change and the stored reference Jones matrix no longer correctly describes the polarization transformation of the changed reference set-up. Even a minor change in the positions of the patchcord will yield a different reference set-up. Moreover, it is almost impossible to judge how much the reference Jones matrix has changed. Therefore it is really hard to completely eliminate any environmental impact on the PDL of a DUT.

Setting the switch “Use Reference" to 'OFF' deactivates the reference matrix, if desired.

By pressing ‘**Save**’ all measured data including the reference Jones matrix are stored to disk and can be reloaded with ‘**Load**’.

The File has the format:

```
PAT9000 Jones-Matrix/PDL Measurement   Thorlabs
Date: 06-10-2002    Time: 13:40:08
[SETTINGS]
REFERENCE_JM      :         1
[REFERENCE_JONES_MATRIX]
R11_AMOUNT        :     0.911
R11_ANGLE         :   -40.746
R12_AMOUNT        :     0.414
R12_ANGLE         :    20.136
R21_AMOUNT        :     0.394
R21_ANGLE         :   159.685
R22_AMOUNT        :     0.918
R22_ANGLE         :    40.781
[JONES_MATRIX]
J11_AMOUNT        :     0.902
J11_ANGLE         :     9.426
J12_AMOUNT        :     0.436
J12_ANGLE         :    -8.392
J21_AMOUNT        :     0.423
J21_ANGLE         :  -171.522
J22_AMOUNT        :     0.904
J22_ANGLE         :    -9.445
[EIGENVECTORS]
EVEC1_AZIMUT     :   77.852
EVEC1_ELLIPTICITY:   -34.982
EVEC2_AZIMUT     :  -10.949
EVEC2_ELLIPTICITY:    34.275
[EIGENVALUES]
EVAL1_AMOUNT      :     1.001
EVAL1_ANGLE       :   -27.021
EVAL2_AMOUNT      :     0.999
EVAL2_ANGLE       :    27.021
[PDL]
PDL           [dB]:     0.114
PHASE        [DEG]:    54.043
```

2.7.4 Notes for high precision PDL measurements

NOTE

Please avoid any movement or vibration of the fibers between polarizer module, device under test and polarimeter module.

The fiber from the laser source to the polarizer module must lay tranquil too, since polarization changes in the polarizer are transformed into power fluctuations.

For high precision PDL measurements down to '0.01 dB' the averaged numbers of polarization measurements should be increased.
The setting can be changed in the main screen.

Suggestion:	'Revolutions' = '2'
	'Averaging' = '8'

NOTE

For highest accuracy and reproducibility of the measured values the user can do his own calibration of the polarimeter in advance.
Remember that also FC/APC connectors have a PDL which adds up to your measurement result.

➔ (Refer to chapter 2.3.8, on page 44)

The statement 'Rate' defines the screen refreshment rate. Select 'Rate' = '1'.

The following figure shows the additional ideal PDL depending on the angle of the APC connector. However, poor or dirty connector surfaces can severely increase the connector PDL.

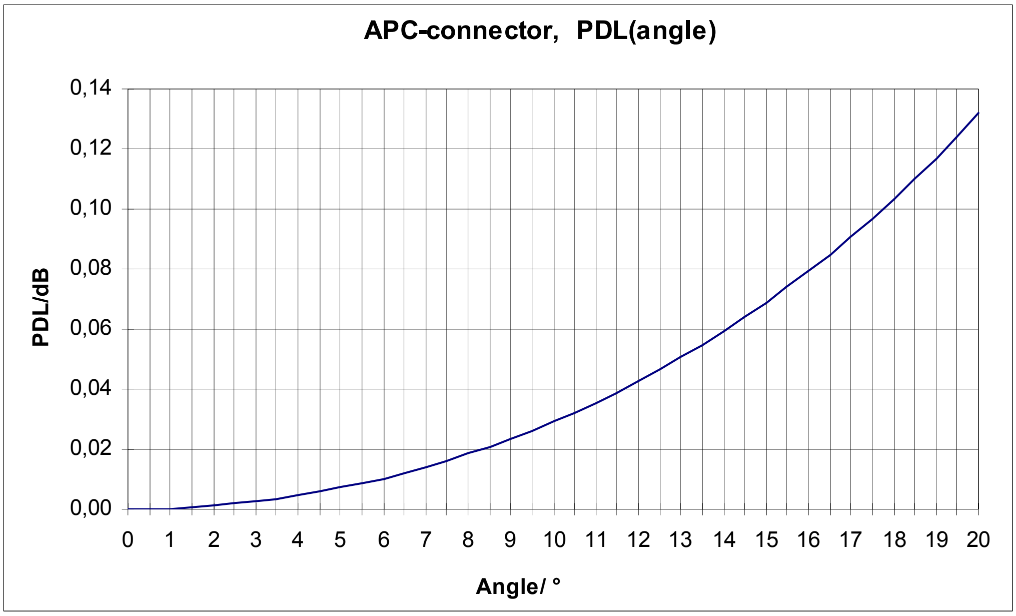

Figure 40 PDL of an ideal FC/APC connector

2.7.5 Wavelength selective PDL measurements

With the PAT 9000B the PDL of passive and active optical components as a function of wavelength can be characterized if an external tunable laser is available.
The measurement procedure resembles the Jones matrix analysis in PMD measurements. The polarimeter PAN 9300 (NIR or FIR), a polarizer module POL 9320 (NIR or FIR), a tunable laser source and the corresponding software are required.

Measurement set-up

Connect the output of the tunable laser to the input of the polarizer module POL9320 by a singlemode fiber with FC/APC connectors at both ends.

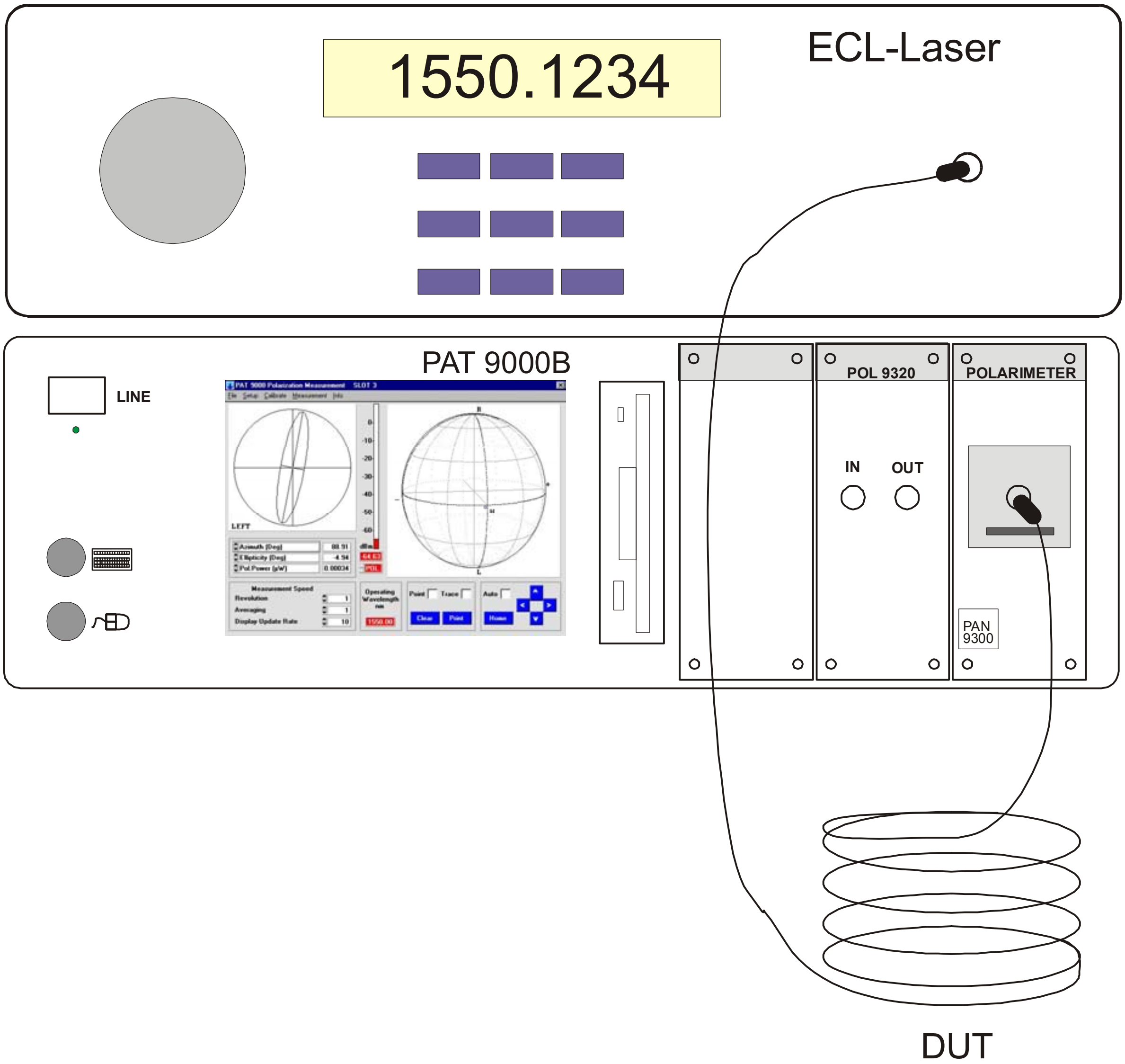

Figure 41 Measurement set-up for wavelength dependent PDL

Insert the device under test between the output of the polarizer module and the input of the polarimeter module. All fiber connections should show low attenuation and be reflection free.
For PDL measurements all fibers should be tightly clamped to the table. Every movement or vibration will affect the polarization of the light wave and increase the measurement errors.
The whole set-up should be positioned on a stable surface. We recommend additional fixing of the fibers on the table with adhesive tapes.

Measurement procedure

Use a set-up according to Figure 41.
Make sure that all patchcords are installed properly and sufficient optical power is applied to the polarimeter module. The power level should be more than -40 dBm.
When a PDL measurement is started the polarizer position is automatically optimized for maximal average transmission through the polarizer and the DUT for the start wavelength. The optimization is not done for all subsequent wavelength due to time consumption. It is expected that the initial optimization is also approximately good enough for all other wavelengths. This can however not be guaranteed.
Weak signal levels (< -40 dBm) may decrease the accuracy of the polarization measurements since the detector noise becomes more and more dominant. In that case you should increase the value for 'Revolution' and 'Averaging' in the main window.

➔ (Refer to section 2.3.4 "Measurement speed" on page 34)

Suggestion:	Revolutions	= '4'
	Averaging	= '2'

The displayed value of the measured polarization in this low power situation must remain stable. Fluctuations may be caused by vibrations or mechanical instability of the feeding fiber. Optimize the fixation of the patchcords etc. with adhesive tapes.
Now select 'Measurement / Jones-Matrix/PDL / PDL versus Wavelength' You are asked to determine the laser for PDL measurements (Figure 33, section 0, applies also for PDL measurements vs. wavelength).

The following screen shows up:

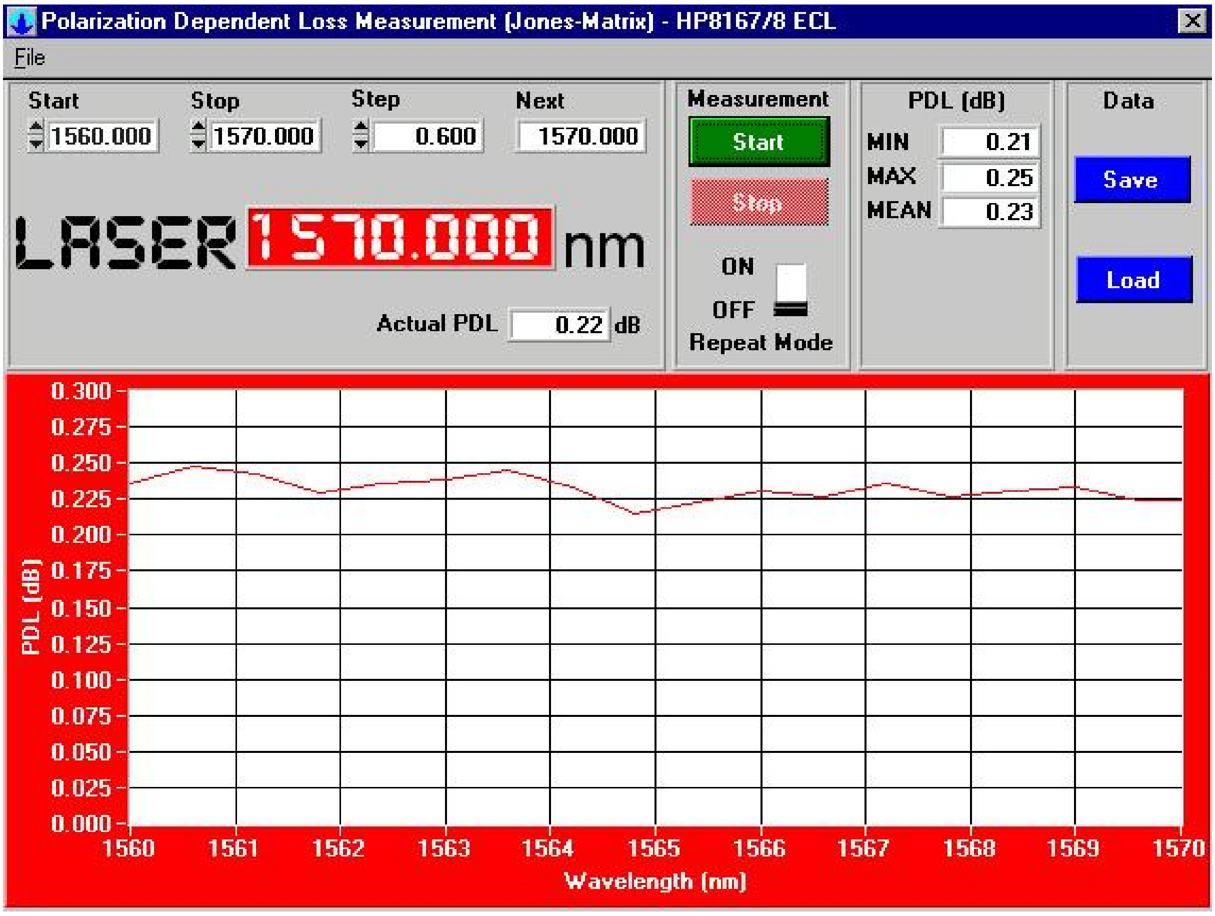

Figure 42 Example of a wavelength dependent PDL measurement

NOTE

To measure PDL the polarizer module sequentially generates three linear states of polarization (0°, 45° and 90°). The automatic optimization routine assures a low attenuation for these three states of polarization.

The Jones matrix is measured for each wavelength and the PDL is calculated from the singular values as described above.

Defining the wavelength range

Set the start- and stop-wavelength of the desired tuning range (in nm) in the fields **'Start'** and **'Stop'**.

Enter an appropriate step-size in the field '**Step**'.

Starting the measurement

Push the '**Start**' button.

Depending on the type of laser it will take some time to reach the start wavelength and to step through the scan range.

Pressing '**Stop**' interrupts the measurement at any time.
The field '**Laser**' shows the current wavelength setting of the laser source.
The field '**Next**' displays the wavelength of the following step.
'Actual PDL' shows the PDL value measured previously.

Measurement results

The measured values are continuously displayed in a diagram showing the dependency of the PDL on the wavelength.
Already during and after the measurement procedure the section 'PDL (dB)' gives the numerical values of minimum, maximum and average PDL.
Use '**Save**' and '**Load**' to store or load the measured data to or from a data file '*NAME*.PDL' on the hard- or floppy disc.
The data are arranged in the following format (ASCII):

```
PAT 9000B PDL (Jones-Matrix) Measurement   Thorlabs
Date: 04-20-2003    Time: 12:55:26
[WAVELENGTH]
START         [nm]: 1540.00
STOP          [nm]: 1560.00
STEP          [nm]:     2.0
POINTS            :      11
[PDL_DATA]
PDL_MIN       [dB]:  0.112
PDL_MAX       [dB]:  0.413
PDL_AVG       [dB]:  0.245
LAMBDA [nm]         PDL [dB]
   1540.00,          0.23,
   1542.00,          0.25,
```

The stored text files can be edited with any text editor or inserted in a graphic or spread sheet program for further processing.

Repeat Mode

To examine time dependency of the PDL the PAT 9000B can periodically repeat the wavelength scanning PDL measurement in defined time steps. Just set the „**Repeat Mode**“ button to ‘ON’ before activating ‘Start’.
After ‘Start’ set the time lag between two measurements in seconds. The value ranges from 0 to 3600 s = 1 hour. Please make sure to select the repeat time larger than the time needed for a single measurement. Only this guarantees exact timing between consecutive steps.
Enter an appropriate file name “*NAME*.REP”. After each run the measured PDL result with its time stamp are stored in this file.
The measurement cycle continues until the user pushes the „Stop“ button.

The files *.REP are in the following (ASCII) format.

```
PAT 9000B PDL (Jones-Matrix) Measurement   Thorlabs
PDL versus time measurement
Date: 04/22/03
Time         PDL [dB]
13:30:00      0.108
13:35:00      0.114
13:40:00      0.127
...
```

2.8 Polarization Mode Dispersion

2.8.1 Definitions and Terms

The key parameters on polarization mode dispersion (PMD) in fibers or optical components are the differential group delay (DGD), the principal states of polarization (PSP), the PMD value and its variation with wavelength. For any component or fiber there exists an input polarization state with the slowest and with the fastest signal propagation speed, called the fast and the slow principal states (PSP). The DGD is the difference in group delay at a specific wavelength between the slow and the fast PSP. The PMD value is the mean or the RMS value of the distribution of the DGDs over wavelength.

The PAT 9000B offers the Jones-Matrix-Eigenanalysis (JME) method for the most complete characterization of the polarization mode dispersion. By scanning the tunable laser over a wavelength range the DGD and PSPs versus wavelength are measured and plotted on the screen. The mean and RMS PMD values are then evaluated. The DGD distribution can be visualized in a histogram with Maxwellian fit as well. The measurements can be repeated automatically to monitor temporal variations.

This method can be ideally applied to measure DGD and PMD in fibers with random mode coupling and in optical components like isolators or demultiplexers with low mode coupling. The optional software package SW Hires is specially dedicated for narrowband components characterization, e.g. multiplexer, fiber bragg gratings.

The step size for JME PMD measurements can be dynamically adapted for optimal speed and accuracy.

The PMD of installed fiber links can be done with the package SW PMD EXT/JM and two PAT 9000B mainframes.

The PMD measurement methods 3 Stokes parameter-wavelength-scanning method (WLS) and the arc-angle method (ARC) are included in the software package SW PMD for convenience. However, the JME method is known to yield the most accurate results compared to other techniques. Moreover, the JME method gives a complete wavelength dependent information on polarization mode dispersion including the differential group delay distribution, the location of the principal states of polarization as well as higher order polarization mode coefficients. Therefore the JME technique is the method of choice for PMD measurement.

For a better understanding of polarization mode dispersion please have a look at the application notes on our webpage.

The Poincaré Sphere method/analysis (PSA) is also known under its earlier name "arc angle method", whereas the Fixed analyzer technique with 3-Stokes parameters was named wavelength scanning method (WLS) as well.

2.8.2 PMD measurement with the Jones matrix eigenanalysis

The Jones matrix eigenanalysis offers the following advantages:

- the polarization behavior of the principal states of polarization (PSP) is measured for each wavelength step
- the difference in group delay is measured for each wavelength step
- the extreme values of the DGD (min, max.) are determined
- a high dynamic range is possible (attenuation up to 50 dB)
- the PMD can be measured over a wide range from 0.001 ps ... 400 ps (the 400 ps depends on the stepsize, e.g. 10pm)

The Jones matrix eigenanalysis yields the following PMD parameters:

- DGD(λ)
- mean and RMS PMD value
- minimum and maximum DGD over wavelength
- statistical DGD distribution (histogram, Maxwell's curve fitting)
- Principal States of Polarization (PSP) (on request)
- PSP(λ).

The measurement procedure of the Jones matrix requires the polarimeter module PAN 9300, a polarizer module POL 9320, a tunable laser source and the corresponding software.

2.8.2.1 Measurement set-up

Connect the output of the tunable laser to the input of the polarizer module POL9320 with a single mode fiber with FC/APC connectors at both ends. Insert the device under test between the output of the polarizer module and the input of the polarimeter module. All fiber connections should have low attenuation and be reflection free.

For PMD measurements all fibers should be tightly clamped down. Any movement or vibration will affect the polarization of the light wave and increase the measurement error. The whole equipment should rest on a stable surface. We recommend to fix the fibers additionally with e.g. adhesive tapes.

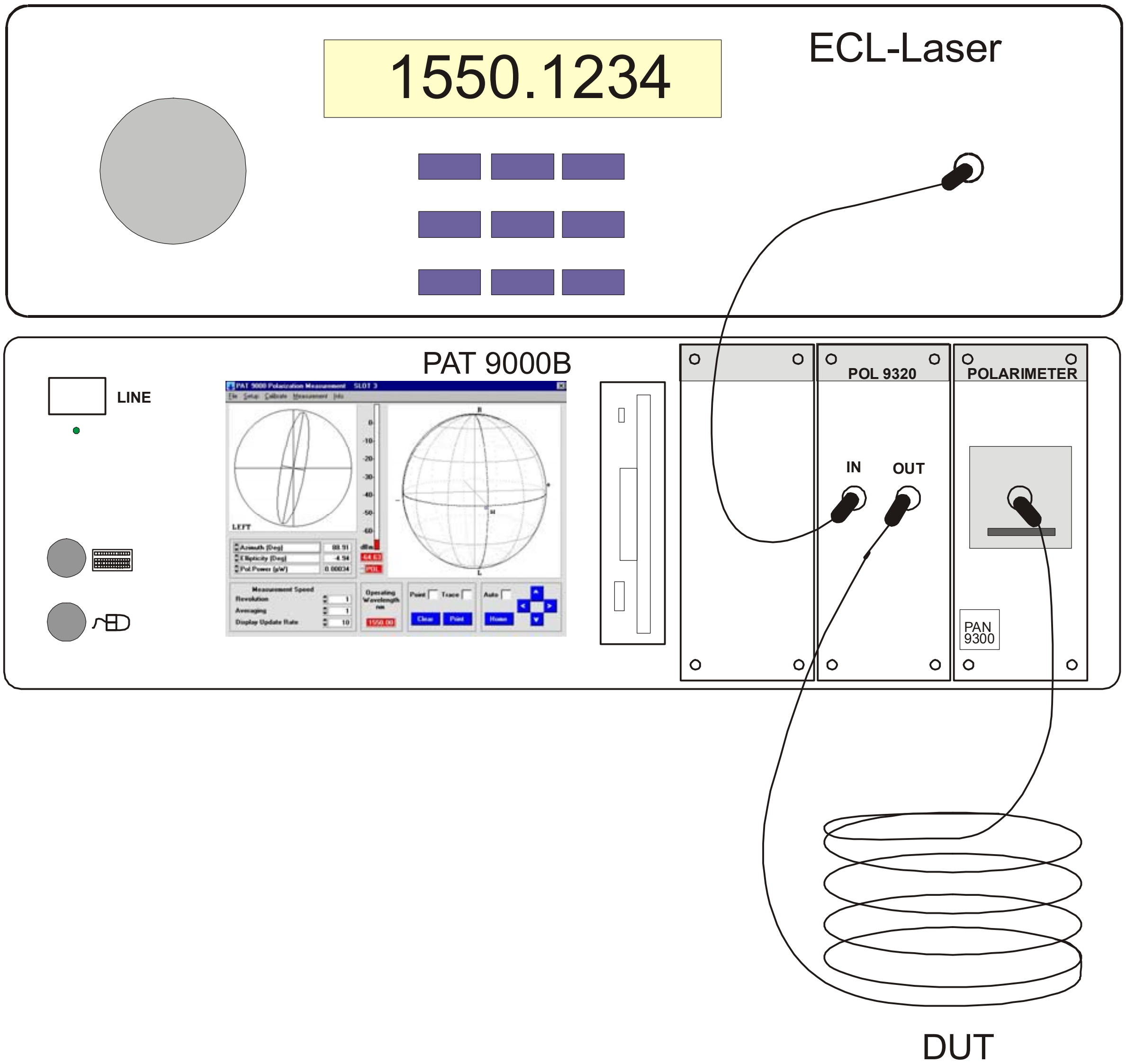

Figure 43 PMD measurement set-up for the Jones matrix eigenanalysis

2.8.2.2 Measurement procedure

Make sure that all patchcords are installed properly and sufficient optical power is applied to the polarimeter module. The power level should be more than -40 dBm. Check the right polarization at the polarizer input. Unfavorable polarization may strongly attenuate your signal. An optimization of the polarizer position is possible in menu ‘Set-up / Show POL Panel’.

➔ (Refer to section 2.4.3, "Controlling the POL module" on page 51)

When the PMD measurement is started the polarizer position is automatically optimized for the start wavelength. It is assumed that this optimized polarizer set-up gives also good results for all other wavelengths. The position of the patchcord from the laser source to the polarizer should of course not be changed anymore!

Weak signal levels (< -40 dBm) may decrease the accuracy of polarization measurements due to detector noise becoming more and more dominant. You should then increase the value of 'Revolution' and 'Averaging' for the polarization measurements.

➔ (Refer to section 2.3.4 "Measurement speed" on page 34)

Suggestion for weak signal conditions:	Revolutions	= '4'
	Averaging	= '2'

In the case of weak signals go to the main window and observe the display of the measured polarization on the Poincaré sphere. It must be stable for good results. Fluctuations may be caused by vibrations or mechanical instability of the feeding fiber. Optimize the fixation with e.g. adhesive tapes.

Also back reflections into the laser cavity, especially with high coherence lasers, can lead to fluctuations in the polarization displayed. All optical connections then must be optimized for lowest back reflections.

Now select the menu item 'Measurement / PMD / Jones matrix method’.

You are asked to determine the laser for PMD measurements (Figure 33, section 0, also for PDL measurements vs. wavelength).

The following screen shows up:

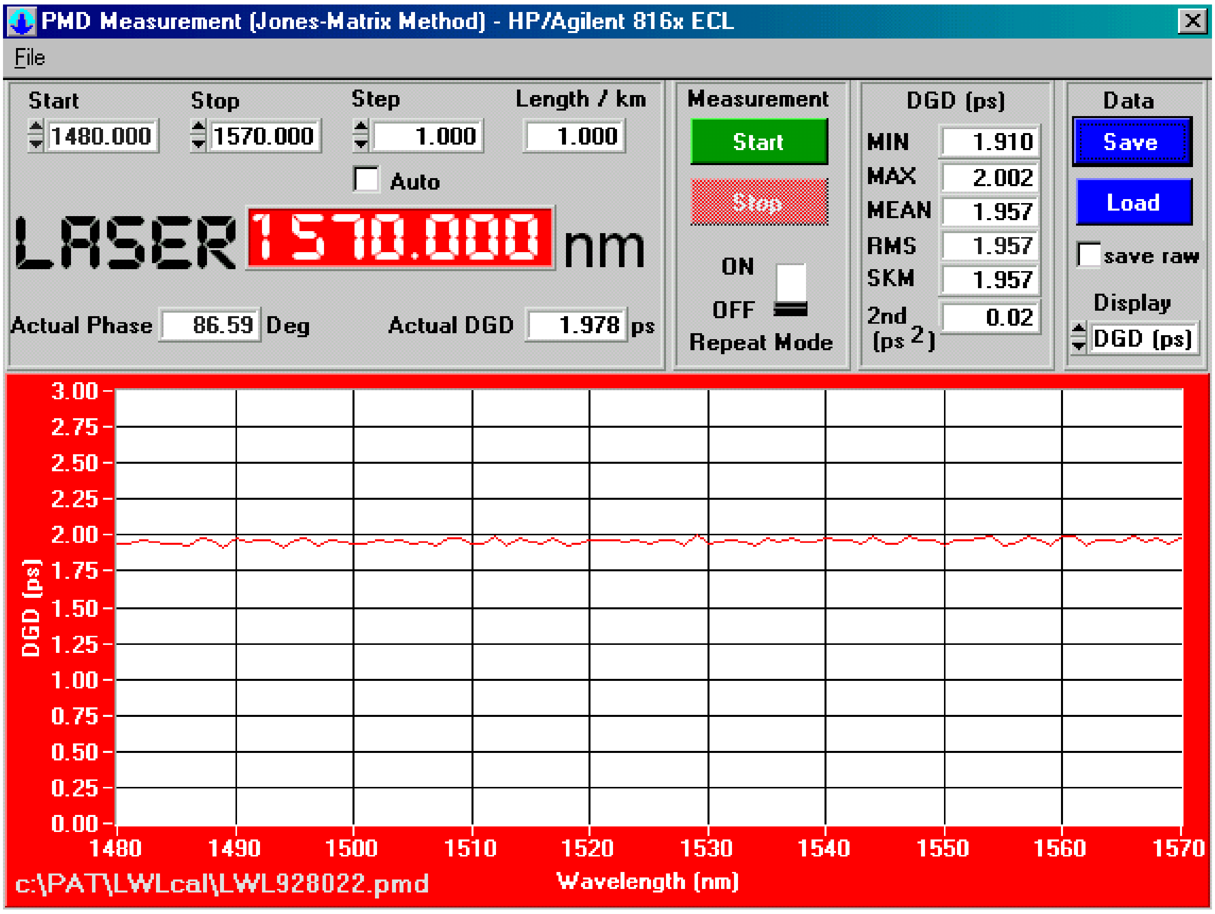

Figure 44 Screen display for the Jones matrix eigenanalysis

To determine the PMD with the Jones matrix eigenanalysis the laser source must be tuned for at least one wavelength step.

The fields in the **left control section** with the label LASER let you define the scan parameters.

Determining the wavelength range

Enter the start- and stop-wavelength of the desired tuning range in nm in the fields **'Start'** and **'Stop'**.

Selecting the wavelength step size

The wavelength step size has to be defined in the field '**Step**'. For each tunable laser there is an individual minimal step size that can not be exceeded.

The selected wavelength step must harmonize with the PMD of the device under test. You can choose a wavelength step according to the following table or select the automatic step size control.

NOTE

If the selected step size is too high, ambiguities will occur in the phase measurement and the measurement will yield too low PMD values. If the step size is too low, inaccuracies due to only tiny changes of the DGD will increase.

Due to the phase periodicity of π (180°) any phase difference between the fast and slow principal state exceeding 180° can not be uniquely resolved, but will be mapped into the basic interval 0° … 180°. Therefore, the DGD values corresponding to phase differences larger than π can not be safely detected. Therefore, for every wavelength a maximal measurable DGD value exists which can be calculated by:

$$DGD_{max} * \Delta\lambda < \lambda^2 / 2c$$

DGD_{max} depends on the wavelength step size: the smaller the step size, the larger is the maximal measurable DGD value.
The following table lists for the two wavelengths 1550nm and 1310nm the maximum measurable DGD value according to this formula. Since the PMD value is the average value of the DGD distribution a safe determination of the PMD value requires that even DGD values much larger than the PMD value are unambiguously detected: i.e that they still meet the above requirement. Therefore in the relationship between the PMD value and the wavelength step size a safety factor is incorporated to give room for large DGD values. Since the distribution for fibers with a strong mode coupling is broad (Maxwellian like) the built-in safety factor (8) is larger than for weak mode coupling as in isolators with narrow DGD distributions (safety factor of 2).

The table gives our recommendations for the correlation between wavelength step size and expected PMD value.

wavelength step size [nm]	1550nm			1300 nm		
	Max. measurable DGD [ps]	safely measured PMD [ps] with mode coupling		Max. measurable DGD [ps]	safely measured PMD [ps] with mode coupling	
		weak	strong		Weak	strong
0.01	400	200	50	280	140	40
0.02	200	100	25	140	70	20
0.05	80	40	10	56	28	8
0.10	40	20	5	28	14	4
0.20	20	10	2.5	14	7	2
0.50	8	4	1	5.6	2.8	0.8
1.00	4	2	0.5	2.8	1.4	0.4
2.00	2	1	0.25	1.4	0.7	0.2
5.00	0.8	0.4	0.1	0.56	0.28	0.08
10.0	0.4	0.2	0.05	0.28	0.14	0.04
20.0	0.2	0.1	0.025	0.14	0.07	0.02
50.0	0.08	0.04	0.01	0.056	0.028	0.008
100	0.04	0.02	0.005	0.028	0.014	0.004

NOTE

For devices under test with low mode coupling, (e.g. with polarization maintaining fibers) i.e. with lower variations of DGD over wavelength, relatively wide phase differences of 90° as measurement results are recommended to achieve the highest accuracy.

For devices under test with strong mode coupling, i.e. with strong fluctuations of DGD, the measured phase difference should cover the whole allowed range (0 … 180°) so that even peak phase differences can be determined unambiguously and the best accuracy is achieved.

If working with a device with unknown PMD, start with the lowest possible step size. If the measured DGD values are narrowly distributed increase the step size so that the maximal measured phase difference is a little bit smaller than 180°. If the measured DGD values exhibit a broad distribution with a tail, increase the step size until the whole phase range 0 … 180° is used.

Set the desired wavelength step size in the field '**Step**'.

Automatic step width control

The step size can also be adapted dynamically.

Activate the field '**Auto Step**'. At the start wavelength of each measurement the step size is determined by a search algorithm for the optimal value depending on the device under test. For subsequent wavelength intervals the algorithm makes use of the above formula to estimate and search for the appropriate step size.

NOTE

Since the automatic search for optimum step width is very time consuming you should not use it if the PMD of the DUT is known approximately beforehand.

The field '**Laser**' shows the present wavelength of the laser source.

The field '**Actual Phase**' gives the phase difference between the fast and slow principal state in degrees. The phase range is limited mathematically to 0 ... 180°. You must ensure that the phase shift remains in this range by selecting a suitable wavelength step. The field '**DGD**' gives the current DGD value calculated from the actual phase value.

Length input for the PMD coefficient

Input the fiber length in the field '**Length / km**'. This only serves to calculate the PMD coefficient for the device under test. It is the PMD value scaled to square root of the length of the device. If the length is unknown, set length to 1.0 km..

The **measurement section** in the control panel with the Start button control the execution of the scan.

Push the '**Start**' button to start a PMD measurement. Depending on the type of laser the time needed to get to the start wavelength and executing a wavelength step may differ.

'**Stop**' interrupts the measurement at any time.

The toggle button '**Repeat Mode**' selects/deselects repetition of the PMD measurement after some time period to be defined.

2.8.2.3 JME Measurement results

The measured values are continuously displayed in a diagram showing the dependency of the DGD on the wavelength.
The fields in the result section **DGD [ps]** provide the minimum and maximum DGD, the mean PMD value and the RMS PMD value. Even during the scan these parameters are constantly updated based on the number of up to then measured samples.
Recall that the PMD value is either the mean average ('**MEAN**') or the RMS average ('**RMS**') of the DGD distribution. Both values are given for convenience.
The RMS PMD value is measure for the width of the DGD distribution, whereas the mean PMD value is the average of the distribution.
For an ideal long fiber with strong mode coupling the mean and the RMS PMD value are correlated by constant factor. However, there is no correlation for non fiber devices or poor mode coupled devices.
The so called PMD coefficient is given in the field "SKM" (RMS PMD/√Length/km) This value makes only sense for a long fibers with high mode coupling since then the absolute PMD scales with the square root of the fiber length. The PMD coefficient is then a figure of merit to compare the PMD of different fiber types independent of the fiber length. If there is no strong mode coupling in your device or you don't know the behavior, simply set the length/km to 1.0.
The dependency of the DGDs from wavelength can change due to ambient conditions, especially for long fibers with high mode coupling. The diagrams of the device under test may look completely different when taken under different environmental conditions.
However, the mean and RMS PMD value remain (for ideal components) unchanged. I.e. the temporal average of the DGD distribution at one specific wavelength is identical to the average of the DGD distribution sampled at one specific time but over many wavelengths. This has been proven mathematically. Please refer to application notes on our webpage for more details.

After the measurement you can select the displayed parameter by clicking on the "Display" button:

- DGD (ps): Differential Group Delay vs. wavelength
- Histogram: Statistical Distribution of measured DGD values in histogram form
- PSP: Principle states of polarization s1, s2 and s3 vs. wavelength
- 2nd PMD: Second order PMD coefficient vs. wavelength

The 2nd order PMD coefficient takes into account the length variation of the PMD vector and its change of orientation on the Poincaré sphere. It is calculated according to the following formula:

$$PMD2\_coeff = \sum_{i=3}^{N} \frac{1}{2} \frac{\lambda(i)-\lambda(i-1)}{\lambda(N)-\lambda(1)} \sqrt{\left(\frac{\partial DGD(i)}{\partial \omega}\right)^2 + \left(\frac{\partial \vec{S}_{PSP}(i)}{\partial \omega}\right)^2}$$

The factor of 0.5 is due to theory. The PSP vector $\mathbf{S}_{PSP}$ in the above formula is the normalized unit vector pointing into the direction of the fast principal state. N is the number of wavelength points at which the Jones matrix is measured. Since the PMD2_coeff involves the second order derivative of the DGDs and the PSPs the average can only be taken over N-2 data points. The sum runs only from 3 to N since for internal PAT SW data management reasons the first and second DGD and $\mathbf{S}_{PSP}$ values are identical. Due to the SW feature, that every scan can be stopped at any intermediate wavelength point without loss of already recorded data, the theoretical scaling factor 1/(N-2) must be treated as running factor and is therefore approximated by $\frac{1}{N-2} = \frac{\lambda(i)-\lambda(i-1)}{\lambda(N)-\lambda(1)}$. Since the accuracy of DGD and PSP values reduces with decreasing step size, the weighting factor $\frac{\lambda(i)-\lambda(i-1)}{\lambda(N)-\lambda(1)}$ decreases also the importance of less accurate DGD values within the average.

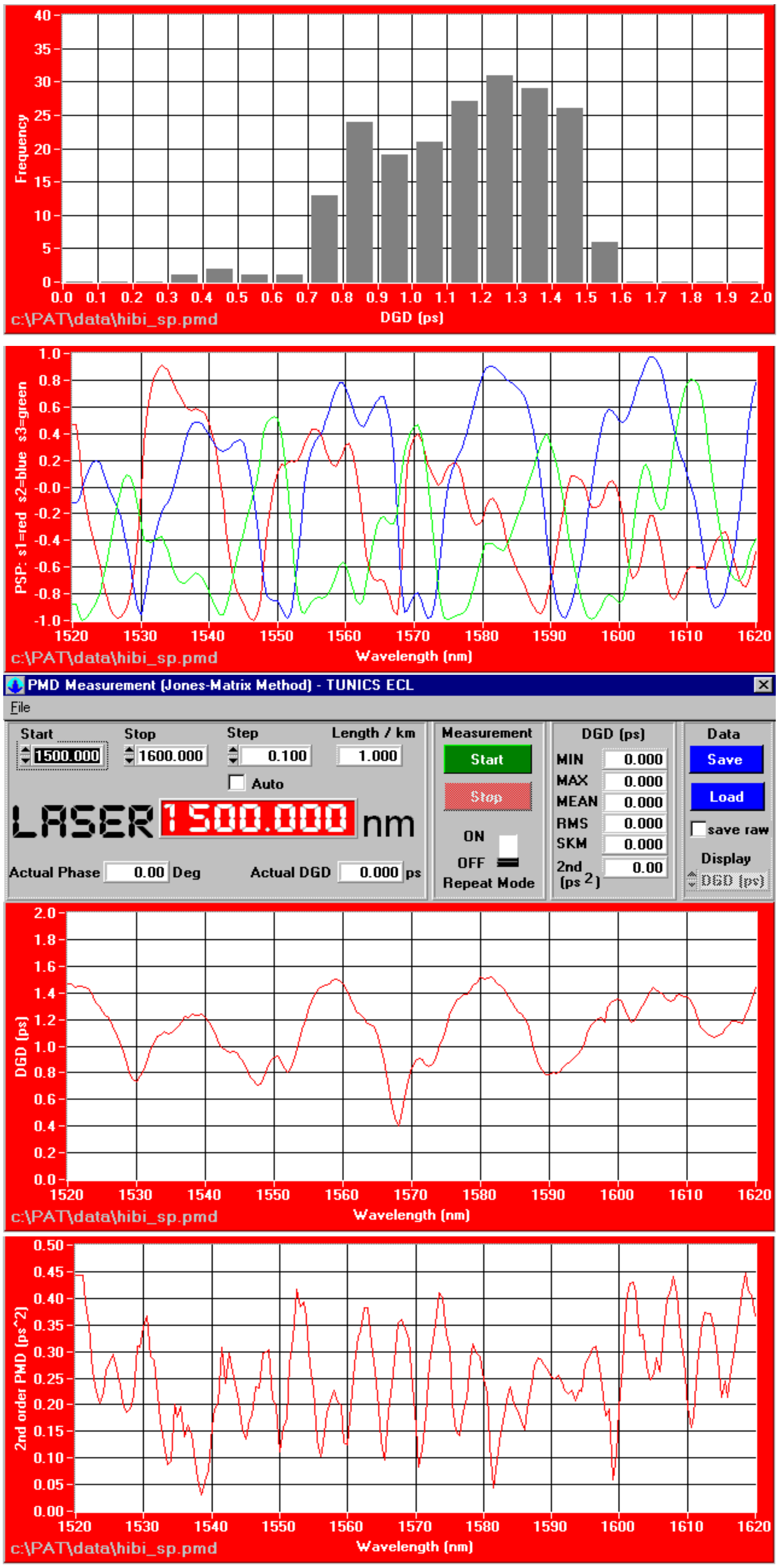

Figure 45 JME PMD measurement results

DGD histogram, PSP(λ) , DGD(λ), 2nd order PMD(λ)

The measurement screens are shown in Figure 45.

For devices exhibiting high mode coupling like long standard fibers a Maxwellian distribution is expected. Devices with an almost constant DGD only show one vertical bar in the histogram.

The fields '**Save**' and '**Load**' help to store or re-load the measured data into or from a data file '*NAME*.PMD' on hard- or floppy disc.
The distribution, PSP(λ) and 2nd PMD(λ) diagrams can be generated for data loaded from a file as well in the described way.

The data files have the following (ASCII) format:

```
PAT9000 PMD Jones-Matrix-Measurement   Thorlabs
Date: 11-02-2002    Time: 13:04:07
[FIBER]
FIBER_LENGTH [km]: 1.000
[WAVELENGTH]
START        [nm]: 1530.000
STOP         [nm]: 1570.000
STEP         [nm]:    0.400
POINTS           :       38
[PMD_DATA]
PMD_MIN      [ps]:    0.000
PMD_MAX      [ps]:    0.005
PMD_AVG      [ps]:    0.002
PMD_RMS      [ps]:    0.003
PMD_SKM   [ps/skm]:   0.003
LAMBDA [nm]       PMD [ps]     PSPout s1     s2           s3
   1530.000,        0.005,     -0.836,     -0.549,       0.003,
   1531.100,        0.005,     -0.836,     -0.549,       0.003,
   1532.200,        0.005,     -0.507,     -0.762,      -0.402,
   1533.300,        0.001,      0.294,     -0.085,      -0.952,
   1534.400,        0.003,      0.310,      0.941,      -0.138,
   1535.500,        0.003,      0.946,     -0.172,       0.273,
```

The stored text files can be edited with any text editor or inserted in a graphic or spread sheet program for further processing.
You can also save the raw data of a measurement. You just mark the "**save raw**" field below the save/load buttons. Then the s1, s2, s3, DOP, P_pol, P_unpol and S0 values are stored for every wavelength step in the file "PMD_MEAS.RAW" instead of the derived PMD parameters.

2.8.2.4 Repeat mode

To examine the time dependency of the PMD the PAT 9000B periodically repeats the total DGD measurement scan after defined time steps. Set the switch **"Repeat Mode"** to 'ON' before activating **'Start'**.
Then enter the time lag between two measurements in seconds. The range extends from 0 to 1440 min (= 1 day). Make sure that the repeat time selected is larger than the measurement time for a scan. Thereafter enter a file name *NAME*.REP. The measured data will be stored in this file.
The measurement proceeds until the operator hit's the **"Stop"** button.

The files *.REP have the following (ASCII) format:

```
PAT9000 PMD Jones-Matrix Measurement   Thorlabs
PMD versus time measurement (Repeat mode)
[FIBER]
FIBER_LENGTH [km]: 1.000
[WAVELENGTH]
START          [nm]: 1533.00
STOP           [nm]: 1533.50
STEP           [nm]:    0.10
POINTS             :       6
Date: 05-05-1999    Time: 09:37:00
[PMD_DATA]
PMD_MIN        [ps]:   3.196
PMD_MAX        [ps]:  23.028
PMD_AVG        [ps]:  13.078
PMD_RMS        [ps]:  15.321
PMD_SKM    [ps/skm]:  15.321
LAMBDA [nm]         PMD [ps]
   1533.00,          23.028,
   1533.10,          23.028,
   1533.20,          21.621,
   1533.30,           3.196,
Date: 05-05-1999    Time: 09:38:00
[PMD_DATA]
PMD_MIN        [ps]:  10.265
PMD_MAX        [ps]:  29.252
PMD_AVG        [ps]:  18.762
PMD_RMS        [ps]:  20.110
PMD_SKM    [ps/skm]:  20.110
LAMBDA [nm]         PMD [ps]
   1533.00,          18.329,
   1533.10,          18.329,
   1533.20,          29.252,
   1533.30,          10.265,
```

2.8.3 High Resolution Jones-Matrix PMD measurement

This method for PMD measurement is quite similar to the Jones Matrix Eigenanalysis explained previously. However, is takes into account the special requirements concerning the characterization of narrow band optical components like fiber bragg gratings (FBG) or arrayed waveguide grating filters (AWG).
With the standard JM Eigenanalysis for measuring optical components like fibers, EDFA's, isolators etc. there is the possibility to measure small differential group delays with relatively large wavelength steps.
In contrast optical components with a small bandwidth exhibit usually small differential group delays and there is moreover only a small scanning region available for the PMD measurement. To mitigate this detrimental measurement situation the high resolution measurement method (HiRes) has been developed. It uses special averaging techniques on the Stokes parameters of the measured output polarization states.
A variety of measurement uncertainties are induced by the device under test itself. For example multiple internal reflections and external reflections in fiber connections can lead to strong polarization changes. Especially at steep pass band edges the polarization fluctuations can be much stronger than the PMD related fluctuations. Measurement errors of some 100% and group delay changes of several 10 ps would result.
We recommend to take DGD values only within the passband since only there they are of interest.
The HiRes averaging technique takes the following issues into account and processes the data as follows:

- Measurement of the output polarization of the DUT for each of the three polarizer positions (like standard measurement)
- Measurement of polarization, signal quality in the polarimeter and rms fluctuation of polarization
- Variable averaging of measurement values dependent on the given scatter of the data at each wavelength
- The measured wavelength dependent polarizations ($s_1(\lambda)$,$s_2(\lambda)$,$s_3(\lambda)$) are smoothened mathematically without inducing significant errors in DGD.
- A measured polarization is adapted to it's neighbor polarization state only within its own measurement uncertainty. Thus the statistic polarization noise is strongly suppressed but the real DGD related polarization fluctuations stay unchanged.

- SOP data points whose scatter is too large are not taken into account. Since the DGD value can not be reasonably calculated for them the values at this wavelength are not evaluated and taken into account for the smoothing.

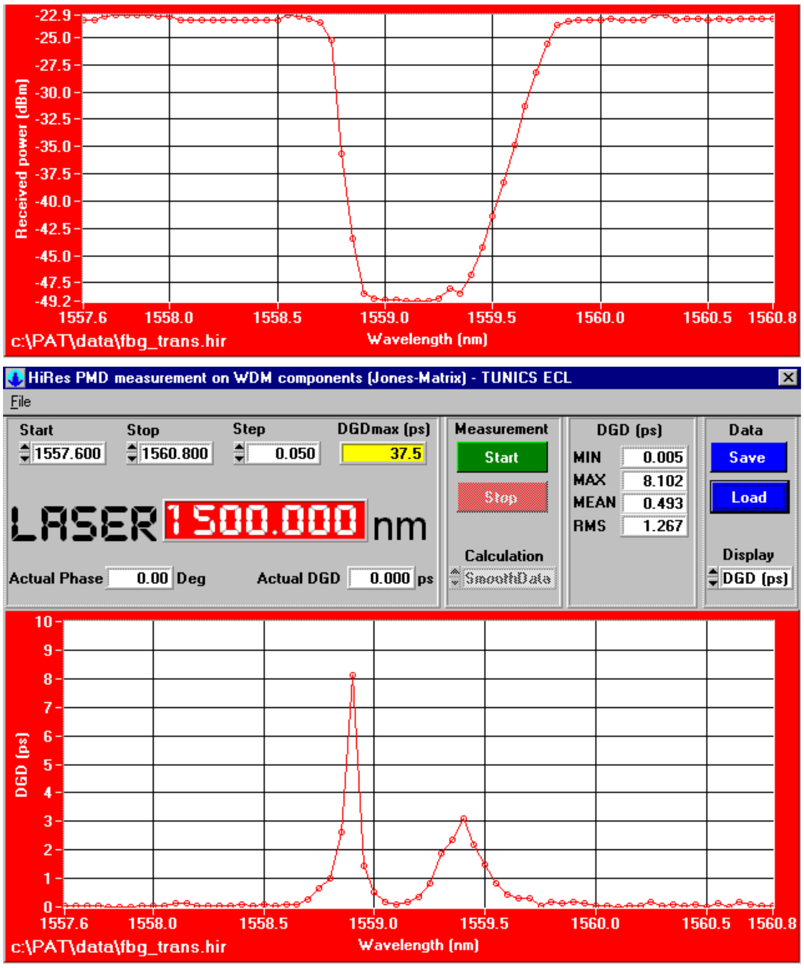

Figure 46 DGD of transmissive fiber bragg grating

Figure 46 shows the differential group delay of a fiber bragg grating in transmission. The lower part shows the optical power detected by the polarimeter. It can be clearly seen, that the filter slopes yield higher DGD values.
The measurement technique of the High Resolution Jones matrix technique requires the polarimeter module PAN 9300, a polarizer module POL 9320, a tunable laser source and the corresponding software option.

2.8.4 PMD measurement on already installed fibers with JME

The principle measurement setup for PMD measurements with the Jones-Matrix Method on installed fibers is shown in Figure 47.

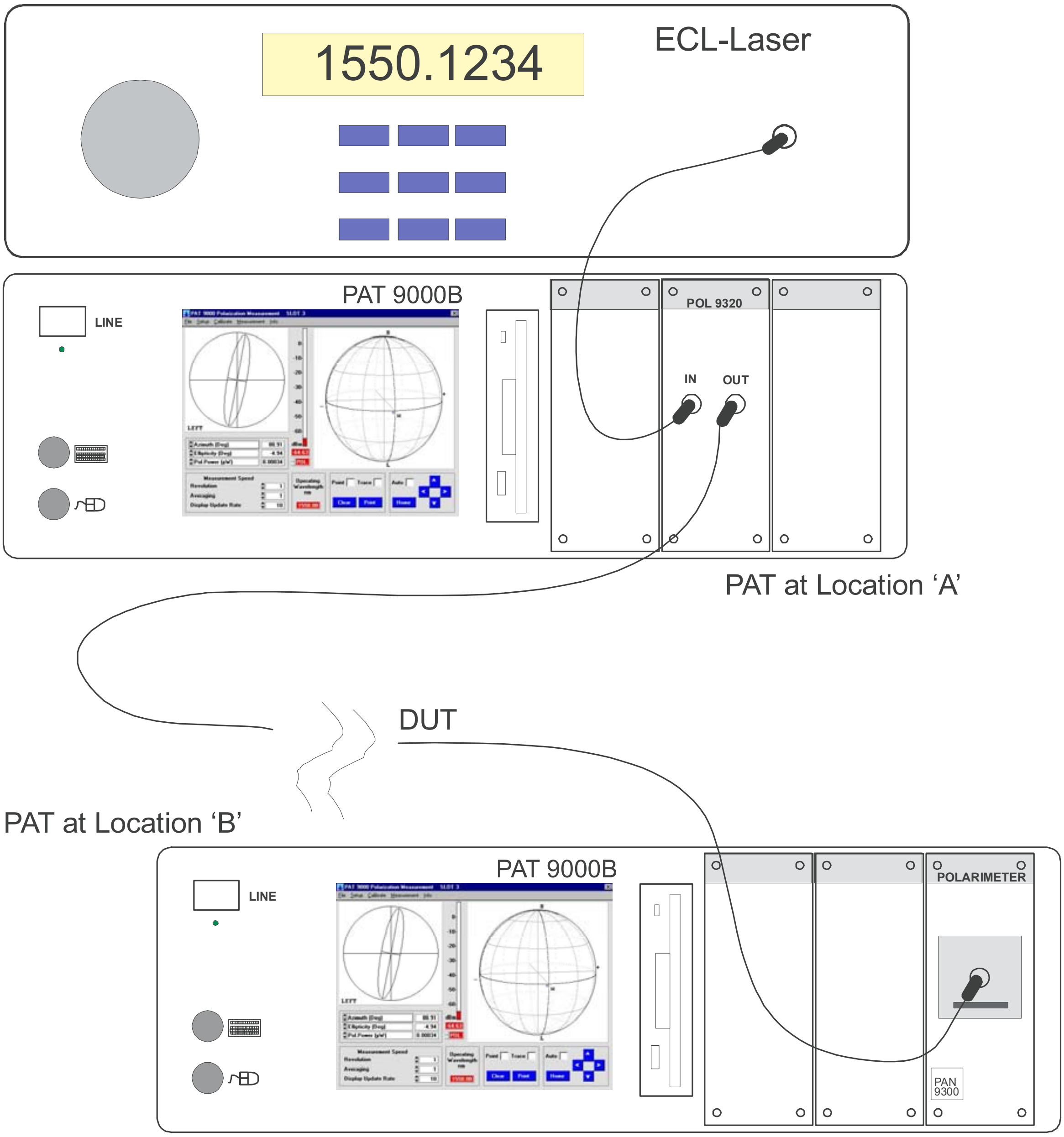

Figure 47 PMD measurement setup for already installed fibers

On the transmission side a PAT9000B with a polarizer plug-in module and a tunable laser source is needed. The receiving part also consists of a PAT 9000B, with a polarimeter module and the "turbo" software option.

Both transmitter and receiver can be located an arbitrary distance apart and do not need a data link in-between them. The synchronization of both units is done only by the recognition of the predefined measurement sequence.
The only information needed on the receiver side are the start- and stop wavelength and the number of wavelength steps in-between resp. the width of the wavelength steps. Please make sure that the scanned wavelength region is an integer multiple of the wavelength step to assure proper operation.

NOTE

The larger the expected PMD (e.g. the larger the distance between transmitter and receiver), the smaller the used wavelength steps must be for a reliable measurement!

The equipment on the transmit side cycles continuously until stopped manually.
The receiving station stops the measurement after a full measurement cycle has been identified and recorded. The corresponding measurement values are then displayed and can be stored.
Note that the JME method is more susceptible to vibrations of the fiber than interferometric PMD measurement techniques due to the longer measurement time and the evaluation of polarization states.
The measurement can be repeated automatically after a predefined time from 0 to 1440 min (24h). Set the 'repeat mode' switch to 'on'. If you start the measurement the repeat time must be entered.

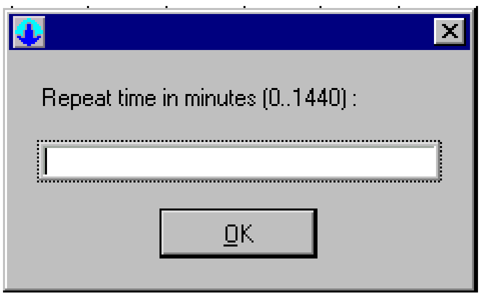

Figure 48 Entering the repeat time

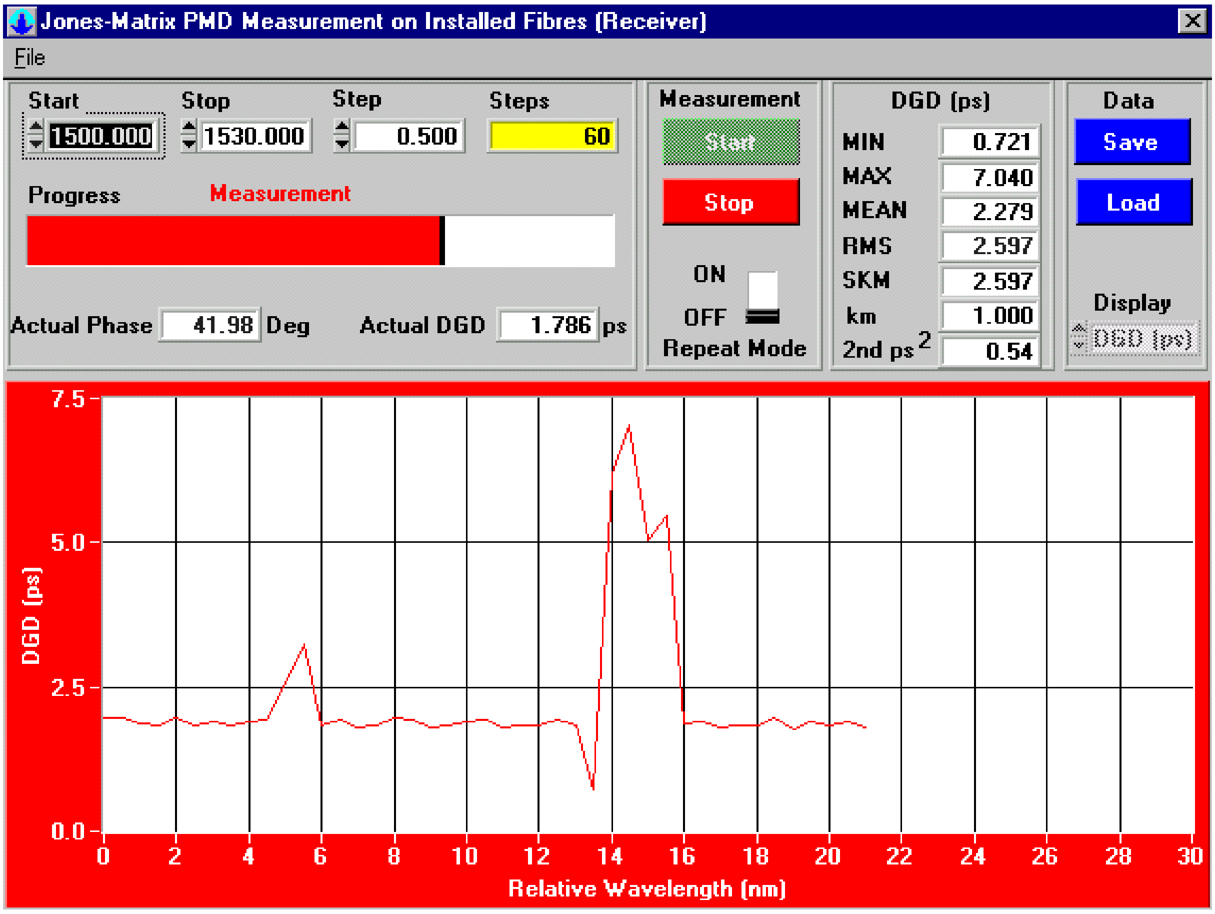

Figure 49 PAT 9000B as receiver in installed fiber measurement

☝Attention☝

Displayed values during measurement may differ significantly from the final results, because the precise laser wavelength necessary for the calculation can only be determined after the complete measurement cycle has finished! The final measurement values are then re-calculated and the absolute wavelengths are displayed!

2.8.5 PMD measurement in Poincaré Sphere technique

The Poincaré sphere analysis (PSA) technique has been also named arc angle method.
The PSA method is based on the measurement of polarization changes at the output of the device under test while changing the input wavelength.

NOTE

The result of this measurement procedure will only be valid under certain conditions!
The device under test must possess two wavelength independent eigenvectors and the input polarization must be set in a way to ensure an even distribution of power to these eigenvectors.

If these conditions are not given, the measured result will be smaller than that of the Jones matrix eigenanalysis or of other PMD measurement techniques.

2.8.5.1 Measurement set-up

The measurement set-up is shown in Figure 50.
Connect the output of the tunable laser to the input of a manual polarization controller and the output of the device under test to the polarimeter module PAN 9300.
For small wavelength changes of the laser the output polarization will follow an arc shaped trace on the Poincaré sphere. A circle can be fitted with a least square routine to any point on the arc such that the perimeter of the circle matches to the fitted section of the arc. The subtended angle of the arc is in direct relation to the wavelength change and to the DGD of the device under test at this wavelength.

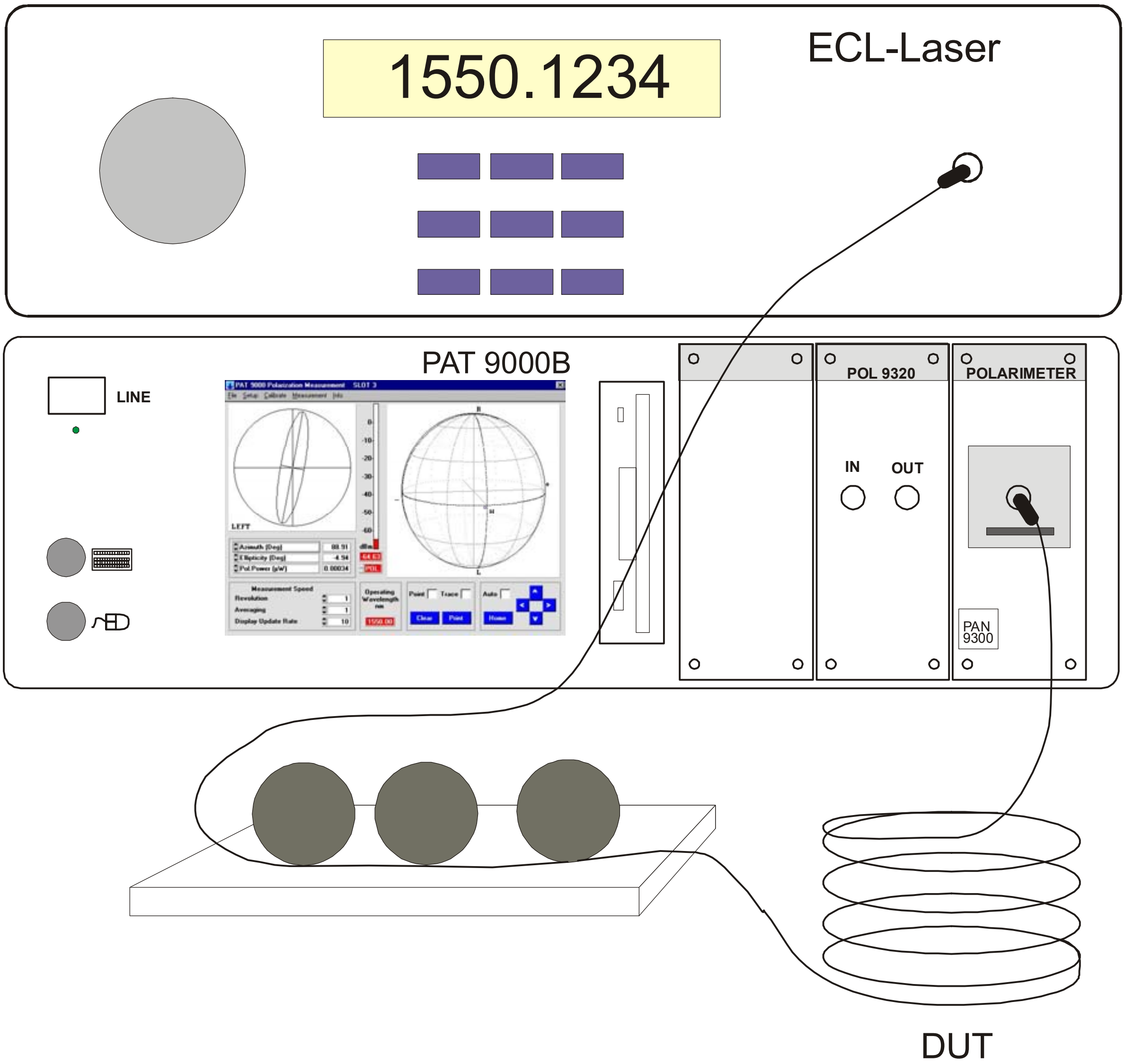

Figure 50 PMD measurement set-up for the Poincaré Sphere Method

2.8.5.2 Measurement procedure

Make sure that all patchcords are installed properly and sufficient optical power is applied to the polarimeter module. The power level should be more than -40 dBm. Weak signal levels (< -40 dBm) may decrease the accuracy of polarization measurements due to detector noise becoming more and more dominant. You should then increase the value of 'Revolution' and 'Averaging' for the polarization measurements.

➔ (Refer to section 2.3.4 "Measurement speed" on page 34)

Suggestion for weak signal conditions: Revolutions = '4'

Averaging = '2'

In the case of weak signals go to the main window and observe the display of the measured polarization on the Poincaré sphere. It must be stable for good results. Fluctuations may be caused by vibrations or mechanical instability of the feeding fiber. Optimize the fixation with e.g. adhesive tapes.
Also back reflections into the laser cavity, especially with high coherence lasers, can lead to fluctuations in the polarization displayed. All optical connections then must be optimized for lowest back reflections.
Depending on the nature of the device under test the input polarization will more or less influence the measurement result. Only if the launched power is evenly distributed among the two principal states of polarization the measurement result yields the correct value. The launched polarization state must therefore be tuned by means of a manual polarization controller preceding the device under test until the indicated DGD value reaches its maximum.

NOTE

Since the PSP's are wavelength dependent, the optimal launch condition must in principle be searched for each wavelength step or at least after a few scanning steps. Otherwise the measured DGD values will be always smaller than the results of the Jones matrix eigenanalysis or of other PMD measurement techniques.

2.8.5.3 Adjusting the optimum input polarization

Return to the main screen and activate the trace option on the Poincaré sphere by clicking **'Trace'**

Set a wavelength range and scan continuously (refer to the corresponding operating manual). In the meantime change the polarization with the manual polarization controller until the resulting diameter of the circular trace or the arc section on the Poincaré sphere is maximized. It can happen that the circle is never closed since the DGD behavior within the chosen wavelength range changes to rapidly.
The length of the trace depends on the wavelength and DGD at that wavelength.

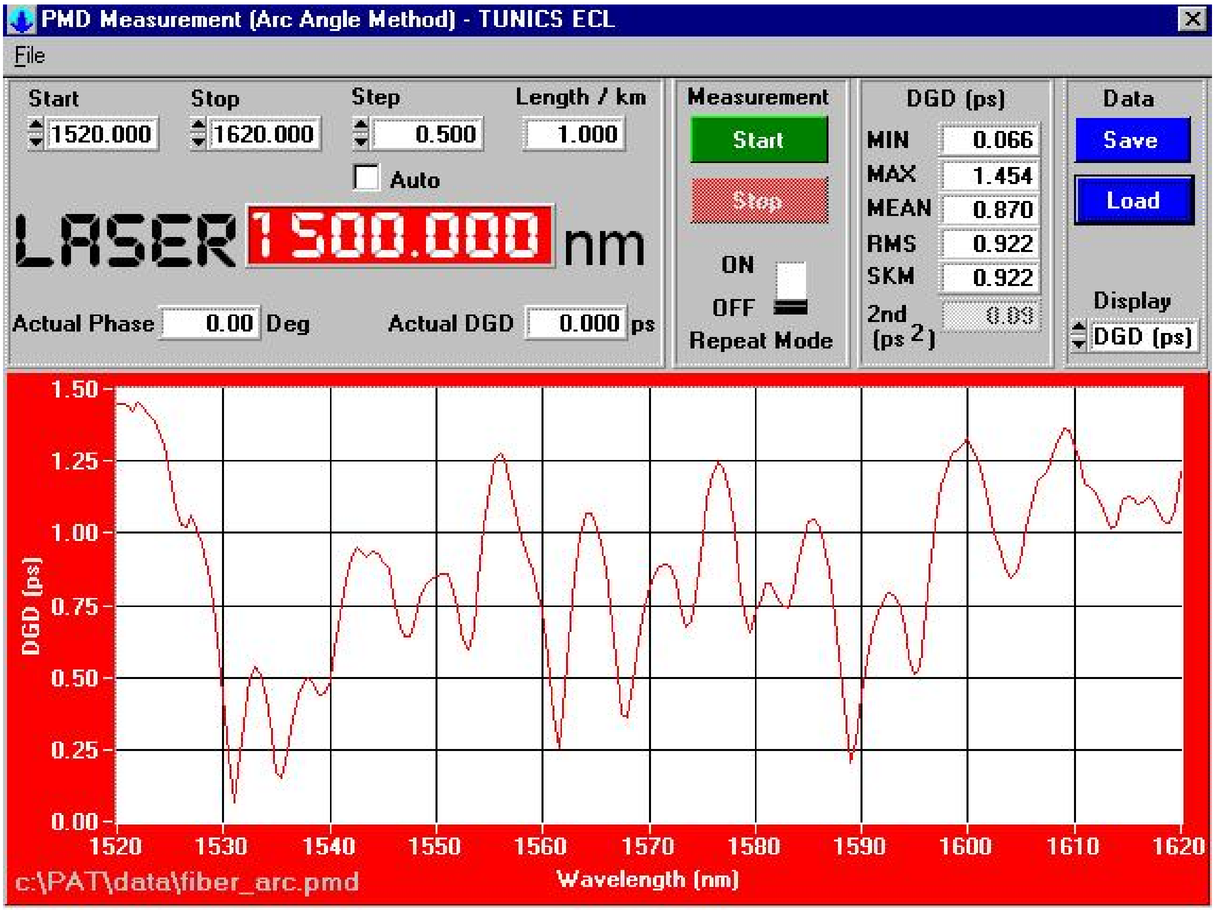

Figure 51 Screen display in Poincaré Sphere technique

To measure the PMD by means of the Poincaré Sphere technique the laser source must be tuned for at least one wavelength step.

Determining the wavelength range

Set the start- and stop-wavelength of the desired tuning range in nm in the fields **'Start'** and **'Stop'**.

The wavelength difference between two polarization measurements can either be selected constant or variable by activating **'Auto'**.

➔ (Refer to "" on page 92)

Set the desired wavelength step with **'Step'**.

For the Poincaré sphere measurement technique the same statements apply with regard to step size as for the Jones matrix Eigenanalysis.

➔ (Refer to section 2.8.2, "PMD measurement with the Jones matrix eigenanalysis" on page 86)

The arc angle must be in the range 0 ... 180°. If the step size is too large, ambiguities in phase measurement will occur and the measurement will yield too small DGD values. If the step width is to small, the arc angle is too short and the measurement accuracy will degrade.

Starting the measurement

Push the '**Start**' button. Depending on the type of laser the time needed for reaching at start wavelength and executing a wavelength step may differ.
'**Stop**' interrupts the measurement at any time.

The field '**Laser**' shows the present wavelength of the laser source.

The field '**Actual Phase**' gives the phase difference between the fast and slow principal state in degrees. The phase range is limited mathematically to 0 ... 180°. You must ensure that the phase shift remains in this range by selecting a suitable wavelength step. The field '**DGD**' gives the current DGD value calculated from the actual phase value.

NOTE

The program can not recognize if the phase shift per wavelength step exeeds180°. The calculation of the matrix will always show values between 0 and 180°. A phase of 190° for example, is read out as 170°.

2.8.5.4 Measurement results

The measured values are continuously displayed in a diagram showing the dependency of the DGD on the wavelength.
Already during and after the measurement procedure the fields in the section '**DGD**' provide the minimum and maximum DGD, the mean PMD value and the RMS PMD value.
The other parameters are as described in the JME section.
The dependency of the DGD from wavelength can change continuously due to ambient conditions.
After the measurement or with data loaded from a file you can look to the statistical distribution of the measured DGD values by pushing the '**Histogram**' button

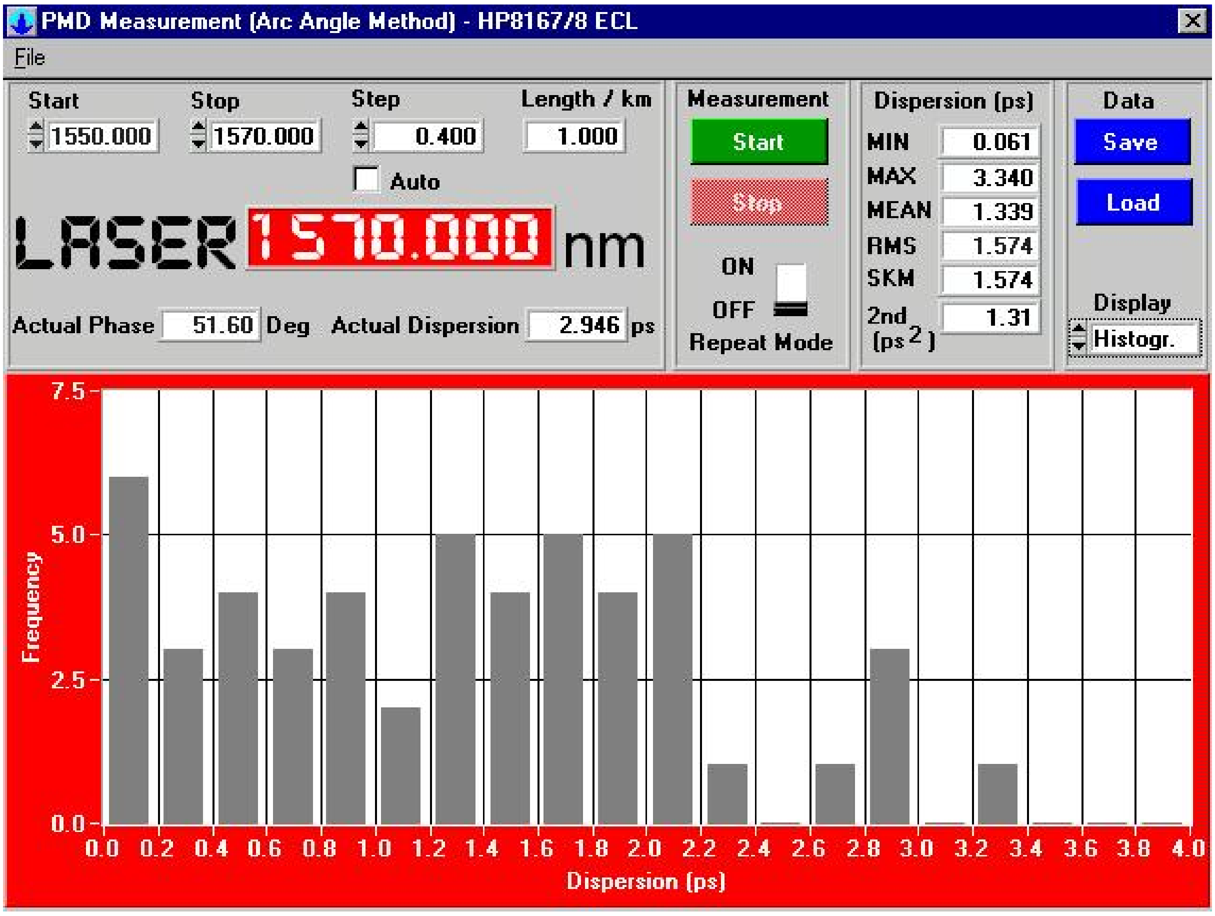

Figure 52 Histogram of a PMD measurement in Arc angle technique

Use the same key, now labeled ‘Diagram’, to return to the normal display.
Neither the principal states of polarization nor the 2nd order PMD coefficient are evaluated with the arc angle method.

The fields '**Save**' and '**Load**' help to store or re-load the measured data into or from a data file '*NAME*.PMD' on hard- or floppy disc.

The data files are of the following format:

```
PAT 9000B PMD Arc-Angle-Measurement   Thorlabs
Date: 10/17/01    Time: 21:20:44
[FIBER]
FIBER_LENGTH [km]: 4.000
[WAVELENGTH]
START         [nm]: 1520.00
STOP          [nm]: 1530.00
STEP          [nm]:    1.00
POINTS            :      11
[PMD_DATA]
PMD_MIN       [ps]:   1.041
PMD_MAX       [ps]:   1.155
PMD_AVG       [ps]:   1.117
PMD_RMS       [ps]:   1.118
PMD_SKM   [ps/skm]:   0.559
LAMBDA [nm]        PMD [ps]
   1520.00,          1.041,
   1521.00,          1.041,
   1522.00,          1.125,
...
```

The stored text files can be edited with any text editor or inserted into a graphic or spread sheet program for further processing.

2.8.5.5 Repeat Mode

To examine the time dependency of the PMD the PAT 9000B periodically repeats the total DGD measurement scan after defined time steps. Set the switch **“Repeat Mode“** to ‘ON’ before activating **‘Start’**.

Then enter the time lag between two measurements in seconds. The range extends from 0 to 1440 min (= 1 day). Make sure that the repeat time selected is larger than the measurement time for a scan. Thereafter enter a file name *NAME*.REP. The measured data will be stored in this file.

The measurement proceeds until the operator hit’s the **“Stop“** button.

The files *.REP are written in the following (ASCII) format (see next page):

```
PAT 9000B PMD Arc-Angle-Measurement   Thorlabs
PMD versus time measurement (Repeat mode)
[FIBER]
FIBRE_LENGTH [km]: 1.000
[WAVELENGTH]
START         [nm]: 1533.00
STOP          [nm]: 1533.50
STEP          [nm]:    0.10
POINTS            :       6
Date: 05-05-2002    Time: 09:37:00
[PMD_DATA]
PMD_MIN       [ps]:   3.196
PMD_MAX       [ps]:  23.028
PMD_AVG       [ps]:  13.078
PMD_RMS       [ps]:  15.321
PMD_SKM   [ps/skm]:  15.321
LAMBDA [nm]        PMD [ps]
   1533.00,         23.028,
   1533.10,         23.028,
   1533.20,         21.621,
   1533.30,          3.196,

Date: 05-05-2002    Time: 09:38:00
[PMD_DATA]
PMD_MIN       [ps]:  10.265
PMD_MAX       [ps]:  29.252
PMD_AVG       [ps]:  18.762
PMD_RMS       [ps]:  20.110
PMD_SKM   [ps/skm]:  20.110
LAMBDA [nm]        PMD [ps]
   1533.00,         18.329,
   1533.10,         18.329,
   1533.20,         29.252,
   1533.30,         10.265,
...
```

2.8.6 PMD measurement, 3 Stokes param. wavel. scanning method

2.8.6.1 Measurement set-up

This method requires the polarimeter module PAN 9300, a tunable laser source and the corresponding software option.
The set-up is shown in Figure 53.
Connect the output of the tunable laser to the input of the device under test and its output to the input of the polarimeter module using patchcords with FC/APC connectors at both ends.
With this technique the S-parameters s_1, s_2 and s_3 are recorded vs. wavelength and displayed in three diagrams (see Figure 54). The PMD value is calculated from the number of minima and maxima occurring in each diagram. The larger the DGD at a specific wavelength is the faster do the polarizations changes occur. Since the polarization in the Poincaré sphere representation always lies on the Poincaré sphere the Stokes parameters continuously cycle between extrema values when the laser is scanned. The number of extrema for a scan is statistically related to the PMD value in the scan range.
Obviously if the scan range is too small then there are only a small number of extrema found and the determined PMD value is by statistical reasons very inaccurate. The scan range must be chosen to monitor at least 10 extrema for each Stokes parameter.

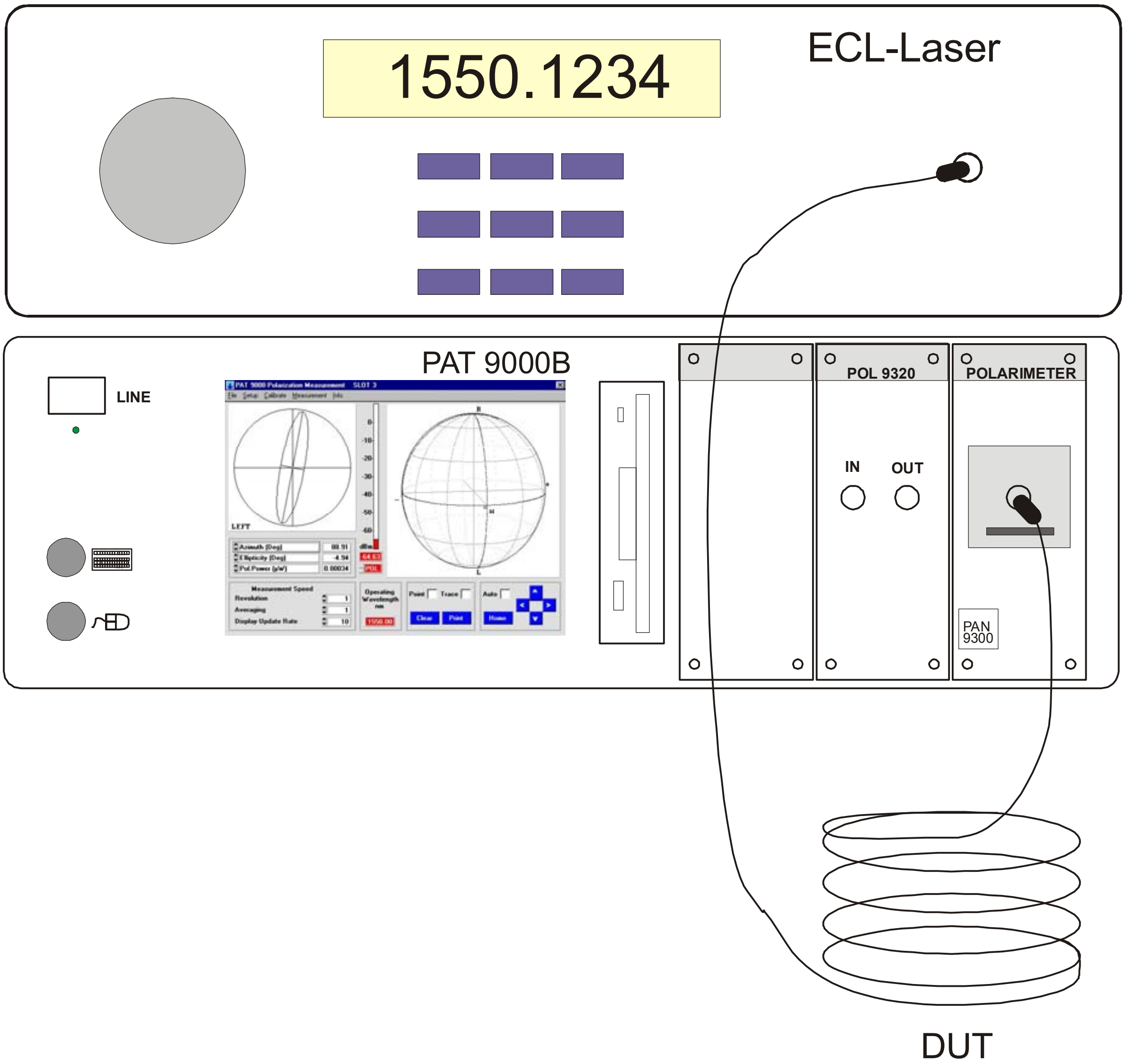

Figure 53 PMD set-up for 3 Stokes-Parameter method

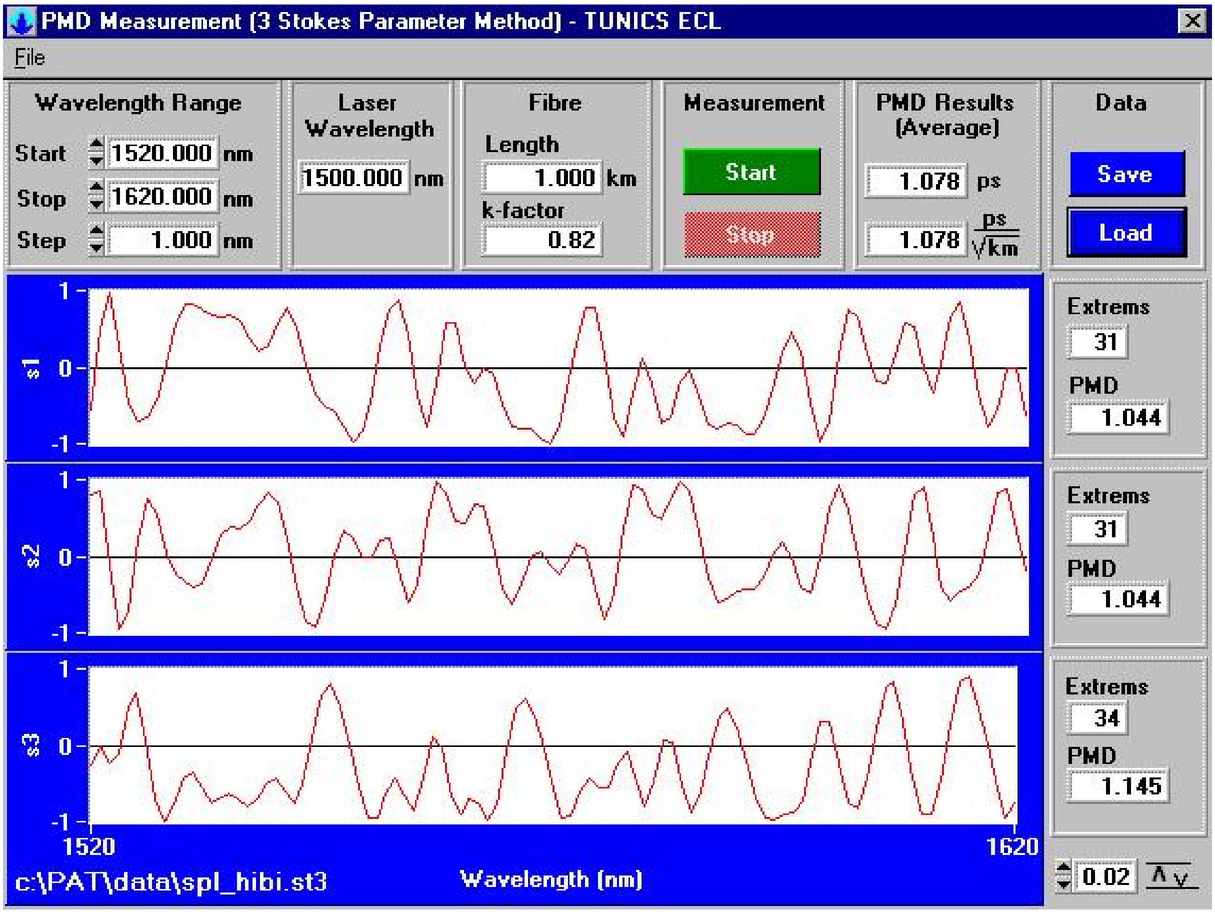

Figure 54 Screen display for 3 Stokes parameter wavelength scanning

Determining the wavelength range

Enter start- and stop wavelength of the desired tuning range in nm in the fields **'Start'** and **'Stop'**.

Select the tuning speed of the laser with **'Speed'**. For test devices with a high PMD select a low tuning speed. If the PMD of the device is low, a higher tuning speed can be used.

The following table gives some hints:

Expected PMD	Recommended tuning speed
0,1 ps	5 nm/s
1 ps	0,5 nm/s
10 ps	0,05 nm/s

Using lasers with discrete wavelength steps like the HP8167/8 models, the field '**Speed**' is replaced by '**Step**'.

For the determination of the wavelength step size the same considerations as in the Jones matrix PMD measurement apply (section 2.8.2). However, we recommend a smaller step size to smoothen the curves in the 3 diagrams.

'**Step**' determines the desired wavelength step.

Push the '**Start**' button to trigger a measurement. Depending on the type of laser the time needed for reaching the start wavelength and proceeding a wavelength step may differ.

'**Stop**' interrupts the measurement at any time.
The field '**Laser Wavelength**' displays the current wavelength of the laser source.

Detection threshold for extrema values

You can set a threshold value which decides whether an extrema is counted as valid or excluded since it is a measurement anomaly (e.g. be generated by some fiber movements). To exclude these anomalies a threshold for maximum and minimum values can be set. Only values within the allowed range are considered for the evaluation of the PMD value.
Under laboratory conditions we recommend a threshold of 0.02. The threshold must not be set too high to avoid that regular maximum or minimum values will be missed.
Enter the desired threshold value in the field ‘ΔΛ‘ in the lower right corner.

2.8.6.2 The k-factor

The theory behind this measurement technique requires a scaling factor, called k-factor. You can enter and modify this value in the field **‘k-factor’** on your own. The theoretical recommendations are:
k = 1: for fibers with low mode coupling (polarization maintaining or short fibers),
k = 0.82: for fibers with high mode coupling (very long standard fibers).
Please note that the real DUT might not match exactly with the statistical assumptions made in the theory. This is one reason why measurement results with this technique might differ from a result taken with the JME method.
The mean PMD value of the 3 Stokes parameter wavelength scanning rated with the k-factor depends less on the input state of polarization or the statistical mode coupling in the fiber than the PMD value measured by the Poincaré sphere method.

2.8.6.3 Measurement results

The measured values are continuously displayed in the three diagrams showing the Stokes parameters s1, s2 and s3 vs. wavelength for the device under test.
Already during and after the measurement of the Stokes vectors the PMD is calculated. The PMD calculation is done separately for each Stokes component (s_1,s_2,s_3) and then they are averaged. The individual PMD values are displayed at the right side of the corresponding diagram. The averaged PMD values is shown in the section PMD Results.

Especially in the case of a low number of extrema the three PMD values can differ significantly due to the low statistical significance of the data.

During the measurement the field **'PMD Results'** displays the numerical read out of the mean PMD value and the PMD coefficient scaled to the square root of the value entered in field length '**Length**'. Please remember that the scaling to Length (PMD coefficient [ps/√km]) makes only sense if the device under test is a long fiber with high mode coupling.

This measurement method does not yield the wavelength dependency of the PMD. The result is an average value for the totally covered wavelength range.
'**Save**' and '**Load**' stores or re-loads the measured data into or from a data file '*NAME*.ST3' on hard- or floppy disc.

The data have the following (ASCII) format:

```
PAT 9000B PMD 3-Stokes-Parameter-Measurement   Thorlabs
Date: 11-11-2001    Time: 15:20:01
[FIBER]
FIBER_LENGTH [km]:  20.000
[WAVELENGTH]
START        [nm]: 1530.00
STOP         [nm]: 1535.00
SPEED      [nm/s]:    0.50
POINTS           :      11
[PARAMETER]
K_FACTOR         :    0.90
DELTA_MM         :    0.03
[PMD_DATA]
PMD_AVG      [ps]:   7.846
PMD_SKM  [ps/skm]:   1.754
LAMBDA [nm]        s1          s2          s3,
   1530.00,      0.920,      0.391,     -0.015,
   1530.17,      0.931,     -0.330,      0.158,
   1530.32,      0.986,      0.133,      0.097,
...
```

The stored text files can be edited with any text editor or fed into a graphic or spread sheet program for further processing.

3 Communication with a PC

3.1.1 General information

This chapter describes the operation of the PAT 9000B via the IEEE 488 interface. The interface gives the following advantages:

- all essential functions can be programmed
- acquisition of all polarization, PDL and PMD data
- simple open language commands
- status reporting of all device parameters

The interface is ready for operation as the program PAT.EXE has been started and the main screen built up. In this state the communication with a PC can be established. Communication is also possible if further windows are opened.

When transmitting the first setting command (addressed as listener) or sending the first status request (addressed as talker) or by reception of an IEEE 488 control command PAT 9000B automatically enters remote mode. The present screen content is replaced by the window "PAT 9000B REMOTE" (Figure 57).

With the IEEE 488 interface the PAT 9000B can receive and transmit. The commands are given in simple open language.
Numerical values can be set in floating point notation or exponential form.

The command to set the operating wavelength, e.g. for 1300 nm, may be as follows:
"L 1300.00;" or **"L 1.3e3;"**
Transmission to the control unit uses the ASCII-code. Several commands can be combined in a string up to 250 characters long. A string of characters is terminated by <CR>, <LF> or by activating the <EOI> signal.
Preferably the <EOI> signal is used when the PC has finished data transmission. Please check about the setting of this parameter in the manual of your GPIB/IEEE 488 interface card.

NOTE

In REMOTE mode the operation via keyboard and mouse is deactivated. By clicking ‘Local’ or by pressing the Esc’ key ‘you can return back to manual operation.

3.2 IEEE 488 interface

The PAT 9000B is equipped with a IEEE488-9000 interface (for example to control an external tunable laser for PMD measurement). The corresponding standard 24-pin IEEE 488 jack is found on the rear panel.

IEEE 488 pre-settings

When the IEEE488-9000 interface is used, the PAT 9000B address must differ from the addresses of other units on the same bus.

The PAT 9000B is pre-set to the address 9 (Board 0, Address = 9).

End of line or end of sequence for PAT 9000B messages to the PC can be adapted by software. As default the <EOI> signal is activated. If your PC expects control characters <CR> and/or <LF> you can change it in the configuration of the PAT.

The data file " C:\PAT\PAT_GPIB.INI" contains all important parameters for the configuration of GPIB/IEEE 488 interface. The parameters in this file are read at each start of the main program. The present configuration can be edited in menu item 'Set-up / GPIB Configuration'.

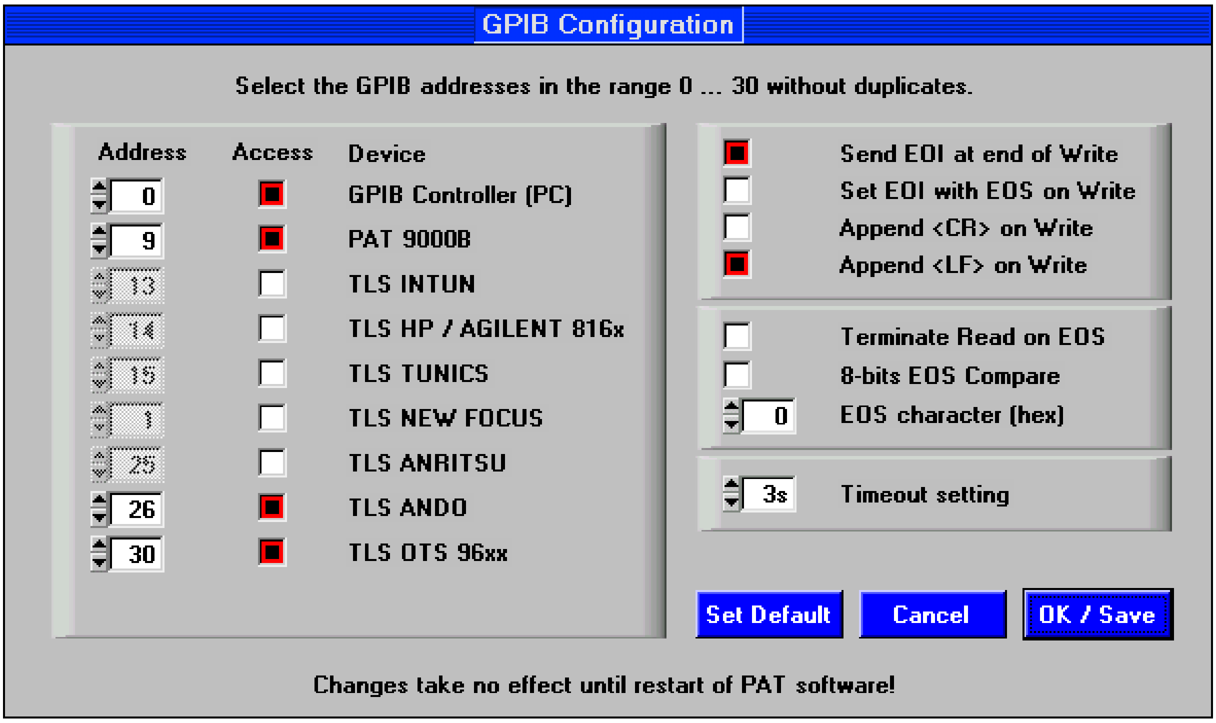

Figure 55 Screen for setting the GPIB communication parameters

3.2.1 Setting the IEEE 488 communication parameters

Select 'Set-up / GPIB Configuration'. The screen shown in Figure 55 appears.
The fields at the left side of the screen determine the units connected to the line to take part in the communication. '**Access**' toggles them between "ON" and "OFF". The corresponding addresses are entered at left. A deactivation of the PAT 9000B itself deactivates the GPIB card.
The GPIB controller is host PC. Activate the GPIB **'Access'** if you want to start data transfer to the PAT 9000B.

NOTES

Your PC software must ensure that after each addressing of the PAT 9000B as talker or listener and after communication end the addressing is annulled. (device unaddress = Yes). Configure your driver software accordingly or use the command ibconfig(pat_address, IbcUnAddr, 1) in your application program.

Please note that the PAT 9000B will need some seconds to enter remote mode and to measure complex parameters (e.g. Jones matrix with many averagings). Set the time-out-value of your IEEE 488 interface card to 'T10s' to tolerate possible waiting periods.

Activate the desired laser in the respective field. The PAT 9000B operates as controller for these lasers.
If you want to control an external laser and the PC communication on your own, a special situation occurs: two controllers (PAT and PC) will compete on the same data bus. To guarantee conflict free operation the PC program must fulfill the following requirements:

- it cannot have the controller function continuously
- it must transfer the controller function after each action (writing / reading) to the PAT 9000B (command pct = pass control)
- it has to request the controller function each time wanted (command rsc = request system control)

The PAT 9000B itself fulfills these conditions and passes its controller function by 'Pass control' back to the PC after each use of the common bus. Therefore the PAT 9000B must know the PC address.

If the PAT 9000B must have controller function (e.g. to control an external laser) with the PC not passing the function to the PAT 9000B, the following error message appears:

ERROR MESSAGE

PAT 9000B could not remotely control external laser source via GPIB

Another GPIB-Controller doesn't release System Control

Start another try? Yes / No

Have the IEEE 488 controller in your PC pass the controller function and select 'Yes'. The operation manual of your interface card tells you how to proceed. If you don't require the remote features of the PAT 9000B, don't connect the PC at all. If you select 'No' the PAT 9000B cannot establish connection to the external laser sources. All parts of the program (e.g. PMD) requiring these lasers will then be locked.
Starting the program the PAT 9000B examines whether all marked units are connected and displays the result in the configuration screen with 'Enable' or, if unsuccessful, with 'Disable' (Figure 56).

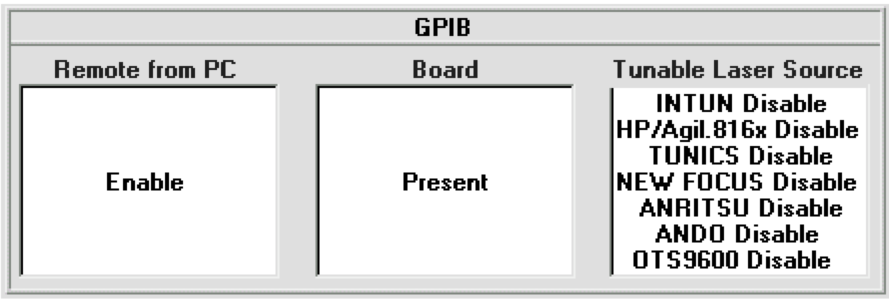

Figure 56 Detail of the PAT configuration screen

Setting the GPIB addresses
At left from the '**Access'** buttons are the address fields '**Address**' for the IEEE 488 bus participants'. All units marked must own an address between 0 and 30.
Every address must be used only once on the same bus.

PRE-SET ADDRESSES:

PC	0
PAT 9000B	9
INTUN	17
HP8167/8	24
TUNICS	16
NEW FOCUS	1
ANRITSU	25
ANDO	26

Should one of the units own an other address, change the device address or change the address set by the PAT 9000B.

IEEE 488 parameters for the PAT 9000B

With the PAT 9000B a lot of settings for communication with a PC and external lasers are possible:

Parameter	Effect	Pre-set value
Send EOI at end of Write	control line <EOI> is activated after each writing operation of the PAT 9000B	yes
Set EOI with EOS on Write	control line <EOI> is activated with EOS-Bytes occurring	no
Append <CR> on Write	append <CR> to each string from the PAT	no
Append <LF> on Write	Append <LF> to each string from the PAT	yes
Terminate Read on EOS	PAT ceases reading operation at EOS-Byte	no
8-bits EOS Compare	8-bit comparison with EOS-Byte	no
EOS character (hex)	Byte to mark 'End Of String'	0
Time-out setting	time limit for data transfer via the bus	3s

By choosing '**Set Default**' all parameters are set back to their initial state.

Save the settings

Use '**OK / Save'** to store changed parameters in the file 'PAT_GPIB.CFG'.

If you click '**Cancel**' all settings remain unchanged.

NOTE

Changes in the GPIB configuration will only become valid after program restart. In communication between PC and PAT 9000B any combination of string terminators <CR>, <LF> and confirmation of <EOI> line are valid.

The following IEEE 488 interface functions are implemented in the PAT 9000B:

- **Talker**
- **Listener**
- **Service Request**
- **Device Clear**
- **Device Trigger**

Set-Up of communication:

Connect the PAT 9000B, the control PC and all further units to the mains and connect the units to each other with shielded IEEE 488 connection cables.

To ensure error free data transfer the interconnecting cables between units should be no longer than 2 meters and the total cable length should be less than 20 meters.

Switch on all units connected to the bus.

After a set command (addressed as listener) or a read command(addressed as talker) the PAT 9000B automatically enters REMOTE mode.

Addressing the IEEE 488 interface of your PC depends on the interface card used and the installed driver software. Ask the hard- and software manual of your interface card for the correct commands to control the bus.

3.2.2 The remote screen

After a set-command (addressed as listener) or a read-command (addressed as talker) the PAT 9000B automatically enters REMOTE mode. The REMOTE screen according to Figure 57 appears.

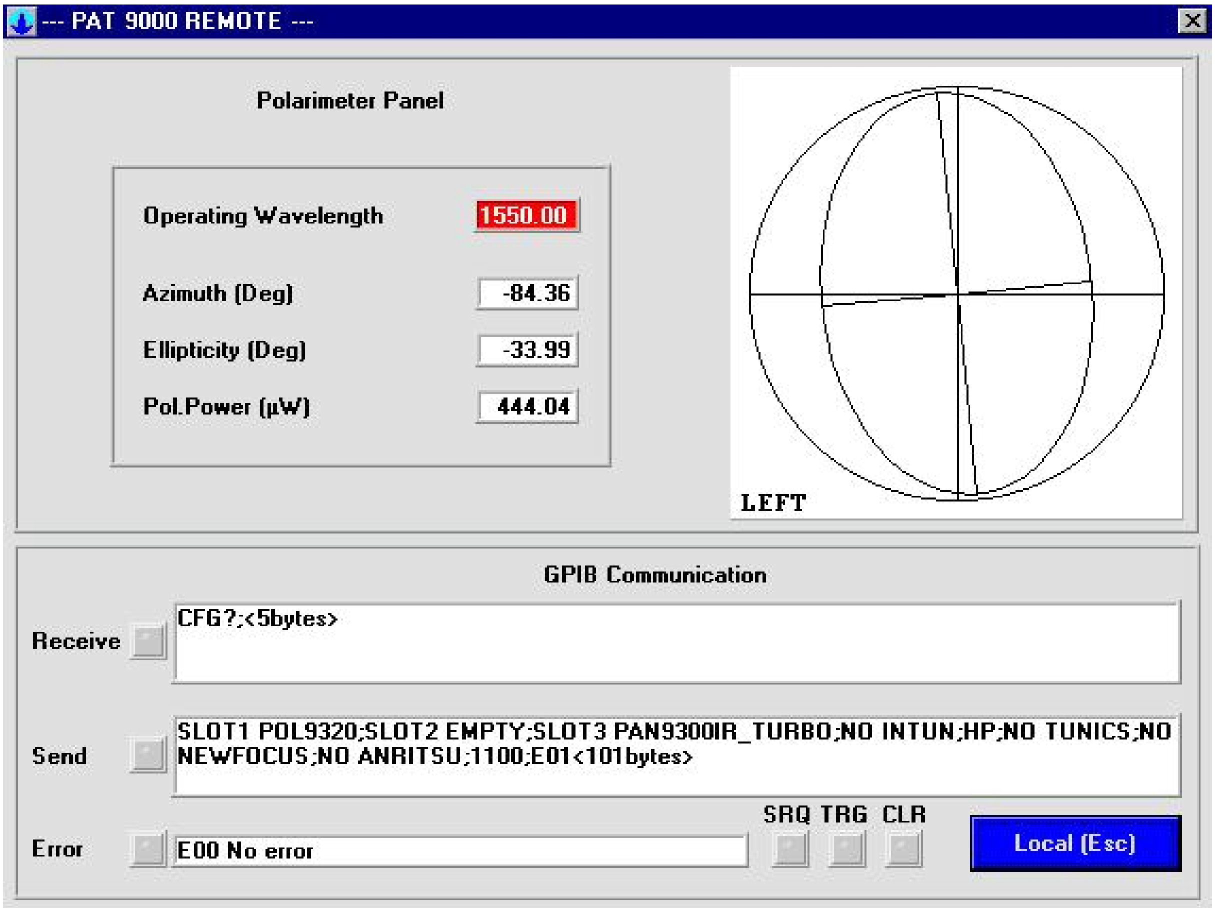

Figure 57 Screen of the PAT 9000B in remote mode

The upper half of the screen **'Polarimeter Panel'** gives the measured data of the active polarimeter module.

The field '**Operating Wavelength'** shows the operating wavelength. The value must coincide (if necessary, set via GPIB programming) with the radiation wavelength at the optical input.
The following three parameters (here azimuth, ellipticity and power) are the same as on the main screen, selected in "Setup/Parameter Selection". Their values - as well as the polarization ellipse – are for control of the measured polarization's.

The lower half of the screen '**GPIB Communication'** serves for monitoring and possible error detection of the data transfer.

If the PAT 9000B receives data on the bus the LED situated next will flash briefly. The character string is displayed in the field ‘**Receive**’.

If the PAT 9000B transmits a string it is displayed in the field ‘**Send**’. The corresponding LED flashes briefly. Non printable characters are shown in brackets, e.g. LF = [0x0a].

If during communication an error is detected, the field ‘**Error**’ will display the error number with a short description, e.g. „E05 Range error“. An error in a character string is displayed until a new one is received.

The LEDs ‘**TRG**’ and ‘**CLR**’ signalize receipt and display of an IEEE 488 control command [GET] or [DCL] or [SDC].

➔ (Refer to section 3.2.3).

The LED ‘**SRQ**’ lights up when the PAT 9000B has activated the SRQ signal.

➔ (Refer to section 3.2.4, "Service request commands" on page 127).

3.2.3 IEEE 488 bus commands

For communication via the IEEE 488 bus the standardized control signals [MLA], [MTA], [UNL], [UNT], [ATN], [REN], [SPE], [SPD] are used.
If you write control programs in a high level language, these IEEE 488 control signals are sent to the PAT 9000B by the driver used. You don't have to use them explicitly in your program.
On receipt of the IEEE 488 control commands [GET], [DCL] and [SDC] the PAT reacts as follows:

[GET] Group Execute Trigger
After the command [GET] all previous setting commands are executed (same as with the command "X;").

[DCL] Device Clear
The command [DCL] causes a reset of all programmable values, also of a user specific PAN calibration. Previous programming of the PAT 9000B is cancelled. The PAT 9000B remains in REMOTE mode.

NOTE

The command [DCL] resets all units connected to the IEEE 488 bus.

[SDC] Selected Device Clear
The command [SDC] causes a reset of all programmed values in the selected unit, also of a user specific PAN calibration (compare [DCL]). Previous programming of the PAT 9000B is cancelled. The PAT 9000B remains in REMOTE mode.

NOTE

In comparison to the command [DCL] the command [SDC] resets only the addressed units on the bus.

The commands [GTL] and [LLO] are not used by the PAT 9000B and have no effect.

3.2.4 Service request commands

The command "SRQ bbbbbbbb;" selects states where the PAT 9000B shall activate the SRQ line. The letter b stands for "0" or "1".

SRQ bbbbbbbb; SRQ is activated when:

Programming error occurs (error code other than 0)
a new PMD measurement is available
the complete PMD measurement is finished
the optical input power at the optical head is too high
signal wavelength or calibration incorrect (degree of polarization >100%)
not used
not used
not used

Pre-setting "0" or "1" determines whether the PAT 9000B activates the SRQ line of the IEEE488 bus when the respective condition is fulfilled. A "0" does not activate SRQ, a "1" it activates SRQ on condition fulfilled.

NOTE

The command "SRQ bbbbbbbb;" does not require the execution command "X;" or [GET].

Examples:

SRQ 00000100;	SRQ is activated when the PMD measurement is finished
SRQ 00001001;	SRQ is activated with too high optical power or programming error

The Serial Poll Byte

If the PAT 9000B releases a service request, a serial poll byte is generated the same time giving information about the event that started this service request.

Your PC you can read the serial poll byte. In binary notation it consists of 8 bits which either can be "0" or "1". If a bit is "1", the meaning is

bbbbbbbb

programming error (error code other than 0)

a new PMD measurement is available

the complete PMD measurement is finished

the optical input power at the optical head is too high

signal wavelength or calibration incorrect (degree of polarization >100%)

not used

cannot be used

not used

3.3 Set of commands

Control commands for the PAT 9000B are given in simple clear text. Numerical values can either be entered in floating point notation or in exponential form (= scientific notation). All settings can be made in small or capital letters. Each command must be followed by a semicolon ";". Several commands can be combined in a line and transmitted to the PAT 9000B at a time. The maximum string length up to a terminator is 250 characters.

Example: polarization measurement at 1535 nm

The following example shows a series of commands to prepare a polarization measurement at 1535 nm. The normalized Stokes parameters shall be read.

Command	Meaning
Y 1;<CR>	select polarimeter PAN 9300
L 1535.00;<CR>	set signal to 1535 nm
SB;<CR>	set the desired measurement values in group B
X;<CR> or **[GET]**	execute all previously set commands

Alternatively, all commands together in one line:

```
Y 1;L 1535.00;SB;X;<CR>
```

When addressing the PAT 9000B as talker (control PC sends reading command) the selected status message (here measurement value group B) is transmitted from PAT 9000B.

The string of characters transmitted looks e.g. as follows:

```
 S1 -0.348;S2  0.572;S3 -0.743;PDB -24.93;1100;
E00;<CR><LF>
```

Example: polarization measurement at 1550.8 nm and very low optical power

The following example shows a series of commands to prepare a polarization measurement at 1550.8 nm. The parameters to be read are elevation and ellipticity angle. Due to the low optical power several values for averaging have to be used.

Command	Meaning
Y 1;<CR>	select polarimeter PAN 9300
L 1550.80;<CR>	set signal to 1550.8 nm
R 16;	set number of revolutions for one measurement to 16
A 4;	set number of averagings for a single measurement to 4
SA;<CR>	set the desired measurement values to group A
X;<CR> or **[GET]**	execute all previously set commands

Alternatively, all commands in one line:

Y 1;L 1550.80;R 16;A 4;SA;X;<CR>

When addressing the PAT 9000B as a talker (PC sends a reading command) the selected status message (here measurement value group A) is transmitted from PAT 9000B.

The string of characters looks e.g. as follows:

AMT 46.920;ELL -18.597;POW 0.032;PDB44.95;0100
;E00;<CR><LF>

The following commands have the same meaning (setting the signal to 1300 nm)

L 1300; or L 1300.0; or L 1300.00; or L +1.3e+3; or
L 001300; or L 13e2;

If more than one similar command but with different parameters (e.g. "L 1300;L 1500;X;") are send preceding a software trigger command "X;" only the last command or the parameter of the last command (here 1500 nm) is executed. If a command is given incorrectly or does not make sense, e.g. the command "Y 1;" if no optical head PAN 9300 is inserted in the PAT 9000B the error message "Enn" with "nn" different from "00" appears at the next status request (e.g. here E12 No PAN-IR module error).

NOTE

Errors are only reported once at the next valid status request. Should several errors occurring the meantime, only the first one occurred is reported.

If entering several commands in a line and an error occurs, the incorrect command itself and all following commands are ignored.

In the description of commands the following signs mean:

a	sign (the positive sign can be omitted)
n	digit of a decimal number (0 ... 9)
d	numerical value in floating point or scientific notation
b	0 or 1
.	decimal point
;	command terminator
[ ]	IEEE 488 bus command

3.3.1 Setting of the polarimeter module

PAN d; **Selecting the polarimeter slot of the PAT 9000B**

with: d = 1 slot 1 (at left)
d = 2 slot 2 (in the middle)
d = 3 slot 3 (at right)

If the desired polarimeter module is not available in the given slot, the next status request will show the error message "E09".

Y b; **Selecting the type of polarimeter**

with: b = 1 PAN 9300 (960 ... 1700 nm)

If several polarimeters of same type are inserted in the PAT 9000B, the slot with the lowest number is monitored (1^{st} from left). If the desired polarimeter module is not available in any of the slots, the error message "E12, E46 or E47" will appear at the next status request.

L d; Setting the operation wavelength

with: d = 960.00 ... 1700.00 (PAN 9300NIR/FIR)

NOTES

The wavelength of the light source used must be set in nm to ensure precise measurements.

An incorrect wavelength set will lead to incorrect polarization data, Jones matrix and PDL values.

For PMD measurements it is not necessary to pre-set a wavelength since the PAT 9000B recognizes the respective wavelength of the PMD laser.

The error "E08" can only be recognized in certain cases by the PAT 9000B.

O d; **Setting an offset for the azimuth angle**

with: d = -90.00 ... 90.00

With "O d;" the x-y co-ordinate system of the optical head can be reset. From factory, the horizontal edge of the optical head is identical with the x-axis (theta=0°).

`R d;` **Setting the revolution frequency**
with: d = 0/1/2/4/8/16

With "R d;" the number of revolutions of the λ/4-waveplate, serving for data acquisition, is chosen. A "0" means half a revolution, the fastest operating mode.

NOTES:

This command can be used to influence measurement speed. Furthermore, a high number of revolutions serves for noise suppression at very low optical powers to increase measurement accuracy.

Remember that a high number of revolutions increases the time required to deliver the status request. The PC must guarantee a safe reception of the status message by a correspondingly high TIMEOUT-value.

`A d;` **Setting the averaging**
with: d = 1/2/4/8/16

With "A d;" the number of averaged values for a single measurement is set.

NOTES

This command influences the measurement speed.
The higher the value the longer the measurement will take.

A high number of averaged values reduces noise in the acquired data at very low optical power.

Remember that a higher averaging increases the time until a status request is released. The PC must guarantee a safe reception of the status message by a correspondingly high TIMEOUT-value.

D b; **Operate the input amplifier in AC or DC mode**

with: b = 0: DC
b = 1: AC

This influences the analogue signal processing in the optical head of the PAN 9300. Besides the automatic switch-over for certain measurements a manual switch-over might be useful in the following cases:

1. If the polarization is measured with strongly fluctuating optical power or with rapid changing polarization the setting b = 0 (DC) is favorable.
2. If high optical power at the upper limit of the PAN optical head is to be recorded, select b = 1 (AC).

NOTE

If the parameters DOP, the total optical power SO, PDL, Jones matrix and PMD are to be measured, a switch-over to DC is done automatically.

T b; **Setting the turbo mode**

with: b = 0: turbo mode off
b = 1: turbo mode on

The turbo mode can only be activated if the turbo mode software option is activated for this PAN head.

P_LOW_LIM d; **Set the lower power limit for measurements**

with: d= -100.0 ... –30.0 dBm

Measurements are stopped, when the input power (in any polarization) falls below this limit . Values measured up to then can be stored for further processing.

3.3.2 Loading a PAN calibration data set

If the PAN calibration has been changed by a user calibration, there is the possibility to reload the "original" calibration file, or to load a specific user calibration file.

`LOAD_CAL filename;` The filename must only contain 8 digits, a...z, 0...9, _ or -.
If 'filename' contains an invalid figure, the error "E04, Data format error" is given.

3.3.3 Setting the polarizer module

`POL d;` **Selecting the polarizer slot**

with: d = 1 slot 1 (at left)
d = 2 slot 2 (in the middle)
d = 3 slot 3 (at right)

If no polarizer module is installed in the desired slot of the PAT 9000B at the error message "E10" appears with the next status request.

`POS d;` **Setting the polarizer position**

with: d = 0, 0.18, 0.36 ... 179.82°

The polarizer position can only be set in steps of 0.18°. However, also values in-between are accepted but are rounded of to the next multiple value of 0.18°.

3.3.4 Remote ER-measurements

`L d;` **Set the wavelength for the PAN-module.**

Prior to an extinction ratio measurement, the wavelength for the PAN module calibration must be entered in nm, e.g. **`"L 1550.0"`**.

`ER_TIME d;` **Set the ER measurement time.**

The extinction ratio measurement time is set in seconds and can range from 1 to 20 seconds. The default value is 3 seconds. E.g. **`"ER_TIME 10.0;"`**

`ER_START;` **Starts the extinction ratio measurement.**

`ER_VALUE?;` **Queries the measured ER value.**

A query while the ER measurement is running results in:

"ER_BUSY, <Status>,<Error code>"

But you can enter this query prior to an ER measurement, so the resulting ER value signalizes simultaneously the end of the measurement.

Valid ER-values show up as e.g.:

"ER 23.4dB,<Status>,<Error_code>"

If any error occurred during measurement you will receive:

"ER_NOT_VALID,<Status>,<Error_code>"

3.3.5 Preparing a PDL measurement

`PO;` **Optimizing the polarizer position in the module POL 9320**

Prior to a PMD- or PDL measurement it is recommended to optimize the position of the polarizer in the module POL 9320. This ensures sufficient optical power for the three different states of polarization.

If the command "PO;" is used without a POL 9320 module available the error message "E10" appears.

NOTE

The command will clear a reference-Jones matrix possibly stored before.

In PMD measurements with the Jones matrix technique this optimization is done automatically.

`PR;` **Measuring a reference matrix**

The Jones matrix of the set-up between polarizer module and polarimeter module at the time of measurement is calculated and stored as reference matrix.

NOTE

With all following PMD- and PDL-measurements according to the Jones matrix eigenanalysis the reference measurement is used , i.e. the command "K 1;" must not be executed explicitly.

`K b;` **Considering a Jones reference matrix**

with: b = 0: measurement without reference matrix
b = 1: measurement with reference matrix

This command can be used to toggle the consideration of the reference matrix in PMD- and PDL-measurements according to the Jones matrix eigenanalysis.

3.3.6 Preparing a PMD measurement

`PMD_TYP d;` **Select PMD measurement**

with: d = 1: Jones matrix eigenanalysis
d = 2: circular arc technique
d = 3: 3-Stokes parameter wavelength scanning
d = 4: Jones Matrix high resolution measurement

Depending on the measurement technique selected (d = 1 ... 4) further commands are necessary:

`WAVE_START d; WAVE_STOP d;` (for all measurement techniques)

`WAVE_STEP d;` (for measurement techniques 1 and 2) (also for measurement technique 3, if the laser is not suited for continuous wavelength scanning)

`WAVE_SPEED d; DELTA d; K_FACTOR d;`
(for measurement technique 3)

The following command is possible for all measurement techniques: **`LENGTH d;`**

NOTE

For the Jones matrix eigenanalysis a polarizer module POL 9320 is necessary. If the module is not available, the next status request will display the error message "E10".

`WAVE_START d;` **Start wavelength of measurement range**

The value range for d depends on the provided laser source. Values are set with a maximum of two digits following the decimal point.

The program takes the minimum wavelength from the data file "intu_dat.cfg". This value can be read out with the command "LASER_MIN?;". If d is outside this range the next status request will display the error message "E05".

`WAVE_STOP d;` **Stop wavelength of measurement range**

The value range for d depends on the provided laser source. The value must be higher than the programmed value for "WAVE_START". The setting is in nm with a maximum of two digits following the decimal point.

The program takes the maximum wavelengths from the data file "intu_dat.cfg". This value can be read out with the command "LASER_MAX?;". If d is outside this range the next status request will displays the error message "E05".

`WAVE_STEP d;` **Wavelength step**

with: d = 0.01 ... (WAVE_STOP - WAVE_START)

The value range is between 0.01 nm and the difference between stop- and start wavelength and must be stated with a maximum of two decimal digits.

The command determines the discrete wavelength-steps used for the Jones-matrix analysis. To measure correct PMD values the wavelength step must be in consent with the expected PMD of the device under test.

The programming of the wavelength steps is only required for the measurement techniques Jones matrix and circular arc.

Automatic step size adaptation:

If "WAVE_STEP 0"; is set, the PAT 9000B turns to automatic step size adaptation mode

➔ (refer to Chap. 2.3.2).

WAVE_SPEED d; **Scan speed**

with: d = 0.01 ... 5

The value range is between 0.01 nm/s and 5 nm/s. The value is entered with a maximum of two decimal digits.

This command is set to determine the scanning speed of the wavelength. With devices with a high PMD the speed must not be selected too high. A speed selected too low will increase the required measurement time unnecessarily.

If for the 3 Stokes parameter PMD measurement a laser is used not allowing continuous wavelength scanning, use 'WAVE_STEP' instead of 'WAVE_SPEED'.

DELTA d; **Definition of extreme values (only for 3 Stokes wavelength-scanning)**

with: d = 0.01 ... 2.0

Recommendation: "d = 0.02" if unfavorable measurement conditions are given (vibrations or LWL movements) a higher value, e.g. "0.1", should be set.

With the 3 Stokes wavelength scanning DELTA is the threshold for the definition of an extreme value when measuring the Stokes parameters.

K_FACTOR d; **Mode coupling degree (only for 3 Stokes wavelength scanning)**

with: d = 0.1 ... 2.0

d = 1.0	no mode coupling (e.g. with PM fibers)
d = 0.82	high mode coupling (e.g. in long standard fibers)
d = 0.9	average mode coupling (e.g. in short standard fibers)

With the 3 Stokes wavelength scanning the K_FACTOR is decisive for the comparison of the measured results to those of other PMD techniques. The correct value will depend on the degree of mode coupling in the device under test.

`LENGTH d;` **Setting the fiber length**

with: d = 0.001 ... 1000.0

If the PMD results of long fibers are to be read out directly in ps/√km the fiber length must be set. The calculation is done by the mean square value (RMS) or the average value with the 3 Stokes parameter technique. If no value is programmed for LENGTH, "PMD_SKM?"; "0.0" is read out at the status request.

`PMD_DELAY nn.n;` **Setting the laser delay in seconds (e.g. 10.0) for EDFA measurements**

3.3.7 Starting a PMD measurement

`PMD_START;` **Starts the PMD measurement procedure**

This command starts the PMD measurement. At first all relevant parameters for the measurement are checked with regard to correctness and completeness.
Possible errors are given with the next status request.

3.3.8 Selecting the PMD laser

`PMD_LAS d;` **Selects the active laser for PMD measurements**

with:
- d = 4 external laser INTUN
- d = 5 external laser HP
- d = 6 external laser TUNICS
- d = 7 external laser NEW FOCUS
- d = 8 external laser ANRITSU
- d = 9 external laser ANDO

A laser module is only be allowed for PMD measurements if it has a wavelength tuning range of >=0.02 nm.

NOTE

> The laser module marked d becomes the active laser module.

3.3.9 Enable raw data storage

`PMD_RAW 1;` **Enable raw data storage (s1,s2,s3.DOP,p_pol,p_unpol,S0)**

`PMD_RAW 0;` **Disable raw data storage**

The raw data are stored in the file "PMD_MEAS.RAW

3.4 Reading commands

The PAT 9000B can send different status messages. These contain one or several measured values, the device status code of the PAT 9000B and the error code.
The desired status message is selected with the following commands:
"**CFG?**;" for the PAT configuration;
"**SA;**" "**SB;**" "**SC;**" "**SD;**" "**SE;**" "**S0;**" or "**SS d;**" with "d=0 ... 13" for a polarizer module.
The transmission of the requested status messages via the IEEE 488 interface is triggered by addressing the PAT 9000B as talker [MTA] and by activating the ATN line.
With each status request the previously selected status with the present measurement result is transmitted.

NOTE

Status requests do not require any further execution command "X;".

When no command request is programmed the status "S0;" follows the status request.
The IEEE 488 commands [DCL] and [SDC] cause a reset of the programmed status to the pre-set status "S0;".

The device status code

All strings transmitted contain the device status code. The device status "nnnn" is coded as a 4-digit number as follows:
n1n2n3n4
n4: 0/1: active type of PAN module (0 = VIS; 1 = IR)
n3: 0/1: AC/DC-operating mode (0 = DC; 1 = AC)
n2: 0/1: TURBO mode (0 = off; 1 = on)
n1: 0/1: reference Jones matrix stored (0 = no; 1 = yes)

NOTE

Some error messages can serve to activate the SRQ line. The activation of the SRQ is set with the command "SRQ bbbbbbbb".

➔ (Refer to section 3.2.4, "Service request commands" on page 127)

CFG?; **Status request of the PAT 9000B configuration**

After receipt of the status command "CFG?;" the PAT 9000B sends at each following status request the actual configuration of the PAT 9000B including the connected external laser, the device status code of the PAT 9000B, the error code and finally the set string terminator.

The transmitted character string looks like this:

SLOT1 *string1;* SLOT2 *string2;* SLOT3 *string3; intun_string;hp_string;tunics_string;newfocus_string;anritsu_string;ando_string;*nnnn;Enn;<EC>

with:	***string1/2/3***	string of characters to identify a module. Possible strings are PAN9300IR_NORMAL PAN9300IR_TURBO POL9320 EMPTY
	intun_string	string for external laser INTUN, possible are: INTUN / NO_INTUN
	***hp_string*s**	string for external laser HP, possible are: HP / NO_HP
	tunics_string	string for external Tunics laser TUNICS / NO_TUNICS
	newfocus_string	string for external NewFocus laser NEWFOCUS / NO_NEWFOCUS
	anritsu_string	string for external Anritsu laser ANRITSU / NO_ANRITSU
	ando_string	string for external ANDO laser ANDO / NO_ANDO
	nnnn	device status code
	Enn	error code
	<EC>	string terminator

3.4.1 Reading commands for polarization measurements

SS d; **Status request of a single polarization measurement value**

with: d = 0/1/2/.../14

After receiving the status command "SS d;" the PAT 9000B transmits on each following status requests the desired measurement value, the device status code of the PAT 9000B, the error code and the selected string terminator.

The string is transmitted as follows:

VALnn annn.nnn;nnnn;Enn;<EC>

with:		
	VALnn	desired measurement value corresponding d.
	nnnn	device status code
	Enn	error code
	<EC>	string terminator

The command "SS d;" (d=0/.../14) enables the reading of all available polarization values.

SS d;	Parameter	Description	String of characters
SS 0;	theta	elevation angle θ	VAL00 annnn.nnn;nnnn;Enn;<EC>
SS 1;	eta	ellipticity angle η	VAL01 annnn.nnn;nnnn;Enn;<EC>
SS 2;		axis ratio tan | η |	VAL02 annnn.nnn;nnnn;Enn;<EC>
SS 3;	DOP	degree of polarization DOP	VAL03 annnn.nnn;nnnn;Enn;<EC>
SS 4;	tan_psi	tan ψ	VAL04 annnn.nnn;nnnn;Enn;<EC>
SS 5;	aa	power ratio a	VAL05 annnn.nnn;nnnn;Enn;<EC>
SS 6;	delta	phase difference Δ	VAL06 annnn.nnn;nnnn;Enn;<EC>
SS 7;	P_pol	polarized power P_{pol}	VAL07 annnn.nnn;nnnn;Enn;<EC>
SS 8;	ext_rat	extinction ratio ER	VAL08 annnn.nnn;nnnn;Enn;<EC>
SS 9;	s1	normalized Stokes parameter S_1	VAL09 annnn.nnn;nnnn;Enn;<EC>
SS 10;	s2	normalized Stokes parameter S_2	VAL10 annnn.nnn;nnnn;Enn;<EC>
SS 11;	s3	normalized Stokes parameter S_3	VAL11 annnn.nnn;nnnn;Enn;<EC>
SS 12;	P_pol_dbm	polarized power (dBm)	VAL12 annnn.nnn;nnnn;Enn;<EC>
SS 13;	S0_dbm	total power	VAL13 annnn.nnn;nnnn;Enn;<EC>
SS 14;	P_unpol_dBm	unpolarized power(dBm)	VAL14 annnn.nnn;nnnn;Enn;<EC>

S0; **Status request of all available polarization measurement values**

After receiving the status command "S0;", after starting the program or after [DCL] and [SDC] the PAT 9000B transmits on each following status request all available measurement values, the status code of the selected polarimeter module, the error code and finally the selected string terminator.

The string is transmitted as follows:

VAL00 annnn.nnn;VAL01 annnn.nnn;VAL02 annnn.nnn;
VAL03 annnn.nnn;VAL04 annnn.nnn;VAL05 annnn.nnn;
VAL06 annnn.nnn;VAL07 annnn.nnn;VAL08 annnn.nnn;
VAL08 annnn.nnn;VAL09 annnn.nnn;VAL10 annnn.nnn;
VAL11 annnn.nnn;VAL12 annnn.nnn;VAL13 annnn.nnn;
VAL14 annnn.nnn;nnnn;Enn;<EC>

with: **VALnn** measurement value
➔ (refer to section 2.3.2)
nnnn device status code
Enn error code
<EC> selected string terminator

The two digit number "VAL" is identical to those number used with the status request of a single polarization value.

SA; Status request of polarization measurement values (group A)

Group A contains the following polarization measurement values:
Azimuth (Deg), ellipticity (Deg), power (µW), power (dBm)

After receiving the status request "SA;" the PAT 9000B sends on each following status request the desired four measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator.
The string is transmitted as follows:

AMT ann.nnn;ELL ann.nnn;POW nnnn.nnn;PDB ann.nn;
nnnn;Enn;<EC>

with: **AMT** elevation angle in degrees
ELL ellipticity angle in degrees
POW polarized optical power in µW
PDB polarized optical power in dBm
nnnn device status code
Enn error code
<EC> selected string terminator

`SB;` Status request of polarization measurement values (group B)

Group B contains the following polarization measurement values:

s1, s2, s3, Power (dBm)

After receiving the status command "SB;" the PAT 9000B transmits on each following status request the desired four measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator. The string is transmitted as follows:

`S1 an.nnn;S2 an.nnn;S3 an.nnn;PDB ann.nn;`
`nnnn;Enn;<EC>`

with:

S1	normalized Stokes parameter s_1
S2	normalized Stokes parameter s_2
S3	normalized Stokes parameter s_3
PDB	polarized optical power in dBm
nnnn	device status code
Enn	error code
<EC>	selected string terminator

SC; **Status request of polarization measurement values (group C)**

Group C contains the following polarization measurement values:

Power-split-ratio a , DELTA (Deg), TAN (PSI), power (dBm)

After receiving the status command "SC;" the PAT 9000B transmits on each following status request the desired four measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator. The string is transmitted as follows:

PSR n.nnn;DEL annn.nnn;TAN nn.nnn;PDB ann.nn;
nnnn;Enn;<EC>

with:
- **PSR** power ratio a
- **DEL** phase difference Delta in degrees
- **TAN** tan ψ
- **PDB** polarized optical power in dBm
- **nnnn** device status code
- **Enn** error code
- **<EC>** selected string terminator

SD; **Status request of polarization measurement values (group D)**

Group D contains the following polarization measurement values:

Azimuth (Deg), ratio of axis , extinction ratio (dB), power (dBm)

After receiving the status command "SD;" the PAT 9000B transmits on each following status request the desired four measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator. The string is transmitted as follows:

AMT ann.nn;ROA n.nnn;ER nn.nnn;PDB ann.nn;
nnnn;Enn;<EC>

with:
- **AMT** elevation angle in degrees
- **ROA** axes ratio
- **ER** extinction ratio in dB
- **PDB** polarized optical power in dBm
- **nnnn** device status code
- **Enn** error code
- **<EC>** selected string terminator

SE; **Status request of polarization measurement values (group E)**

Group E contains the following polarization measurement values:

Degree of Pol. (%), Power (µW), Power (dBm), S0

After receiving the status command "SE;" the PAT 9000B transmits on each following status request the desired four measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator. The string is transmitted as follows:

DOP nnn.nn;POW annnn.nn;PDB ann.nn;S0 an.nnn; nnnn;Enn;<EC>

with:
- **DOP** degree of polarization in %
- **POW** polarized optical power in µW
- **PDB** polarized optical power in dBm
- **S0** total optical power
- **nnnn** device status code
- **Enn** error code
- **<EC>** selected string terminator

3.4.2 Reading commands for PDL and Jones matrix measurements

PDL; Status request of PDL and phase

After receiving the status command "PDL;" the PAT 9000B transmits on each following state-request the desired measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator.

The string is transmitted as follows:

PDL nn.nnn;PHA annn.nnn;RET nnnn.nn;nnnn;Enn;<EC>

with:
- **PDL** polarization depending attenuation in dB
- **PHA** phase difference of the Jones matrix eigenvalues in degrees
- **RET** retardation (0 ... lambda)
- **nnnn** device status code
- **Enn** error code
- **<EC>** selected string terminator

If a reference Jones matrix was measured previously using the command "PR;" this is automatically considered.

JM; Status request of the Jones matrix

After receiving the status command "JM" the PAT 9000B transmits on each following status request the desired measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator.

The string is transmitted as follows:

J[11] n.nnn annn.nnn; J[12] n.nnn annn.nnn; J[21] n.nnn annn.nnn; J[22] n.nnn; annn.nnn;nnnn;Enn;<EC>

with:
- **J[11]** Jones matrix element: modulus phase (degrees)
- **J[12]** Jones matrix element: modulus phase (degrees)
- **J[21]** Jones matrix element: modulus phase (degrees)
- **J[22]** Jones matrix element: modulus phase (degrees)
- **nnnn** device status code
- **Enn** error code
- **<EC>** selected string terminator

If a reference Jones matrix was measured previously, this is automatically considered.

JME; **Status request of the eigenvalues and eigenvectors of the Jones matrix**

After receiving the status command "JME;" the PAT 9000B transmits on each following status request the desired measurement values, the status of the selected polarimeter module, the error code and finally the selected string terminator.

The string is transmitted as follows:

EVAL1 nn.nnn annn.nnn;EVAL2 nn.nnn annn.nnn;EVEC1 ann.nn annn.nn;EVEC2 ann.nn annn.nn;nnnn;Enn;<EC>

with:

EVAL1	eigenvalue1: modulus		phase (degrees)
EVAL2	eigenvalue2: modulus		phase (degrees)
EVEC1	eigenvector 1:	elevation angle	ellipticity angle (degrees)
EVEC2	eigenvector 2:	elevation angle	ellipticity angle (degrees)
nnnn	device status code		
Enn	error code		
<EC>	selected string terminator		

The eigenvectors are not read out in form of complex Jones vectors.

If a reference Jones matrix was measured previously, this is automatically taken into account.

3.4.3 Reading commands before or after a PMD measurement

LASER_MIN?; **Wavelength limit of the tunable laser**

After being addressed as talker the PAT 9000B sends the lower limit of the wavelength range of the active PMD laser.

The string is transmitted as follows:

WMIN nnnn.nn;nnnn;Enn;<EC>

with:	**WMIN**	minimum possible laser wavelength in nm
	nnnn	device status code
	Enn	Error code
	<EC>	selected string terminator

The PAT 9000B takes the value "WMIN" from the data file „intu_dat.cfg“.

LASER_MAX?; **Wavelength limit of the tunable laser**

After being addressed as talker the PAT 9000B transmits the upper limit of the wavelength range of the active PMD laser.

The string is transmitted as follows:

WMAX nnnn.nn;nnnn;Enn;<EC>

with:	**WMAX**	maximum possible laser wavelength in nm
	nnnn	device status code
	Enn	error code
	<EC>	selected string terminator

The PAT 9000B reads the value "WMAX" from the data file „intu_dat.cfg“.

3.4.4 Status request during PMD measurement

A PMD measurement in progress, data regarding the previous measurement can be requested through a reading procedure (addressing the PAT 9000B as talker)
With the PMD measurement techniques 1 and 2 (Jones matrix eigenanalysis and arc angle technique) the string looks as follows:

CNTnnn;WAVEnnnn.nn;DISPnnnn.nnn;AVGnnnn.nnn;RMSnnnn.nnn;nnnn;Enn;<EC>

with:

CNT	number of previous PMD measurement points
WAVE	wavelength of previous measurement point in nm
DISP	PMD of the last measurement point in ps
AVG	mean value of all measured points in ps
RMS	rms PMD value of all measured points in ps
nnnn	device status code
Enn	error code
<EC>	selected string terminator

With the PMD measurement 3 (3 Stokes parameter technique) the string is transmitted as follows:

CNTnnn;WAVEnnnn.nn;S1an.nnn;S2an.nnn;S3an.nnn;AVGnnnn.nnn;RMSnnnn.nnn;nnnn;Enn;<EC>

with:

CNT	number of previous PMD measurement points (s1, s2, s3)
WAVE	wavelength of the last measurement point in nm
S1	measured Stokes parameter s1 of the last measured point
S2	measured Stokes parameter s2 of the last measured point
S3	measured Stokes parameter s3 of the last measured point
AVG	mean value of all measured points in ps
RMS	rms PMD value of all measured points in ps
nnnn	device status code
Enn	error code
<EC>	selected string terminator

3.4.5 Reading commands after a remote PMD measurement

PMD_AVG?; **Requesting the mean PMD value**

With the measurement techniques 1 and 2 (Jones matrix eigenanalysis and Poincaré sphere technique) the mean PMD value of all measured points DGD(λ) is calculated and read out.

With the measurement technique 3 (3 Stokes parameter technique) it is only possible to state one value describing the average PMD in this wavelength range.

The read out is given in ps.

The string is transmitted as follows:

AVG nnnn.nnn;nnnn;Enn;<EC>

with:

AVG	**"AVERAGE"**
nnnn.nnn	mean PMD value in ps
nnnn	device status code
Enn	error code
<EC>	set terminator

PMD_RMS?; **RMS PMD value**

With the measurement techniques 1 and 2 (Jones matrix eigenanalysis and circular arc technique) the rms PMD value of all measured points DGD(λ) is calculated and read out.

With the measurement technique 3 (3 Stokes parameter technique) the mean value (same as with PMD_AVG?;) is read out. The value is given in ps.

The string is transmitted as follows:

RMS nnnn.nnn;nnnn;Enn;<EC>

with:

RMS	**"Root mean square"**
nnnn.nnn	mean square value of the PMD in ps
nnnn	device status code
Enn	error code
<EC>	selected string terminator

`PMD_SKM?;` **Mean square value per √ km**

For devices under test with a dependency PMD ∝ √km (e.g. very long standard fiber). The read out is given in ps/√km.
A value can only be given if, prior to the start of the PMD measurement, a valid value for LENGTH has been programmed, otherwise 0.0 is read out.
With the measurement techniques 1 and 2 (Jones matrix eigenanalysis and arc angle technique) the rms PMD value of all measured points DGD(λ) is divided by √(LENGTH) and read out. With the measurement technique 3 (3 Stokes parameter technique) the mean PMD value of PMD_AVG?; is divided by √(LENGTH) and read out.
The string is transmitted as follows:

`SKM nnnn.nnn;nnnn;Enn;<EC>`

with: **`SKM`**

`nnnn.nnn`	length related rms PMD value in ps/√km
`nnnn`	device status code
`Enn`	error code
`<EC>`	selected string terminator

EXTREMES?; **Number of extreme values (only with 3 Stokes parameter measurement)**

For each Stokes parameter s1, s2 and s3 the number of extreme values (maximum and minimum values) is read out.

The string is transmitted as follows:

EX1 nnn;EX2 nnn;EX3 nnn;nnnn;Enn;<EC>

with:

EX1	number of extreme values for s1
EX2	number of extreme values for s2
EX2	number of extreme values for s3
nnnn	device status code
Enn	error code
<EC>	selected string terminator

PMD_FILE?; **PMD data in form of a file (*.pmd)**

PMD_HIR_FILE?; **PMD high resolution data in form of a file (*.hir)**

If a valid file of the previous measurement is available, this is read out completely. Since the file contains several <CR> and <LF> characters and may be very long, the request with the IEEE488 function "ibrd" is unfavorable. We recommend the function "ibrdf" (ReadFile).

The file has, depending on the measurement technique, the same format as those files stored with a PAT 9000B without GPIB/IEEE 488 interface

➔ (refer to 2.8.5.4, "Measurement results" on page 107).

The high resolution data contains the smoothed data. If these calculations are not sufficient accurate, the file contains the message "PMD uncertainties too high! No HiRes calculation possible!"

3.4.6 Loading the raw data file 'PMD_MEAS.RAW'

PMD_RAW *FILE?;* *Read the raw data file into the buffer and display the values (s1,s2,s3,DOP,ppol,p_unpol,S0)*

3.5 List of commands

Description	Data	Command
Setting of polarimeter PAN 9300:		
POLARIMETER select slot	d = 1/2/3	**PAN d;**
TYPE OF POLARIMETER	b = 1	**Y b;**
WAVELENGTH	d in nm	**L d;**
THETA_OFFSET	d in °	**O ad;**
REVOLUTIONS	d = 0/1/2/4/8/16	**R d;**
AVERAGING	d = 1/2/4/8/16	**A d;**
AC/DC MODE	b = 0/1	**D b;**
TURBO MODE	b = 0/1	**T b;**
REFERENCE JONES-MATRIX	b = 0/1	**K b;**
OPTIMIZE POL. POSITION	none	**PO;**
MEASURING REFERENCE-JM	none	**PR;**
LOAD CALIBRATION DATA	filename	**Load_CAL filename;**
SET POWER LIMIT	d=-100.0 ... –30.0 dBm	**P_LOW_LIM d;**
Set polarization of POL 9320		
POLARIZER select slot	d = 1/2/3	**POL d;**
POLARIZER position in degree	d = 0 ... 179.82	**POS d;**
Executing commands:		
EXECUTING COMMANDS	none	**X;** or **[GET]**
Preparing status message:		
CONFIGURATION	none	**CFG?;**
ALL MEASUREMENT VALUES	none	**S0;**
SINGLE MEASUREMENT VALUE	d = 0/../14	**SS d;**
MEASUREMENT VALUE GROUP A	none	**SA;**
MEASUREMENT VALUE GROUP B	none	**SB;**
MEASUREMENT VALUE GROUP C	none	**SC;**
MEASUREMENT VALUE GROUP D	none	**SD;**
MEASUREMENT VALUE GROUP E	none	**SE;**

Description	Data	Command
Measurement of PDL and Jones matrix:		
MEASURING PDL	none	`PDL;`
MEASURING JONES MATRIX	none	`JM;`
MEASURING EIGENVALUES, EIGENVECTORS OF JONES MATRIX	none	`JME;`
ER measurements:		
Set ER measurement time	d=1...20	`ER_TIME d;`
Start ER measurement	none	`ER_START;`
Read measurement value	none	`ER_VALUE?`
Preparing PMD measurement:		
Select PMD-LASER	d = 4 ... 10	`PMD_LAS d;`
for INTUN:	d = 4	
for HP:	d = 5	
for TUNICS:	d = 6	
for NEW FOCUS:	d = 7	
for ANRITSU:	d = 8	
for ANDO:	d = 9	
Set PMD measurement technique	d = 1/2/3	`PMD_TYP d;`
for Jones matrix eigenanalysis	d = 1	
for Poincaré Sphere technique	d = 2	
for 3 Stokes parameter technique	d = 3	
Set start wavelength	d in nm	`WAVE_START d;`
Set stop wavelength	d in nm	`WAVE_STOP d;`
Set wavelength step	d in nm	`WAVE_STEP d;`
Set tuning speed	d in nm/s	`WAVE_SPEED d;`
Threshold for extreme values	d = 0 ... 2	`DELTA d;`
Degree of mode coupling	d = 0.1 ... 2	`K_FACTOR d;`
Set fiber length	d in km	`LENGTH d;`
Starting PMD measurement		
Starting PMD measurement	none	`PMD_START;`
Reading commands before or after a PMD measurement:		
Lower limit wavelength of the adjusted PMD laser	none	`LASER_MIN?;`
Upper limit wavelength of the adjusted PMD laser	none	`LASER_MAX?;`

Description	Data	Command
Reading commands after a PMD measurement:		
Mean PMD value	none	**PMD_AVG?;**
rms PMD value	none	**PMD_RMS?;**
Length related mean square value	none	**PMD_SKM?;**
Number of extrema with 3 Stokes measurement	none	**EXTREMES?;**
PMD data in form of a file	none	**PMD_FILE?;**

meaning:

- **n** digit of a decimal value (0 ... 9)
- **a** sign (positive sign can be omitted)
- **d** numerical value in floating point or scientific notation
- **.** decimal point
- **;** command terminator
- **[ ]** IEEE 488 bus command

If a transmission error occurs all commands given since the last "**X;**" or **[GET]** are ignored.
All commands given with the exception of "**SRQ nnnn;**" are only executed with the following "**X;**" or **[GET]** (Group Execute Trigger).

3.6 Error messages

The following table lists the error codes "**Enn;**" from the status messages of the PAT 9000B.

Enn	Description
E00	no error
E01	incorrect command or wrong character
E02	string of characters too long (> 250 characters without terminator)
E03	command buffer overflow (>8 commands without trigger command "**X;**" or **[GET]**)
E04	incorrect parameter format
E05	parameter outside the allowed range
E06	parameter has too many digits after the decimal point
E07	optical power too high
E08	incorrect operating wavelength or incorrect optical head calibration (degree of polarization measured >100 %)
E09	no PAN9300 module (in the activated slot)
E10	no POL 9320-Modul (in the activated slot)
E12	no PAN-IR module
E13	no tunable laser
E14	incorrect type of PAN set
E15	type of PMD not set
E16	no reference Jones matrix available
E17	incorrect start wavelength
E18	incorrect stop wavelength
E19	incorrect wavelength step
E20	incorrect wavelength speed
E21	incorrect length of fiber
E22	incorrect K-factor
E23	incorrect value for delta_mm
E24	no PMD data available
E25	no PMD file available
E26	no turbo mode available for PAN9300
E29	no tunable laser for PMD measurements available
E30	No or wrong authorization code
E31	No turbo file existent
E33	Power below limit setting

E34 Insufficient measured points
E35 Unable to calculate ER
E36 Not sufficient fiber stress
E37 No typical PMF behavior (Warning only)
E38 Bad linear eigenmodes (Warning only)
E39 Error loading calibration file *.set
E46 No PAN-NIR
E47 No PAN-FIR
E99 1. Status request after switching the unit on or voltage failure of the unit

3.7 Network connection

On the back of the unit a standard 8-pin RJ 45 connector allows to operate the PAT 9000B in a network environment with 10/100 MBit (twisted pair) data rate.

This Ethernet connection must be configured in the standard Windows 98 software according to the demands of the local area network used.

4 Service and maintenance

4.1 Changing the line voltage

The PAT 9000B operates with line voltages of 90 ... 132V and 184 ... 264 V. The unit automatically adapts to the line voltage available.

4.2 Changing the mains fuse

If the mains fuse has opened the fuse can be easily replaced from the rear without opening the unit.

☝Attention☝

To avoid risk of fire only the appropriate fuse must be used: IEC60127-2/V, T1.25H250V, 5 x 20 mm, 250 V, 1.25 AT (slow response).

Turn off the PAT 9000B and disconnect the mains cable. Open the fuse drawer in the mains connector (see Figure 58) with a screwdriver.

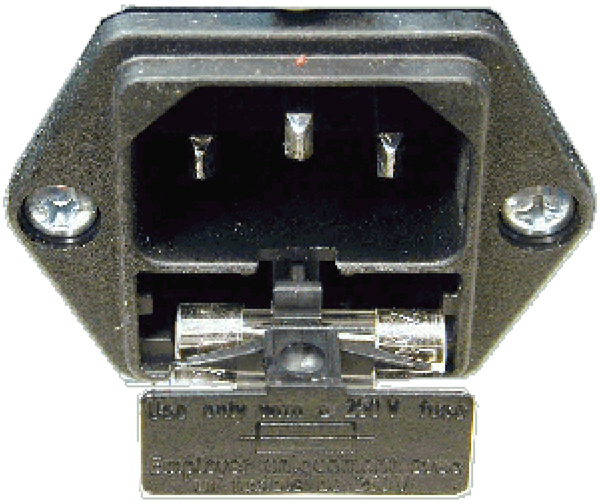

Figure 58 Changing the mains fuse

Replace the defective fuse (one spare fuse is included in the fuse holder) and close the drawer.

4.3 Calibration Certificate

The PAT 9000B is delivered with a certificate of calibration, valid for one year. To maintain the calibration status, you should send the unit once a year for recalibration to *Thorlabs GmbH*, Germany.

4.4 Maintenance and repair

The PAT 9000B does not require any regular maintenance by the user. The frame and the LCD monitor may be cleaned with a soft, moistened cloth and a mild detergent.
The PAT 9000B does not contain any parts to be repaired by the user. In case of malfunction the respective module or the mainframe with the module are to be sent to *Thorlabs GmbH Germany* for repair. Please contact Thorlabs in advance to obtain a RMA number.

4.4.1 Changing modules

☝Warning☝

Never change modules with the PAT turned on!
This could damage mainframe and / or module.

Switch off the PAT 9000B.
Loosen the four screws at the upper and lower edge of the module.
Remove the present module from the mainframe.
Put the desired module onto the guide rail in the mainframe and push the module into the unit until it locks in position.
Fasten all screws again on the front panel of the module and switch on the mainframe PAT 9000B for auto-configuration.

5 Listings

5.1 List of abbreviations

The following abbreviations are used in this manual

ASCII	American Standard Code for Information Interchange
APC	Angled Physical Contact
CLR	CLeaR
CR	Carriage Return
CRD	Character Response Data
DBR	Distributed Bragg Reflector
DC	Direct Current
DCL	Device Clear
DEC	Device Error Condition Register
DEE	Device Error Event Register
DES	Device Error Status
DFB	Distributed Feedback
DOP	Degree Of Polarization
DUT	Device Under Test
ECL	External Cavity Laser
EDE	Enable Device Error Event Register
EDFA	Erbium Doped Fiber Amplifier
EOI	End Of Information
ER	Extinction Ratio
ESE	Standard Event Status Enable register
ESR	Event Status Register
FC	Fiber Connector
FC/APC	Fiber Connector / Angled Physical Contact
FC/PC	Fiber Connector / Physical Contact
FIN	Command FINished
GET	Group Execute Trigger
GPIB	General Purpose Interface Bus
IEEE	Institute for Electrical and Electronic Engineering
IL	Insertion Loss
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LF	Line Feed
LS	Laser Source Module

PAN	Polarization ANalyzer
PC	Personal Computer
PC	Physical Contact
PD	Photo Diode
PDG	Polarization Dependent Gain
PDL	Polarization Dependent Losses
PM	Polarization Maintaining (fiber)
PMD	Polarization Mode Dispersion
PSP	Principal States of Polarization
RMS	Root Mean Squared
RQS	ReQuest Service Message
SDC	Selected Device Clear
SEL	SELect
SKM	per Square Root KiloMeter
SOP	State Of Polarization
SRE	Service Request Enable Register
SRQ	Service ReQuest
STB	STatus Byte Register
SW	Soft Ware
TEC	ThermoElectric Cooler (Peltier Element)
TRG	TRiGger
VGA	Video Graphics Adapter

5.2 List of figures

5.3 Certifications and compliances

Certifications and compliances

Category	Standards or description	
EC Declaration of Conformity - EMC	Meets intent of Directive 89/336/EEC for Electromagnetic Compatibility. Compliance was demonstrated to the following specifications as listed in the Official Journal of the European Communities:	
	EN 61326	EMC requirements for Class A electrical equipment for measurement, control and laboratory use, including Class A Radiated and Conducted Emissions[1,2,3] and Immunity.[1,2,4]
	IEC 61000-4-2	Electrostatic Discharge Immunity (Performance criterion B)
	IEC 61000-4-3	Radiated RF Electromagnetic Field Immunity (Performance criterion B)
	IEC 61000-4-4	Electrical Fast Transient / Burst Immunity (Performance criterion B)
	IEC 61000-4-5	Power Line Surge Immunity (Performance criterion B)
	IEC 61000-4-6	Conducted RF Immunity (Performance criterion B)
	IEC 61000-4-11	Voltage Dips and Interruptions Immunity (Performance criterion B)
	EN 61000-3-2	AC Power Line Harmonic Emissions
Australia / New Zealand Declaration of Conformity - EMC	Complies with the Radiocommunications Act and demonstrated per EMC Emission standard[1,2,3]:	
	AS/NZS 2064	Industrial, Scientific, and Medical Equipment: 1992
FCC EMC Compliance	Emissions comply with the Class A Limits of FCC Code of Federal Regulations 47, Part 15, Subpart B[1,2,3].	

[1] Compliance demonstrated using high-quality shielded interface cables.

[2] Compliance demonstrated with PAN 9300, POL 9320, and DGD Reference modules installed.

[3] Emissions, which exceed the levels required by these standards, may occur when this equipment is connected to a test object.

[4] Minimum Immunity Test requirement.

Certifications and compliances

Category	Standards or description	
EC Declaration of Conformity - Low Voltage	Compliance was demonstrated to the following specification as listed in the Official Journal of the European Communities: Low Voltage Directive 73/23/EEC, amended by 93/68/EEC	
	EN 61010-1/A2:1995	Safety requirements for electrical equipment for measurement control and laboratory use.
U.S. Nationally Recognized Testing Laboratory Listing	UL3111-1	Standard for electrical measuring and test equipment.
	ANSI/ISA S82.01:1994	Safety standard for electrical and electronic test, measuring, controlling, and related equipment.
Canadian Certification	CAN/CSA C22.2 No. 1010.1	Safety requirements for electrical equipment for measurement, control, and laboratory use.
Additional Compliance	UL3111-1	Standard for electrical measuring and test equipment.
	IEC61010-1/A2:1995	Safety requirements for electrical equipment for measurement, control, and laboratory use.
Equipment Type	Test and measuring	
Safety Class	Class 1 (as defined in IEC 61010-1, Annex H) - grounded product	

5.4 Address

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Our company is also represented by several distributors and sales offices throughout the world.
Please call our hotline, send an E-mail to ask for your nearest distributor or just visit our homepage **http://www.thorlabs.com**