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PerkinElmer

FD440

Portable
Chromatic Dispersion
Test Set

INSTRUCTION MANUAL

Version 3.0 January 2000

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PerkinElmer Optoelectronics

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WARRANTY

PerkinElmer Optoelectronics warrants each system to be free from defects in material and workmanship. Obligations under this warranty shall be limited to replacing or repairing, at our option, within ONE year of delivery to the original purchaser, provided authorisation for such return has been given by our authorised representative.

This warranty shall not apply to any system which our inspection shall disclose to our satisfaction, has become defective or unworkable due to abuse, mishandling, misuse, accident, alteration, negligence, improper installation or other causes beyond our control. Instruments manufactured by others, and included in or supplied with our equipment, are not covered by this warranty but carry the original manufacturer's warranty, which is extended to our customers and may be more restrictive. Certain subassemblies, accessories or components may be specifically excluded from this warranty.

We reserve the right to make changes in design at any time without incurring any obligation to install it on units previously purchased.

THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION HEREIN. THIS WARRANTY IS IN LIEU OF, AND EXCLUDES ANY AND ALL OTHER WARRANTIES OR REPRESENTATIONS, EXPRESSED, IMPLIED OR STATUTORY, INCLUDING MERCHANTABILITY AND FITNESS, AS WELL AS ANY AND ALL OTHER OBLIGATIONS OR LIABILITIES OF PERKINELMER , INCLUDING, BUT NOT LIMITED TO, SPECIAL OR CONSEQUENTIAL DAMAGES. NO PERSON, FIRM OR CORPORATION IS AUTHORIZED TO ASSUME FOR PERKINELMER OPTOELECTRONICS ANY ADDITIONAL OBLIGATION OR LIABILITY NOT EXPRESSLY PROVIDED HEREIN EXCEPT IN WRITING DULY EXECUTED BY AN OFFICER OF PERKINLEMER OPTOELECTRONICS.

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SHOULD YOUR EQUIPMENT REQUIRE SERVICE

A. Contact the factory (+44 118 977 3003) to discuss the problem. In many cases it will be possible to expedite servicing by localising the problem to a particular plug-in circuit card. If not, a field service visit may be necessary, this will be decided at the time of the call.

B. If it is necessary to return any equipment to the factory, we require the following information.

(1) Model number and serial number.

(2) Your name (system user).

(3) Your address.

(4) Address to which system should be returned.

(5) Your telephone number and extension.

(6) Symptoms (in detail, including control settings).

(7) Your purchase order number for repair charges, or your service contract number (does not apply to repairs in warranty).

(8) Shipping instructions (if you wish to authorise shipment by any method other than normal surface transportation).

C. CUSTOMERS: Ship the equipment being returned to:

PerkinElmer Optoelectronics
Sorbus House, Mulberry Business Park,
Wokingham, Berkshire. RG41 2GY, U.K.

D. Address correspondence to:

PerkinElmer Optoelectronics
Sorbus House, Mulberry Business Park,
Wokingham, Berkshire. RG41 2GY,U.K.
Phone: +44 (0)118 977 3003
Fax : +44 (0)118 977 3493
Email service_fiberoptics@perkinelmer.com

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Chapter 1

Hardware Installation, Ventilation Requirements and General Specification.

1.1 Introduction to the FD440.

The FD440 is a precision portable fiber optic test instrument to measure the chromatic dispersion and relative spectral attenuation of a test fiber presented to the unit. This FD440 instrument can be used in field measurements, research, quality control, type approval and incoming inspection applications within the fiber optics manufacturing industry. The FD440 consists of two units, the Transmitter unit and Receiver unit. Each is placed at opposite ends of the fiber or cable to be tested. Both are AC mains powered. The Receiver unit requires a PC computer with appropriate software for control and data acquisition. The Transmitter unit is free standing and only requires fiber connections to work.

The apparatus to which this instruction manual applies has been supplied in a safe condition. This Manual contains some important information and warnings that must be followed by the user to ensure safe operation and to retain the apparatus in a safe condition. The described apparatus has been designed for indoor use in normal office/factory environments and for outdoor use in dry conditions. Do not operate the FD440 outside where rain or snow can fall onto the unit or in abnormally hot, cold, dusty or damp environments. Similarly, do not place the FD440 units in standing water, or where standing water could collect.

The FD440 Receiver Unit contains a Class 1 laser (in accordance with both US 21 CFR Chapter 1, Sub-chapter J, and IEC 825-1) operating at 1550nm, used for the COMMS fiber "up-link". Be sure to observe appropriate laser safety procedures. Lasers at Class I level are described as "eye-safe".

1.2 Initial Inspection.

Newly received FD440 apparatus should be inspected for shipping damage. If any is noted, immediately notify PerkinElmer Optoelectronics and file a claim with the carrier. The shipping container should be saved for possible inspection by the carrier.

WARNING !

THE PROTECTIVE GROUNDING MAY BE RENDERED INEFFECTIVE IN DAMAGED APPARATUS. DAMAGED APPARATUS SHOULD NOT BE OPERATED UNTIL ITS SAFETY HAS BEEN VERIFIED BY QUALIFIED PERSONNEL. DAMAGED APPARATUS SHOULD BE TAGGED TO INDICATE TO A POTENTIAL USER THAT IT MAY BE UNSAFE AND THAT IT SHOULD NOT BE OPERATED.

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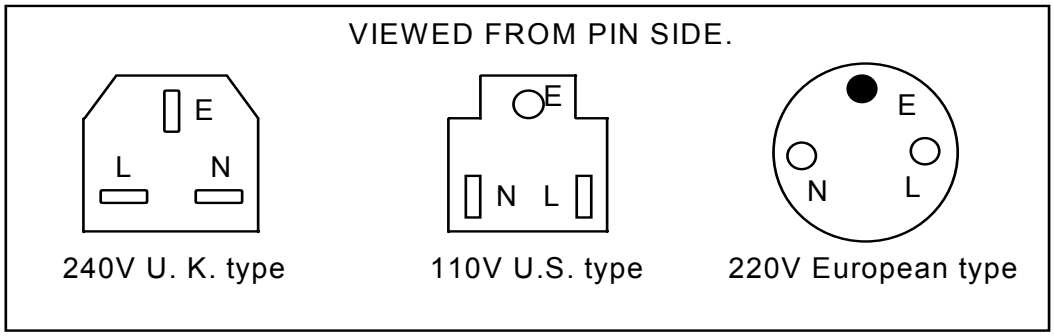
1.3 Electrical Safety Mechanism and Power Cord.

As defined in IEC Publication 61010, Safety Requirements for Electronic Measuring Apparatus, the FD440 is Class 1 apparatus, that is apparatus that depends on connection to a protective conductor to earth ground for equipment and operator safety. Before any other connection is made to the apparatus, the protective earth terminal shall be connected to a protective conductor. The protective connection is made via the earth ground prong of the FD440 power cord (IEC) plug. This plug shall only be inserted into a socket outlet provided with the required earth ground contact. The protective action must not be negated by the use of an extension cord without a protective conductor, by use of an "adapter" that does not maintain earth ground continuity, or by any other means.

When the FD440 system is first installed, a suitable power cord plug will be provided. The power cord plugs provided for the U.K. and the U.S. are each illustrated in Figure 1-1. Should it be necessary to change the power cord plug, an approved type for the country of operation should be used. In every case the wiring colour code is as follows:-

Brown	**- Live**	**(L)**
Blue	**- Neutral**	**(N)**
Green/Yellow	**- Earth**	**(E)**

Figure 1-1 Power Cord Plugs With Polarity Indication



WARNING !

IF IT IS NECESSARY TO REPLACE THE POWER CORD OR THE POWER PLUG, THE REPLACEMENT CORD OR PLUG MUST HAVE THE SAME POLARITY AS THE ORIGINAL. OTHERWISE A SAFETY HAZARD FROM ELECTRICAL SHOCK, WHICH COULD RESULT IN PERSONNEL INJURY OR DEATH, MIGHT RESULT.

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1.4 POWER VOLTAGE SELECTION.

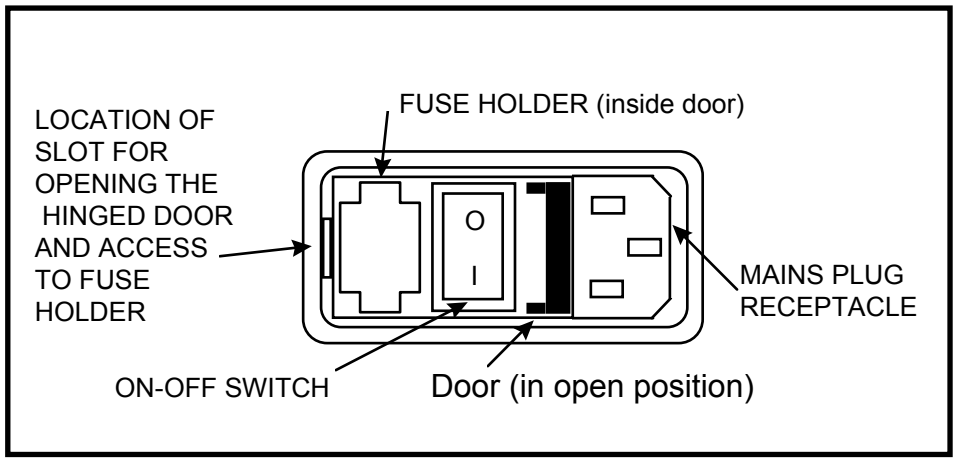
CAUTION !

Before plugging in the power cord, first ensure that the equipment voltage ranges correspond to the voltage of the local AC power supply.

The FD440 can operate from AC voltage ranges from 90V to 260V, 48 to 62 Hz without adjustment. The mains inlet assembly is shown in Figure 1-2. Note that the mains inlet assembly incorporates fuse holder, on-off switch and mains plug receptacle in one unit.

CHANGING THE LINE FUSES SHOULD ONLY BE DONE BY A QUALIFIED SERVICE TECHNICIAN, AND THEN ONLY WITH THE INSTRUMENT DISCONNECTED FROM ALL SOURCES OF POWER.

Figure 1-2 Line Cord/Fuse Assembly.



1.5 Line Fuse.

Referring to Figure 1-2, the fuse is accessed by first removing the power cord from the mains inlet assembly. Using a small flat-blade screwdriver in the small slot located at the end of the mains inlet assembly opposite the plug receptacle, prise open the small hinged door in the centre of the mains inlet assembly door. To replace the fuse, lift out the red plastic fuse holder located next to the On-Off switch with the help of a small screwdriver. When the fuse holder has been removed, remove existing fuse and refit new correct fuse into its recess.

Use **2.0 A anti-surge (T), 250Vac, 20/ 32 mm** fuse for operation at **90- 260 V**

Refit the fuse holder into the assembly. Close and click shut the hinged door.

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1.6 Ventilation Requirements.

Both FD440 units incorporate forced air ventilation. The ventilation ducts are located on the rear panel of the FD440 Transmitter unit, but on the rear and underside of the Receiver unit. The rubber corners on the units allow convection and air-flow underneath the unit to assist cooling, and the corners must **not** be removed for this reason, especially when the unit is rack mounted. Also ensure the FD440 units are placed on hard surfaces, to ensure no blockage of the air-flow by the rubber corner pieces sinking in (e.g. on carpets).

Ensure that unit is operated with at least 75 mm (3") of clear space behind the unit.

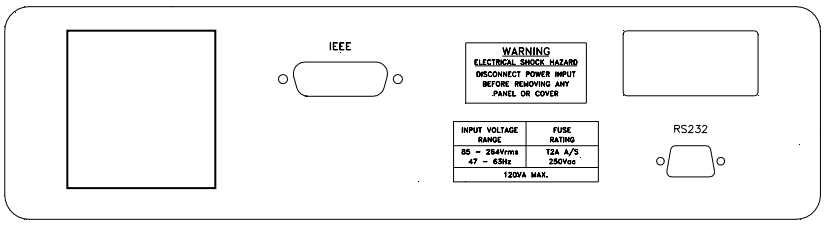
The overall operating requirements are that the ambient temperature be restricted to the range of 0°C to 35 °C. All the air inlet filters must be kept clean (see 1.9 Regular Maintenance).

1.7 Hardware Installation.

PLEASE NOTE. INSTALLATION AND INITIAL POWER UP SHOULD ONLY BE CARRIED OUT BY AN INSTALLATION ENGINEER EMPLOYED OR NOMINATED BY PERKINELMER OPTOELECTRONICS OR BY A TRAINED/EXPERIENCED ENGINEER.

Figure 1-3 Panel Layouts- Receiver Unit.

REAR



FRONT



The basic procedure is to site the unit and computer system on a stable level surface(s), which are dry and free of obstructions at the rear of the unit to allow ventilation (see 1.6 Ventilation Requirements, for detailed requirements), to connect cables and switch power on. The electrical cable connections required are on the rear panel. The basic connections needed are AC mains power on both units and the IEEE interface connection to the control computer on the Receiver unit only. Do not use the RS232 connector. The test fiber and COMMS fiber are each connected to the fiber connectors on the front panels of each unit.

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Full diagnostics of the state of the instrument upon arrival after shipment is best left to qualified service personnel nominated or employed by PerkinElmer Instruments and **it is advisable, for safety reasons, not to power up the unit prior to the service personnel's arrival**. This is in case there should be internal shipment damage that might result in hazardous operation of the unit if the damage were not quickly recognised, the power turned off and the damage rectified.

Check the PC voltage settings and alter these as required in accordance with their respective instruction manuals. Connect up AC power and IEEE.

The FD440 is controlled from an IBM or compatible personal computer. Control is via the IEEE 488 bus. When the computer and FD440 system are supplied by EG&G the IEEE interface card is already installed, set up and tested. For more information on the interface refer to EG&G. The preset use of IEEE addresses is given below:

0	**Used by the computer**.
11	**Used by FD440**.

Start Up:

WARNING !

BEFORE CONNECTING POWER TO THE SYSTEM ENSURE THAT THE CORRECT VOLTAGE SETTINGS ARE SELECTED AND THE LINE FUSE IS OF THE CORRECT RATINGS AS OUTLINED ON PAGES 1-2 TO 1-3.
ENSURE THAT THE COMPUTER AND PERIPHERALS ARE CORRECTLY SET FOR THE PREVAILING LINE VOLTAGE ACCORDING TO THE SEPARATE COMPUTER INSTALLATION MANUAL.

After the interconnections have been completed, power can then be applied to each FD440 A/C INPUT located on the rear panel and all computer/VDU units.

Upon switching on the FD440, run the main software (see chapter 2) to initialise the FD440 hardware. Measurements can now proceed immediately the control software is running (see Chapter 2), but it is advisable to wait 30 minutes for the system to fully stabilise to obtain best accuracy, particularly if system references (see chapter 3) are to be taken. Measurements may be taken using the operating procedures described in Chapter 3.

1.8 Regular Maintenance.

The main items of regular maintenance are:

a) **Integrity of interconnections and cables** (- Inspect for damage/ connection -see above)
b) **fiber connectors** (keep clean- Refer to Chapter 3 for advice on cleaning/servicing these)
c) **air inlet filters on each unit's rear panel** (keep clean- see below)

It is important to ensure that the air filters are cleaned at regular intervals. If the system is being used in a dusty environment, it is recommended that the filters are checked and/or cleaned at least once per week.

The air filters are each located on the rear panel. The filter can be removed by unscrewing the screw in the air filter cowling assembly a quarter turn, using the edge of a coin or screwdriver. Remove the filter

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material and clean it either a) by using a vacuum cleaner; or b) by washing it in warm soapy water, followed by rinsing in clean water. Always allow the filter to dry before replacing it on the FD440. It is also advisable to ensure that the filter support gauze behind the filter is clean and unobstructed.

The filter material may also be replaced altogether; contact the factory for details of replacement filter material.

1.9 Damage And Abnormal Stresses in Use.

Whenever it is likely that the protection provided by the connection to earth ground has been impaired, the apparatus shall be made inoperative and secured against any unintended operation.

The protection is likely to be impaired if, for example, the apparatus :

(1) Shows visible damage, or the input mains cable has been damaged;
(2) Fails to perform the intended measurement;
(3) Has been subjected to prolonged storage or operation under unfavourable conditions;
(4) Has been subjected to severe transport stresses;

The apparatus should not be used until its safety has been verified by qualified service personnel.

1.10 Equipment Servicing.

WARNING !

POTENTIALLY LETHAL VOLTAGES ARE PRESENT INSIDE THIS APPARATUS. SERVICE SHOULD BE PERFORMED BY QUALIFIED PERSONNEL ONLY. TO AVOID ELECTRIC SHOCK, DO NOT PERFORM ANY SERVICING UNLESS YOU ARE QUALIFIED TO DO SO. IF IN DOUBT CONTACT THE FACTORY.

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1.11 General Specification For FD440.

Operating wavelength range: 1250 - 1350 nm and/or 1500 - 1600 nm, for chromatic dispersion (std unit).
1200-1350 and 1450-1650 nm for spectral attenuation.

Ambient Temperature range: Operation: 0 - +35°C; 0-70% RH (non-condensing).
Storage: -20 - +65°C; 0-70% RH (non-condensing).

Weight: 19 lb. (9 kg) approx., Receiver Unit.

9 lb. (4 kg) approx., Transmitter Unit.

Dimensions: 14"(W) x 4"(H) x 17"(D) (37 x 10 x 43 cm), approx., Receiver Unit.

14"(W) x 4"(H) x 13"(D) (37 x 10 x 32 cm), approx., Transmitter Unit.

Power Consumption: 120 Watts max. (90-260V 50/60Hz), Receiver Unit.
40 Watts max. (90-260V 50/60Hz), Transmitter Unit.

Fuse rating: 2.0 A (T) (A/S), 240Vac, 20 mm , both units.

Operating Environment: Normal dry indoor office, laboratory or factory conditions.
Outdoor dry conditions, moderate humidity and temperatures.

Safety/EMC: Meets the requirements of :-

BS EN61010-1 :1993 (IEC 1010-1:1990+A1:1992),
BS EN55011 (1991) Group 1, Class A (CSPIR 11:1990),
BS EN50082-1 (1992): IEC 801-2:1991, IEC 801-3:1994, IEC 801-4:1988
BS EN80625-1 :1994 (IEC 825-1:1993)
BS EN80625-2 :1995 (IEC 825-2:1993)

This product conforms to EC Directives 89/336/EEC Electromagnetic Compatibility Directive, amended by 92/31/EEC and 93/68/EEC, & Low Voltage Directive 73/23/EEC amended by 93/68/EEC.

CE

Note: for detailed specifications on each measurement mode or parameter, please refer to PerkinElmer Optoelectronics Technical Specification sheets (Published separately).

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1.12 Laser Safety Statement

The PerkinElmer Instruments FD440 Portable Chromatic Dispersion Measurement System contains a near-infrared low-power laser.

Radiation Specification

The maximum optical peak power of the laser is 700 microwatts, CW (continuous wave). Wavelength is 1550 +/- 20 nm.

The radiation emerges initially from a discrete laser unit within the Receiver Unit which is normally coupled by the COMMS (up-link) fiber to the FD440 Transmitter unit. Emission from this laser is indicated by the red power LED on the front panel of the control unit. If the connection is not made to the Transmitter Unit, the laser radiation will emerge from the fiber connector on the Receiver unit itself.

Warning Labels

Reproductions of the warning labels located on the rear of the Receiver unit are shown below.

Classification

"CLASS 1 LASER PRODUCT"

In accordance with US 21 CFR Chapter 1 Subchapter J, and with IEC 825-1, the laser used is Class 1.

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Chapter 2

System Operation.

2.1 Introduction.

The FD440 instruments are entirely software controlled using a desk top computer. The program is controlled by the use of SOFTKEYS and MENUs from either a keyboard or a mouse. The 'MENU' is the line of labels along the top of the screen. The 'SOFTKEYS' are the keys along the top of the keyboard labelled F1 to F10. The corresponding SOFTKEY functions are displayed along the bottom of the screen. These functions may be selected by the user to perform measurements, store data, print results etc.

Various measurement modes are available on FD440 products depending on the model and installed options. These include Chromatic Dispersion, Length, Polarisation Mode Dispersion etc. Each mode has a similar structure, look and feel.

The system has three levels of operation :-

1. TEST
2. SUPERVISOR
3. ADVANCED SUPERVISOR

The TEST level is for the normal measurements of fibers. It allows the operator to select a test file, enter details of the fiber, check the power through the fiber, run a system reference and perform routine fiber measurements. Each measurement mode shares a common fiber length measurement facility in this level.

The SUPERVISOR level in each measurement mode allows the test files to be edited, the system data to be changed, an optical power spectrum of the system to be displayed and various other facilities to be accessed. To enable the SUPERVISOR mode a password has to be entered correctly. This level can be further split into two levels accessed with two separate passwords.

The ADVANCED SUPERVISOR allows additional calibration /service facilities to be used. Also accessed by means of a password.

2.2 Start up.

Connect the FD440 instrument to the computer as described in Chapter 1 and switch on the instrument power. Switch on the computer, which will automatically load the “Microsoft Windows” software. Run the FD440 software by double-clicking on the FD440 icon. The Receiver unit status LED lights to show the software is successfully running. The system must be switched on before the computer, otherwise when the computer first tries to communicate with the instrument, it will detect that it is not connected and enter an emulation mode.

Summary:

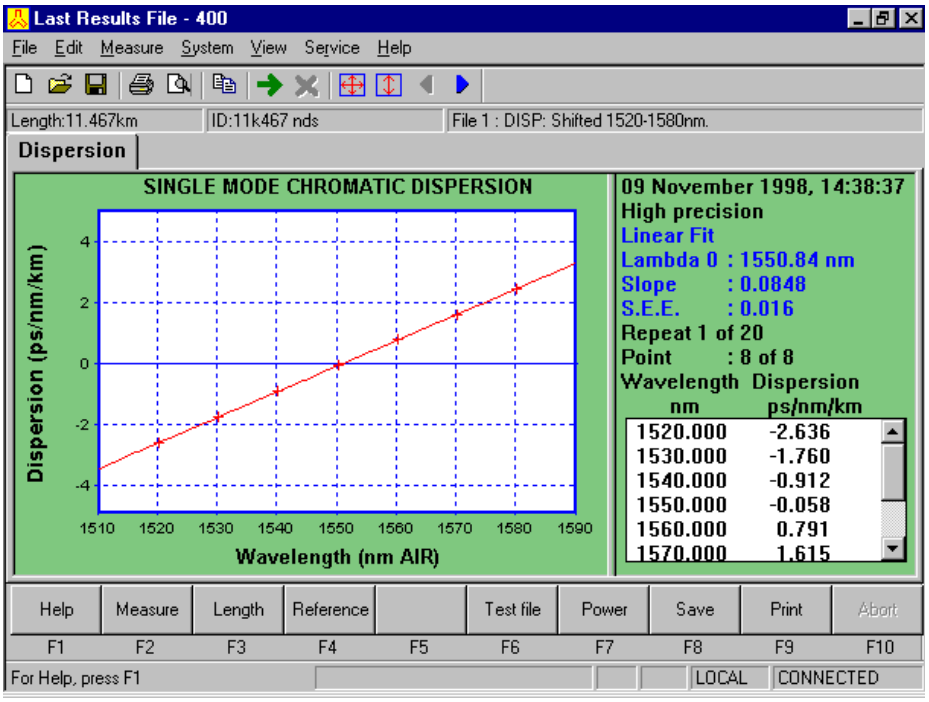
1. Switch on the instrument.
2. Switch on computer.
3. Run the FD440 Software.

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2.3. The Windows Environment.

FD440 Control.

The program runs in the Microsoft Windows environment. As such the control of the program is similar to any other Windows program. The Windows manual supplies a detailed explanation of the operating system as well as the utilities that are supplied with the Windows package. Some of these are accessible from the FD440 software directly.



The main functions on the function keys F1 to F10, as shown at the bottom of the screen are duplicated on the pull down menus.

The system can be controlled with a mouse or just from the keyboard. In this document a 'click ' with the mouse refers to moving the cursor over the item and pressing the left mouse button once. Double click' with the mouse refers to moving the cursor over the item and pressing the left mouse button twice in rapid succession.

Function keys.

The function can be selected by either pressing the corresponding function key on the keyboard or clicking it with the mouse.

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Pull down menus.

From the menu bar at the top of the screen, to select a pull down menu either click it with the mouse or press the Alt key together with the underlined letter in the menu name. To select the **Result** menu press Alt and 'R'. If an item in a menu is in grey it cannot be selected. This is the case for functions which can only be selected after the password has been correctly entered or for functions which are only valid after a measurement has finished, such as **Save**.

Tool bars.

Clicking on the tool bar buttons may access certain frequently used menu items. Position the mouse cursor over the buttons to show context help that indicates their function.

The FD440 contains the following toolbar buttons:

[File-New] [File-Open] [File-Save] [Print] [Print preview] [Copy] [Start] [Abort] [Edit Results] [Rescale Graph] [Toggle Display]

Dialog boxes.

Certain selections bring up a further box, known as a dialog box. These allow various items to be chosen using either the keyboard or a mouse. Dialog boxes contain various types of control functions.

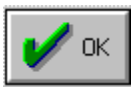
One item selected in the dialog is highlighted by having a dotted lined box around it. This is termed having the input focus. Further key strokes will be aimed at that object. To move the input focus to another object use the TAB key or TAB + SHIFT to retrace the movement.

To exit, click on OK or CANCEL. CANCEL will ignore any new selections and revert to the old settings. OK will use any new settings selected. In most cases the keyboard RETURN will choose OK and ESCAPE will choose CANCEL.

Tab Dialog boxes.

Tab dialogs are used to group entries that may be related onto several pages or “tabs”. Click on the labelled tab at the top of the dialog to allow entries on that page to be displayed and modified.

Buttons.



Most dialog boxes contain a **Cancel** and **OK** button and sometimes further buttons.

The **OK** button can be selected by clicking it with the mouse, pressing Alt and 'O' or often by just pressing RETURN. The **OK** button signifies that you will use the selected item(s), or set ups. The **Cancel** button can be selected by either clicking it with the mouse, pressing Alt and 'C' or by pressing the Escape button. The **Cancel** button will leave the dialog box without using the selected item(s), leaving them in their original state.



The **Apply** button present on tab dialog boxes can be used to accept the selected item(s) or set ups as if the OK button had been pressed. The **Apply** button does not close the dialog box however and allows further modifications to be made. In instances where this facility is inappropriate or not required the button will remain greyed and inaccessible.

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List Box.

A list box is where there is a list of items from which one can be selected. For example in the file select dialog box the test files available are listed. One file can be selected either by clicking over the file name with the mouse or moving the up/down cursor and pressing return. The selected file will be high lighted.

Option buttons.

Option or radio buttons signify a series of options only one of which can be selected. Selecting one automatically deselects the others. They can be selected by either being clicked with the mouse, or pressing the TAB key to move forward to the group of buttons (or shift TAB to move backwards). Then using the cursor keys (<,>) to select the button. For example, in the Setup dialog box the system speed and print out size are option buttons.

Check boxes.

These are square boxes, which may have a tick in the centre. The box is used to signify the item or function shown along side, being selected or not. A tick signifies selection, an empty box signifies no selection. Selection is achieved by either clicking with the mouse or moving to the item with the TAB / shift+ TAB key and then pressing the SPACE bar to toggle the selection. For example the Set up dialog box has a selection called Auto rescale, to automatically rescale the result at the end of a measurement.

Edit boxes.



This is a box which allows the user to enter a number or characters from the keyboard. Select it by using the TAB/shift+TAB key or clicking with the mouse. When the item is initially selected and displayed in inverse video entering a new character will remove all the exiting data. To prevent this press a cursor key first, then edit the existing entry. For example in the Fiber dialog box, the Fiber length, ID and message are entered via edit boxes. Backspace and delete are also allowed.

Drop-down list boxes.

A drop-down list box appears initially as a small rectangular box with the current choice (default) highlighted in the box. The arrow in a square box at the right of the rectangular box opens into a list of available choices when you select it. If there are more choices than can fit in the drop-down list box, scroll bars are provided at the right hand side of the box.

To open a drop-down list box and select an item:

Mouse.

1. Click the arrow in the square at the right of the box to open the drop-down list box.
2. Click the Up or Down scroll arrow or 'drag' the scroll bar to move to the item you want.
3. Click the item.

Keyboard.

1. Press ALT+DOWN ARROW to open the drop-down list box.
2. Use the UP or DOWN ARROW key to reach the item you want, and press ALT+UP ARROW or ALT+DOWN ARROW to select the item.

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An example is the Test File Group drop down list boxes to allow further groups of test files to be accessed**.**

2.4 Installing Software.

New installation.

The FD440 series software runs under the Microsoft Windows operating system. A new computer should have Microsoft DOS and Microsoft Windows loaded before installing the PerkinElmer software. For more information on DOS and Windows refer to their respective manuals.

To install the PerkinElmer software place the 3.5 inch FD440 program disk in the disk drive. The computer should be running Windows.

From the “Start” button, select “Run”. In the box enter:

'A:SETUP', and press return.

The installation program creates a directory 'EG&G' on the hard disk drive 'C'. It copies the main program 'FD440.EXE' and the help file FD440.HLP to a sub-directory C:\EG&G\400 and certain other files. The user is prompted during the installation. The default directory can be changed if necessary. A complete installation copies all the files and is normally recommended. However a part installation can be made allowing the selection of programs or data files. The PerkinElmer icon to run the program is normally installed into the Main window.

Updating installed software.

To install a new version of software place the disk containing the new program in the A: disk drive.

The computer must be running Windows.

From the Program manager select from the top menu, 'File' and then 'Run'. In the edit box enter A:INSTALL and press return.

Select the directory containing the existing FD440 program this is normally the default C:\EG&G\400. Select either full or part installation. Full is recommended. Do not install the icon again.

To run the new version either re-boot the computer or click on the PerkinElmer icon (shown below) in the Windows screen.



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List of installed programs and files.

The FD440 software creates the following text data files in the C:\EG&G\400 directory: SystemFilexxx.INI where xxx is the FD440 ID number . This file are the test data file groups and holds test file data. It is wise to back this file up periodically to a floppy disk.

The program will create a system file SystemFile0.INI if run without the system connected.

Several SystemFilexxx.INI files will be created if the computer is used to run more than one instrument, each will end in a different number, corresponding to the respective instrument ID.

In directory C:\EG&G\400

FD440.EXE

FD440.HLP

SystemFilexxx.ini

Reference .wsr

In directory C:\WINDOWS

FD440.ini

In directory C:\WINDOWS\SYSTEM

MFC42.DLL

MSVCR7.DLL

The following file extensions are used for data files:

Test File Group names	:	.wst
Fiber details files	:	.wsf
Binary data and results	:	.wsd
System Reference data	:	.wsr
Exported ASCII Data	:	.txt

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2.5 Menu Functions.

The main menu provides access to all of the functions needed to control data acquisition, display and storage. It contains the following functions:

Menu	Sub Menu and Fn key	Function Overview
File		
	New Ctrl+N	Creates a new data file ready for a new measurement.
	Open Ctrl+O	Opens a previously stored data file.
	Import Results	Allows results taken on PerkinElmer CD300, CD400 and 4 Series systems to be read from disk.
	Save Ctrl+S F8	Saves the current data file with the current filename, binary format.
	Save As	Saves the current data file with a new file name, binary format.
	Save as Text	Saves the current data in text (ASCII) format
	Page Setup	Allows the printout header and font sizes etc to be changed
	Print Preview	Previews the graph or results to be printed.
	Print Setup	Sets up the printed page format for the printer in use.
	Print F9	Prints the graph or results.
	Revert To Last	Opens the last acquired data file.
	Exit	Exits the FD440 program.
Edit		
	Set Up	Allows global set up of operation sequence, batch file control, etc before and after the measurement.
	Setup Length	
	Test File	Edits a test file or group of test files comprising wavelength and graph display parameters.
	Results	Allows user to manipulate data display, inclusion of data points in fitted curves etc.
	Rescale	The data on screen is re-scaled in y axis to allow data to fill the display area
	Copy to Clipboard	Copies the current screen display to the Windows clipboard
Measure		
	Measure F2	Starts the fiber measurement.
	Length F3	
	Reference F4	Starts system dispersion reference measurements
	Power Bar F7	Displays the power bar to monitor the optical loss in test fiber and

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	connection to FD440.
Power Scan	Allows a complete spectral scan of the LEDs /test fiber
Abort measurement F10	Stops the data acquisition

System

Enter Password	Entry for operator password for access to restricted menu items
View Status	Allows the internal voltages and temperatures within the FD440 to be monitored and printed out.
Configure Screen	Allows the user to customise the function key labels (e.g. for other Languages), and to change the screen background colour.
Configure Menus and Passwords	Allows each menu items to be set up, on one of two password-protected levels, and to edit/set the passwords for each level.
Configure Remote Control	Enables settings for RS232C interface for remote instrument control to be set up (where applicable)
Run Explorer	Starts the standard Windows Explorer file management program
Run WordPad	Starts the standard Windows WordPad word processing program
Run Calculator	Starts the standard Windows on-screen Calculator program

View

Toggle View Reference	Displays the system reference plot for current selected Test file (Dispersion only)

Service **NOTE: it is strongly advised that the Service menu is password protected, to prevent inadvertent calibration corruption.**

Diagnostics	Allows the user to switch on diagnostic capture, to screen, file or Printer for fault diagnosis/recording purposes
Edit Constants	Manual editing of instrument calibration (*experienced users only*!)
Manual Control	Manual control of individual functions (*experienced users only*!)
Statistics	Access to statistical results output (where applicable)
Calibration	Allows access to FD440 calibration utility menus (wavelength etc.)

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Help

Help Topics	Index of help screen topics.
Contents	Displays on-line help
About	Shows the software version number.

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Chapter 3

Operating Principles of the FD440.

3.1 Basic System Architecture.

The FD440 is a highly accurate and reliable fiber test instrument for measuring the chromatic dispersion and spectral attenuation of single-mode optical fibers and cables. This section gives an overview of the basic system architecture and interpretation of the results obtainable from a FD440 instrument. For more detailed explanation of the measurement technique theory, please see Chapter 4.

The system architecture within the FD440 is shown in Figure 3-1. The system is broken down into the Receiver Unit, Transmitter Unit and the computer. The computer operates via the IEEE 488 bus and provides automatic computer control of all measurement functions via user menu selection using a Windows operating system. Inside the Transmitter Unit are the LED light sources (1550 only is standard, 1310 & 1550nm is option). Each LED is thermo-electrically cooled to stabilise their respective operating temperatures. These are driven via a reference fiber (Comms) “up-link” formed by a fiber in the same cable as the test fiber.

A fiber coupler and connector route the LED light into the test fiber or cable. This output light is detected at the Receiver at the wavelength(s) appropriate for the test(s) being performed using a computer-controlled solid-state monochromator. The monochromator is a unique solid-state device called a Solid State Monochromator (SSM). It is used to filter the appropriate measurement wavelengths from the arriving broad-band light. The filtered optical signal passes from the SSM to the optical detector, then as an electrical signal to the digital phase/power detection system. For each wavelength selected by the monochromator, this system measures the light intensity/modulation signal amplitude and modulation signal phase shift at the 70MHz modulation frequency with respect to the master oscillator. From this phase shift, the optical delay in the fiber can be determined. The Receiver also contains a host processor, IEEE interface and master oscillator. For further details on the measurement operations, please refer to Chapter 4.

The pertinent features of the FD440 system are:-

1. High accuracy and repeatability of dispersion measurements.
2. Direct dispersion readout at specified wavelengths.
3. Conforms to TIA FOTP-175 for dispersion measurements.
4. Insensitive to absolute fiber delay changes.
5. High stability dispersion measurements using unique patented double- demodulation technique.
6. Computer controlled solid state monochromator for wavelength control.
7. Fiber guided optical design for reliability.
8. Totally automatic measurements under computer control.
9. Simplicity of operation.
10. Eye-safe light source Class I laser used for COMMS link.

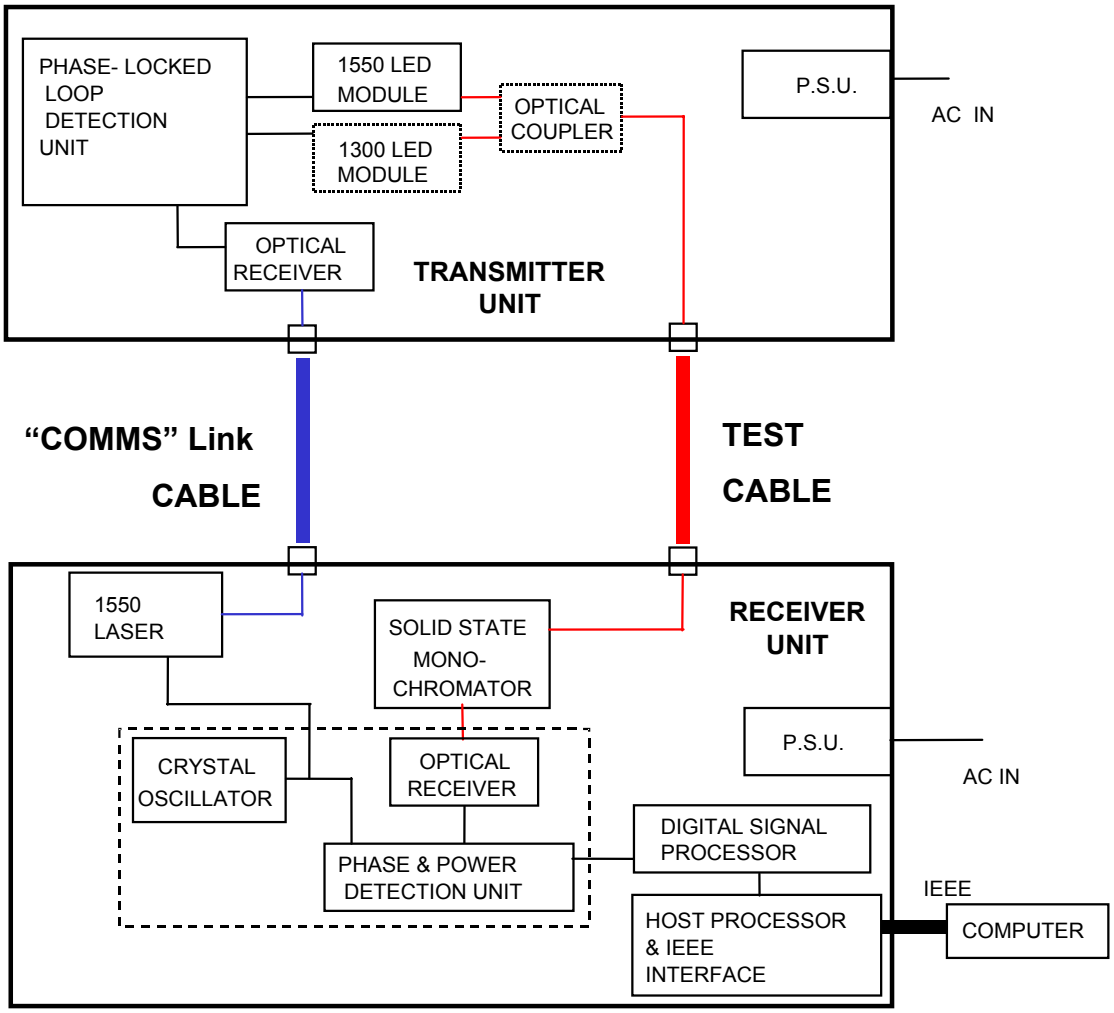
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11.Application to all types of single-mode fibers.

12.Simple interface to bare and cabled optical fibers.

13.High long term stability.

Figure 3-1. FD440 System Architecture.



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3.2 FD440 Measurement Procedures

This section provides further in-depth advice for operating the FD440.

Fiber Interface and Connector Cleaning.

The FD440 provides a pair of fiber optic connectors for interfacing to the users test fiber or cable. A test fiber or cable with the correct connector types at each end may be connected directly to the appropriate FD440 connectors. A similar pair of connectors is provided for the COMMS link fiber. Note that the COMMS link fiber can be of any type, since it only has to carry a constant 1550nm wavelength, upon which a pilot tone is modulated.

All connectors are of the FC-PC type. Adaptors for other fiber connector types may be inserted, if required, but always remember to ensure that back-reflection levels are kept below –30dB when connecting the fibers to the FD440.

Care should be taken not to contaminate any of the bulkhead connectors when connecting a fiber since this can result in both poor measurement performance and permanent damage to the instrument. If connector cleaning is to be attempted on the instrument, PerkinElmer recommends that this be done only under the supervision of a qualified, experienced fiber optic engineer.

Each bulkhead connector of the FD440 is detachable using the two small screws, to allow access to the inner side of the front panel bulkheads. Carefully withdraw the bulkhead a few centimetres to allow the inner pigtail(s) to be disconnected from the bulkhead. The bulkhead may be cleaned or replaced as required. Carefully refit the pigtail, and gently push the bulkhead back into the recess, taking great care not to trap any fibers or wires. Replace the two front panel screws.

Measurement Of System-References.

In order to maintain high accuracy the FD440 provides compensation for its own internal dispersive characteristics. This compensation will require checking every week. It is recommended that the reference be taken *every week* to maintain the best accuracy, in order to null the effects of long-term system drift. This is done by bringing the Receiver and Transmitter units together and using two short fibers connected to test fiber and COMMS (up-link) fiber connectors. Note that separate system-references are required for each dispersion test file to be used. The test files may not be edited after the system-reference has been checked, - if a file is edited, access to that file is denied until the next system-reference checking takes place.

Use softkey F4 in the software control to take system-reference measurements. The data obtained during reference measurement for each file is stored on disk and is automatically subtracted from all subsequent fiber measurements until that system-reference is once again updated.

Measurement Of Test Fiber Or Cable.

Measurement of the test fiber proceeds as follows.

The COMMS up-link fiber is selected from the cable- normally a “dark “ fiber within the test cable. The selected up-link fiber is connected between both units of the FD440. The Transmitter Unit “Locked” LED should illuminate. No, dim or intermittent illumination indicates that the reference fiber loss is too high (e.g. bad splices or connections, or fiber too long).

The test fiber itself is now connected to the system and the light power coupling is maximised or checked using the software key f7. The measurement is initiated by a softkey f2, and after entering the fiber length and other details, takes place under total computer control. At the end of the measurement, the computer presents and stores the data.

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3.3 Basic Operating Procedure.

The FD440 system consists of a transmitter and receiver, one placed at each end of the fiber span. A dedicated laptop is used to control the receiver. Two fibers connect the units: one is the fiber under test, and the other is the communications ("COMM") fiber used to synchronize the operation.

Choose a spare (dark) fiber for the COMMs fiber.

Preparations at the lab include:

1) Creating the likely needed test files (containing all test parameters)

2) Establishing a reference measurement for all these test files (see above)

Field measurement procedures include:

1) Connecting the TEST and COMM fibers

2) Select the most suitable test file according to requirements.

3) Verify the optical connection using the power bar

4) Hit the Measure button (F2)

5) Enter the length of the fiber under test

6) Await the test result

7) Optional steps include verifying that the total loss between transmitter and receiver is acceptable, assigning a name to the saved file, and printing the results. All these optional steps can be automated.

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Chapter 4

Chromatic Dispersion Background.

4.1 Chromatic Dispersion

In a single mode optical fiber, the light travels with a propagation group delay, $\tau(\lambda)$, which is proportional to the fiber length L and is a function of wavelength, λ (see Figure 4-1). This varying delay with wavelength means that light sources, which are not perfectly monochromatic will be time-dispersed. A light pulse will be dispersed in time after travelling along a fiber. This dispersion is called chromatic dispersion. Since most sources in optical communication systems have a finite spectral linewidth, dispersion imparts pulse spreading and therefore limits the maximum data rate (i.e. bandwidth) that can be supported in the system. Dispersion in the fiber is thus a critical parameter to be quantified and controlled.

Fiber delay $\tau(\lambda)$ is quoted in units of $ps.km^{-1}$. Chromatic dispersion, $D(\lambda)$, is simply the derivative of the delay, $\tau(\lambda)$, with respect to wavelength λ, and is a measure of the light pulse spreading observed in a fiber of given length and for a given light spectral width (See Figure 4-1). Dispersion has units of $ps.nm^{-1}.km^{-1}$. The point on Figure 4-1 where the delay curve is flat, corresponding to the zero-crossing of the dispersion curve, is known as the zero-dispersion wavelength or lambda zero, λ_0 (see Figure 4-1), with units of nm (10^{-9} m). At this point, chromatic dispersion is zero and the fiber exhibits maximum bandwidth. Moving away from the zero-dispersion wavelength, the dispersion increases in magnitude, so the bandwidth falls. At the zero crossing point, the slope of the dispersion curve dictates *how fast* dispersion rises as the light source wavelength drifts or tunes away from lambda zero so slope is an important parameter in an optical fiber. Hence the slope at lambda-zero, denoted S_0 is frequently quoted alongside the lambda zero value. S_0 has units of $ps.nm^{-2}.km^{-1}$.

The curve of dispersion in typical single-mode fibers will follow certain defined equations, which are used to interpolate dispersion measurements to find lambda zero and slope. These equations are approved for use by standards authorities, and all are provided in the FD440. There are several types of single mode fiber which have specific dispersion properties. The most common fiber is dispersion-unshifted (Non-Dispersion Shifted, or NDS) fiber, which typically have lambda zeros in the second window near to 1310nm, and are classified in ITU-T 6.6.5.2 and TIA as Class IVa and in IEC as Class B1 fibers. Other fibers are the Dispersion-Shifted (DS) fiber which typically has a lambda zero in the third window close to 1550 nm (classified in ITU-T 6.6.5.2 and TIA as Class IVb and in IEC as Class B2 fibers). Dispersion-Flattened (DF) fibers have very low dispersions in both second and third windows and have been developed to allow high bandwidths for both windows. Special fibers with modified properties include the Non-Zero dispersion (NZD) fibers, which have a small amount of dispersion in the 1550nm region to suppress non-linear optical effects such as Four-Wave Mixing. This improves optically amplified and WDM systems where higher optical power levels are experienced. In NZD fibers, dispersion can be positive at 1550nm (and lambda zero be close to 1520nm) or dispersion can be negative at 1550nm (and lambda zero be close to 1590nm). Finally, there are Dispersion-Compensating (DC) fibers which are specially designed to add (usually) negative dispersion into a fiber system to cancel (usually) positive dispersion that has built up over the long link distance in the NDS, NZD or DS fiber that is used in the link itself. DC fibers are typically inserted in “black box” component form. DC fibers may have large negative dispersion values and a negative slope value.

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It can be seen therefore that chromatic dispersion is a crucially important parameter for modern optical communications systems and the control of dispersion in fiber and cable manufacturing is of high importance. The FD440 is a precision instrument designed to give accurate dispersion measurement results on all types of fiber in field situations.

To measure dispersion, it is effectively necessary to measure the optical delay in the fiber with respect to wavelength. This can be done by measuring delays, then fitting the requisite equation and finally calculating the dispersion, lambda zero and slope. Measurement of delay $\tau(\lambda)$ is typically accomplished by measuring the phase shift ϕ imparted by the fiber delay upon the sinusoidal intensity modulation of a light source of a specific wavelength λ injected into the fiber.

$$\tau(\lambda) = \phi / (2.\pi.f) \quad \text{ps} \qquad (1)$$

where f is the frequency of modulation.

Note that in longer fibers, the phase shift can build up to a high level and the phase detection system could experience 2π phase ambiguities or cycle slips. The cycle slips can only be "counted" if the phase is monitored at sufficiently close intervals of wavelength. This means a complete series of closely spaced fiber propagation delay data points must be collected which can take up valuable measurement time.

In addition, dispersion is only obtained by curve fitting this data and calculating dispersion from the fit coefficients. This procedure relies on knowing the type of fiber and data fit equation to use prior to the measurement. In certain newer types of fiber (e.g. DC fiber), this information is simply not available or a suitable equation has not been approved, and another approach must be sought. This alternative technique is called the "Differential Phase Shift Method" [1], where no such fitting is required, so it can be used to measure all present and future types of silica glass fibers with confidence. This method for measuring chromatic dispersion is defined in the American Telecommunications Industries Association Fiber Optic Test Procedure No. 175 and in IEC-793 and ITU-T G.652. **This is the approach used in the FD440.**

The principle of the Differential Phase Shift Method is to measure the differential fiber group delay $\Delta\tau$ for two wavelengths λ_1 and λ_2 separated by $\Delta\lambda$ and to obtain a direct dispersion measurement without data processing. It is easily proved that chromatic dispersion $D(\lambda_i)$ at the wavelength λ_i midway between the two wavelengths λ_1 and λ_2 is very closely approximated by the differential delay $\Delta\tau$ between the two wavelength points separated by $\Delta\lambda$, if $\Delta\lambda$ is not too large; i.e. :-

$$D(\lambda_i) = d\tau(\lambda_i)/d\lambda \;/\; L \;\cong\; (\Delta\tau \;/\; \Delta\lambda) \;/\; L \qquad \text{ps. nm}^{-1}\text{.km}^{-1} \qquad (2)$$

This approximation is valid for **all** fiber types and makes no assumption about the spectral shape of the delay/dispersion curve, other than that the delay is slowly varying and has no sharp discontinuities. This is true in all known single-mode fiber types. In effect the delay curve is fitted by a short chord of length $\Delta\lambda$, the slope of which is the dispersion. Since $\Delta\lambda$ is always in the range 2-50 nm this approximation is extremely accurate (within 0.005 ps. $nm^{-1}.km^{-1}$). Phase detector cycle slips are counted by using varying values of $\Delta\lambda$.

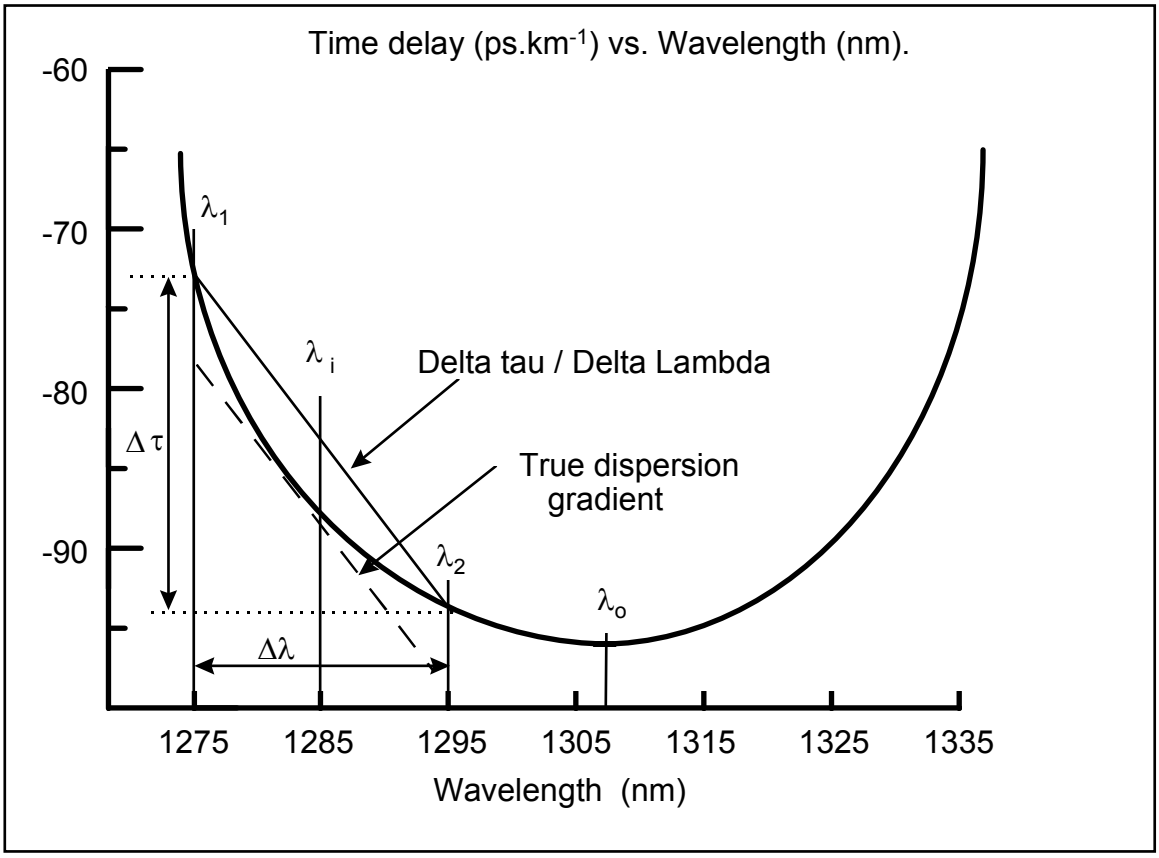
The main advantage of this approach is that a dispersion readout is obtained directly, and no recourse to a recognised data fit equation is necessary. The method operates successfully with dispersion-shifted, dispersion-flattened and dispersion-compensated fiber designs. The instrument will provide dispersion data points only at the wavelengths required by the user and can therefore reduce measurement time under certain conditions. Alternatively, in the case of a known fiber type, a conventional scan of wavelength may be taken and the dispersion data points fitted to the specific ITU-T / IEC / TIA approved equation to obtain other parameters such as dispersion slope and zero-dispersion wavelength(s).

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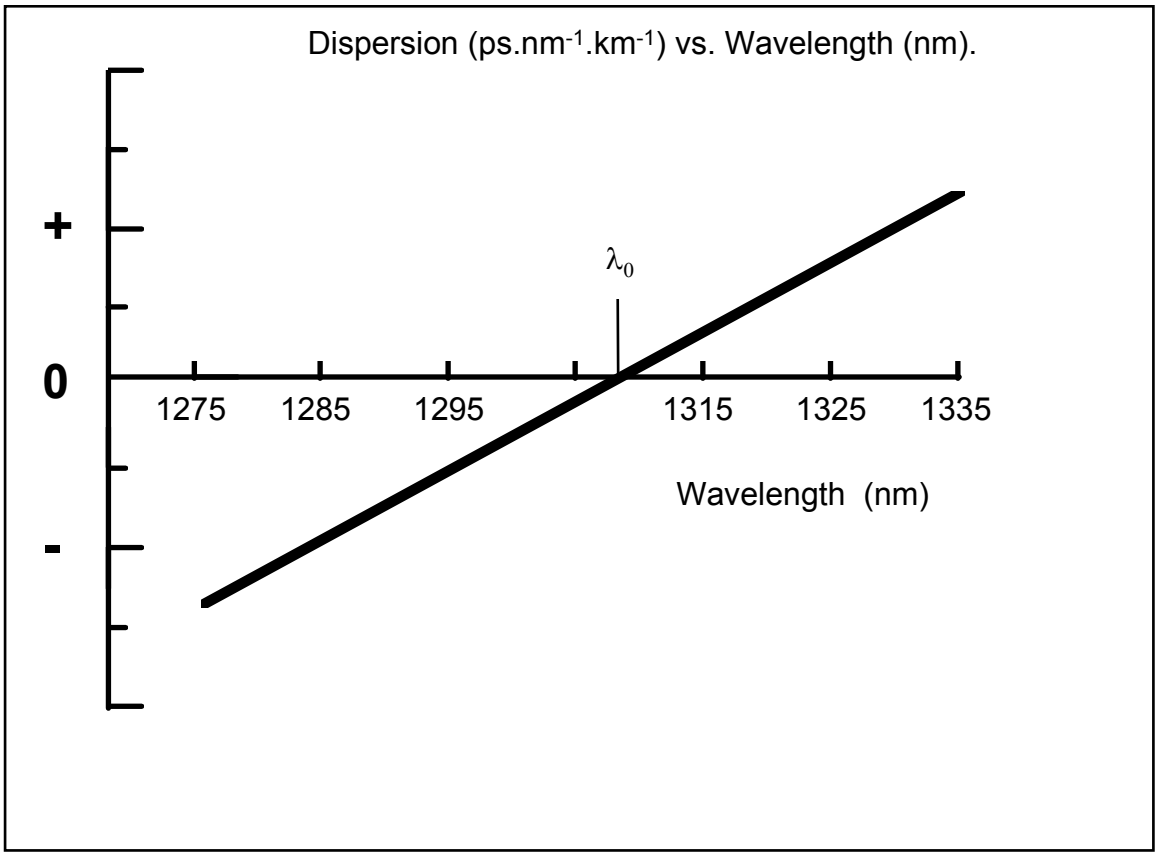
The PerkinElmer FD440 uses a unique variant of the Differential Phase Shift Method called the 'DOUBLE DEMODULATION' method (U.S Patent number 4,750,833). This uses a wavelength modulation method to improve temperature immunity and speed. In the FD440, measurement of differential delay $\Delta\tau$ between λ_1 and λ_2 is obtained by detecting the differential phase shift $\Delta\phi$.

This is explained further below. A simplified block diagram of the system is shown in Figure 4-3 (refer to chapter 3 for a full system diagram) :-

Figure 4-1. Chromatic Delay Curve and Dispersion plot for Unshifted Single Mode fiber.



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A high-frequency digital phase-detection system contained in the FD440 Receiver Unit demodulates the intensity modulation using a reference (COMMS) signal derived from the 70MHz master oscillator (waveform **B** in Figure 4-2, at point labelled "**B**" in Figure 4-3). The COMMS up-link provides an optical signal distribution of waveform B up to the Transmitter unit. In the Transmitter Unit, a phase-locked lop locks onto this waveform, cleaning up the signal, and this replica of waveform B is fed to the LED (s) in the Transmitter unit.

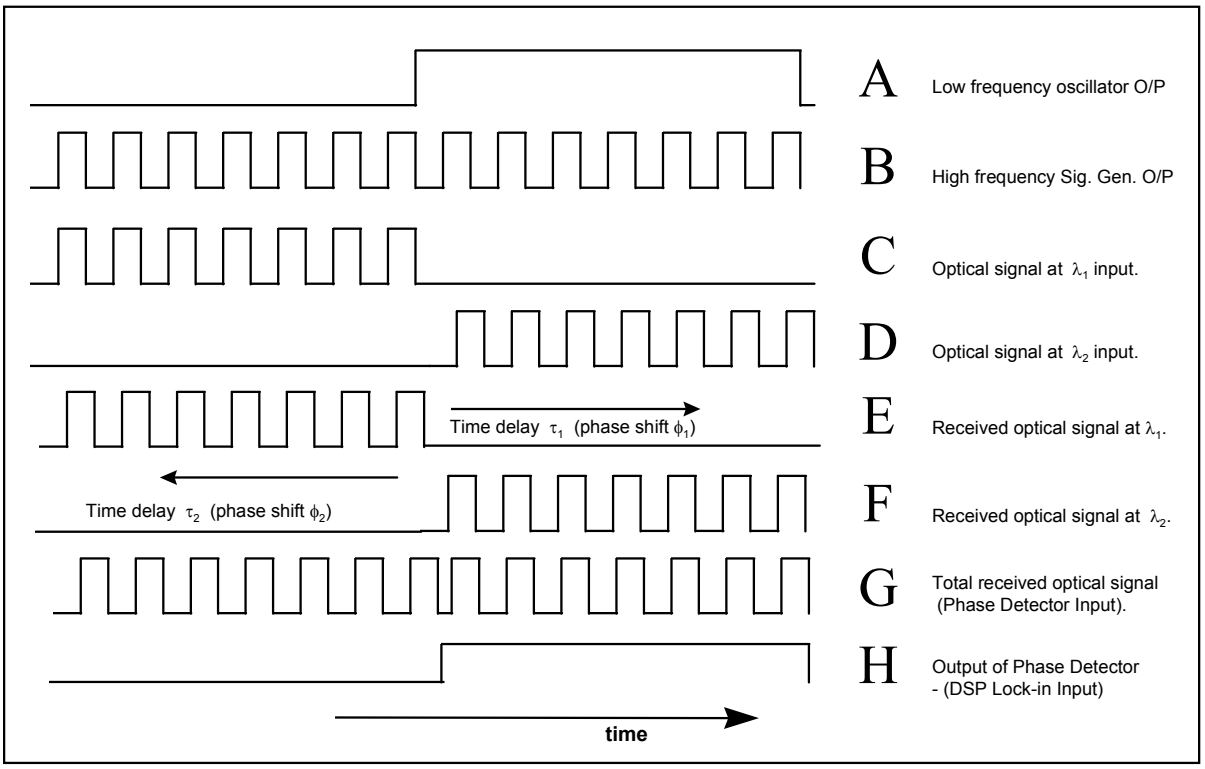
The phase detection system employs frequency conversion techniques combined with analogue-to-digital conversion to produce a digital reading proportional to arrival phase ϕ.

In the double demodulation method used in the FD440, the detection wavelength at the receiver is switched from λ_1 to λ_2 (see Figure 4-1) using a low-frequency oscillator, running at 260 Hz (waveform **A** in Figure 4-2, at point labelled "**A**" in Figure 4-3), using a solid state monochromator. Meanwhile, in the Transmitter Unit the LED(s) is (are) driven with the 70 MHz sinusoidal light intensity modulation sent up-link via the "COMMS" fiber entering the test fiber (waveforms **C**,**D,** at $\square_1$ and λ_2 respectively, in Figure 4-2, at point labelled "**C,D**" in Figure 4-3) Because of the chromatic dispersion in the test fiber (i.e. the delay is different at each wavelength), the detection wavelength switching gives rise to a switch of the modulated phase at the receiver input from ϕ_1 to ϕ_2, at a 260 Hz rate (waveforms **E**,**F** in Figure 4-2, at point labelled "**E,F**" in Figure 4-3). This light is detected by the optical receiver. The electrical waveform after the receiver is a 70MHz waveform, which is square-wave phase-modulated at 260 Hz (waveform **G** in Figure 4-2, at point labelled "**G**" in Figure 4-3). The digital phase detector demodulates the 70MHz signal phase (the *first* level of demodulation). In addition, this detection module measures the optical power from the fiber. The digital readings from the phase detection system represent a square wave at 260 Hz with an amplitude proportional to the differential phase $\Delta\phi$ (hence differential group delay $\Delta\tau$) from the fiber (represented as waveform **H** in Figure 4-2, at point labelled "**H**" in Figure 4-3). This reading passes directly to the Digital signal processor within the FD440. Digital signal processing (DSP) Lock-In amplifier

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techniques are used on the digitised phase readings to demodulate this square wave modulation (the *second* level of demodulation).

Figure 4-2 Double demodulation timing diagram.



By using the Lock-in approach, the a.c. component of the delay $\Delta\tau$ may be detected independently of the d.c. component (i.e. the absolute delay $\tau(\lambda)$). Totally digital methods are used throughout for maximum accuracy and precision. Also, because the d.c. component is removed, slow variation in $\tau(\lambda)$ caused by temperature changes etc. are also eliminated, leading to greater measurement accuracy. Also, the Double Demodulation method removes the effects of low-frequency (1/f) noise and d.c. drift of the phase detection electronics on the measurements. Sources of this noise in the FD440 are the phase detection system and the master 70MHz oscillator, both of which are optimised for best performance in this application [3].

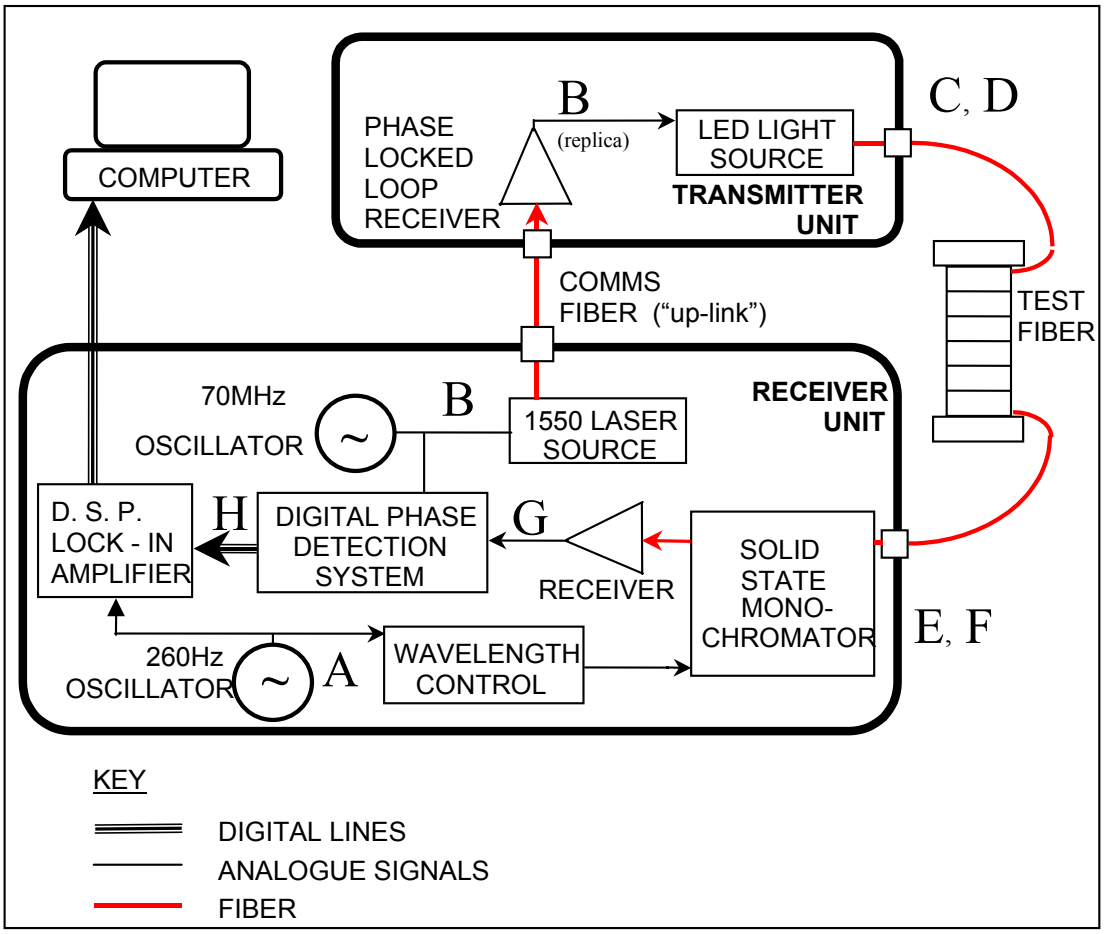
The digital output produced by the (second) demodulation stage (the DSP Lock-in Amplifier) is passed to the computer via IEEE for data calculation and presentation, according to equation (3). Digital signal averaging may be performed inside the DSP processor to provide signal/noise ratio improvement before the data transfer. The fiber chromatic dispersion $D(\lambda)$ per unit length is obtained from the measured differential phase, $\Delta\phi$, the programmed wavelength interval, $\Delta\lambda$ and the modulation frequency (70MHz), f :-

$$D(\lambda) = \Delta\phi / (2.\pi.f.L.\ \Delta\lambda) \qquad \text{ps. nm}^{-1}\ .\text{km}^{-1} \qquad (3)$$

where L is the fiber or cable length in kilometres. Note that the actual fiber length may differ from the cable length, in a loose tube cable type, due to the “excess length” factor designed into the cable.

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Figure 4-3. FD440 Chromatic Dispersion Test Set Block Diagram.



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4.2 Selection Of Dispersion Measurement Wavelengths.

Up to 100 dispersion measurement wavelength points may be selected by the user. It will be found that there are certain optimal wavelength ranges or points which suit the fiber(s) under test and provide the shortest possible measurement time commensurate with the desired repeatability of dispersion values or any data fits used (see below). Typical ranges are 1520 to 1580 in 10nm steps. The control software has these ranges as defaults, but allows free choice of wavelengths. Note that the 1300nm LED is an option on the FD440, and may not be fitted in your instrument.

Please refer to Section 4.5 for information regarding **air** and **vacuum** wavelength.

4.3 Dispersion Data Fits.

The raw dispersion data produced by the FD440 is of extremely high precision and may be used directly to characterise the dispersion of a fiber at certain wavelengths, enabling communication systems designers to accomplish the best performance available from the fiber in an installed system. Significant time-savings may be made by measuring only those wavelengths required by the system design specification.

Alternatively, it may be desirable to calculate the fiber parameters which are commonly used to characterise dispersion, such as zero dispersion wavelength(s) λo (the wavelength(s) at which dispersion is zero) and zero-dispersion slope(s) So (the gradient(s) of the dispersion characteristic at the corresponding zero-dispersion wavelength(s)). This requires data fitting of a pre-determined mathematical function for dispersion to the raw dispersion data. The standard software package allows the user to select one of seven data fit equations. Facilities for removing data points from the fit, changing the graphics display or the fit to be applied, storing/retrieving of edited graphics output to/from disk etc. are also provided.

The data fit output information varies slightly according to the fit used and the number of wavelengths involved. Generally, however, in each case, the coefficients describing the fit equation (A), B, C and (D), the relevant zero dispersion wavelength(s), lambda zero and zero dispersion slope(s) So, printed in units of nm and ps.nm-1.km-1 respectively, are available from the results print-out, according to the user selection of results format. Note that for each fit a minimum number of data points is required to allow the fit to operate correctly, equal to the [number of coefficients (A, B, C etc.) +1]. In the case of the linear data fit a minimum of two points is possible but the S.E.E. (see below) will not be calculated unless at least three data points are used for the fit. In addition, fit 2) requires that the wavelength intervals be equal.

In addition, the Standard Error of the Estimate (S.E.E.) of the data fit is given. In the case of fits 1),3),4),5),6) and 7) this is in units of $ps.nm^{-1}.km^{-1}$ and for fit 2) in $ps.km^{-1}$. This quantity may be used as a measure of the closeness of fit to the raw data. S.E.E. is also useful diagnostic for overall measurement integrity and quality for fibers with known fit equations describing their dispersion behaviour. The lower the S.E.E. value, the better the measurement and the better the fiber fits the predictor equation.

For a given number of fitted points, N (chosen by user), the S.E.E. is calculated as follows:

$$\text{S.E.E.} = \sqrt{\frac{\{\sum_i (\text{Measured Dispersion}_i - \text{Calculated Dispersion}_i)^2\}}{\{N-2\}}} \qquad (4)$$

where i denotes an index i=1 to N, for the wavelengths fitted.

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If repeated measurements are made, statistical data for each λo and slope are also available for printout. In the case of 4 term Polynomial and 5 term Sellmeier fits, statistical data is available for two lambda zeros and slope values.

The data fits available are described below. For other forms of data fit equation, please refer to EG&G Fiber Optics for further advice.

Differentiated 3 Term Sellmeier Equation.

The well-known 3 term Sellmeier equation for fiber delay {see Figure 4-1} may be differentiated to enable fitting to the raw dispersion data produced by the FD440 instrument. The equation is written as:-

$$D(\lambda) = 2.B.\lambda - 2.C\lambda^{-3} \quad ps.nm^{-1}.km^{-1} \qquad (5a)$$

where:-

λ is the optical wavelength in nm.

$D(\lambda)$ is the dispersion in $ps.nm^{-1}.km^{-1}$

B, C are coefficients.

An alternative form is:-

$$D(\lambda) = (So/4).\lambda.(1- \lambda o^4 / \lambda^4) \quad ps.nm\text{-}1 .km\text{-}1 \qquad (5b)$$

where :-

λo is the zero-dispersion wavelength in nm

So is the zero-dispersion slope in $ps.nm^{-2}.km^{-1}$.

Thus,

$$\lambda o = (C/B)^{1/4} \quad nm \qquad (6a)$$

$$So = 8.B \quad ps.nm^{-2} .km^{-1} \qquad (6b)$$

The above fit applies most appropriately to standard (NDS) (un-shifted) single mode fibers (ITU-T 6.6.5.2 / TIA Class IVa) where there is a single zero dispersion wavelength in the 1300 nm wavelength region.

Undifferentiated Sellmeier Equation.

In this case the fiber dispersion data is first integrated to form a set of fiber absolute delay points, and this data fitted to the standard 3-term Sellmeier equation. This is then equivalent to TIA FOTP-169, the phase shift method. The equation is written:-

$$t(\lambda) = A + B.\lambda^2 + C.\lambda^{-2} \quad ps.km^{-1} \qquad (7)$$

where A, B, C are coefficients.

The zero dispersion wavelength λ_0 and zero dispersion slope S_0 are given by :-

$$\lambda o = (C/B)^{1/4} \quad nm \qquad (8)$$

$$So = 8.B \quad ps.nm^{-2} .km^{-1} \qquad (9)$$

NOTE: Since the delay values are obtained by numerical (trapezoidal) integration, some error will be incurred in the process, resulting in a corresponding λ_0 and S_0 error when compared to fit 1), of a magnitude dependent on the exact wavelengths measured.

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The above fit applies most appropriately to standard (NDS) (un-shifted) single mode fibers (ITU-T 6.6.5.2/TIA Class IVa) where there is a single zero-dispersion wavelength in the 1300 nm wavelength region.

Lambda Log Lambda Equation.

Another fit available is the so-called Lambda Log Lambda fit which is applicable to certain types of dispersion-shifted fiber designs (ITU-T 6.6.5.3/TIA Class IVb), where the zero dispersion wavelength is in the 1550 nm wavelength region.

Here, the dispersion data is fitted to an equation of the form:-

$$D(\lambda) = B + C + C.\ln(\lambda) \quad ps.nm^{-1}.km^{-1} \qquad (10)$$

where B and C are coefficients.

The zero-dispersion wavelength λo and zero-dispersion slope So are given by:-

$$\lambda o = \exp -(1 + B/C) \quad nm \qquad (11)$$

$$So = C/\lambda o \quad ps.nm^{-2}.km^{-1} \qquad (12)$$

Linear Equation.

Another fit available is a simple linear regression data fit. This is applicable to all fiber types if the wavelength range is sufficiently small, if a known data fit does not exist or if high accuracy of the fit parameters is not required for a fiber where an alternative fit is available. It is useful where there are too few measurements to enable multi-parameter fits to be used, for example. This fit is recommended for ITU-T 6.6.5.3/TIA Class IVb dispersion shifted (DS) fibers in the region close to lambda zero, and for fibers covered by CCITT 6.6.5.4 in the 1550 nm region.

Here, the dispersion data is fitted to an equation of the form:-

$$D(\lambda) = B.\lambda + C \quad ps.nm^{-1}.km^{-1} \qquad (13)$$

where B and C are coefficients.

An alternative form is:-

$$D(\lambda) = So.(\lambda - \lambda o) \quad ps.nm^{-1}.km^{-1} \qquad (14)$$

where:-

λo is the zero-dispersion wavelength in nm.

So is the zero-dispersion slope in ps/nm $^{-2}$.km^{-1}.

Thus:-

$$\lambda o = -C/B \quad nm. \qquad (15)$$

$$So = B \quad ps.nm^{-2}.km^{-1} \qquad (16)$$

Also

$$D_{1550} = C - B_{1550} \quad ps.nm\text{-}1.km \qquad (17)$$

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Differentiated 4-Term Polynomial.

This fit is designed for dispersion-flattened fiber measurements and is derived from a four-term Taylor Series expansion for the delay t(λ) in wavelength λ . The resulting equation for dispersion D(λ) in λ is of the form:-

$$D(\lambda) = A + B.\lambda + C.\lambda^2 \qquad ps.nm^{-1}.km^{-1} \qquad (18)$$

where A,B and C are coefficients.

The two zero dispersion wavelengths λo and corresponding slopes So are given by:-

$$\lambda o = \frac{-B +/- [\, B^2 - 4.A.C \,]^{1/2}}{2.C} \quad nm \qquad (19)$$

$$So = +/- [\, B^2 - 4.A.C \,]^{1/2} \quad ps.nm^{-2}.km^{-1} \qquad (20)$$

NOTE: Only the λo(s) and slope(s) which fall within the selected graphics wavelength boundaries of the printer output are available to the user.

Differentiated 5 Term Sellmeier Equation.

In this case the dispersion data is fitted to a differentiated 5- term Sellmeier equation (containing terms in λ raised to the powers +2,-2,+4 and -4) . This fit is applicable to most types of fiber, including dispersion-flattened types. The resulting equation has the form:-

$$D(\lambda) = A.\lambda + B.\lambda^{-3} + C.\lambda^3 + D.\lambda^{-5} \qquad ps.nm^{-1}.km^{-1} \qquad (21)$$

where A, B, C, D are coefficients.

The equation has five zero crossings, one of which is at λo=0. In the FD440 the other zero-crossings are found by mathematical iteration using Newton's Method [11], with a series of starting values in the wavelength range chosen for the graphical output of the instrument. This ensures convergence upon all the possible λo values (up to a maximum of four) in the graphics wavelength range selected, which are then checked for duplicate values. Only the differing λo's within the selected graphics boundaries are available to the user. The dispersion slopes at the different λo's are found by direct evaluation from equation (21). This fit is designed for dual window measurements on NDS fibers (ITU-T 6.6.5.2/TIA Class IVa) or for DF fibers. Since this fit is extremely “elastic” it is inadvisable to extrapolate this fit, because the fit may well “curve away from the line” beyond fitted points.

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Differentiated Odd Power 3 Term Sellmeier Equation.

In this case, the fiber delay versus wavelength is now fitted to the equation:-

$$t(\lambda) = A + B.\lambda^{-1} + C.\lambda^{3} \quad ps.km^{-1} \quad (22)$$

Hence the Chromatic Dispersion $D(\lambda)$ per unit length is given by:-

$$D(\lambda) = -B.\lambda^{-2} + 3.C.\lambda^{2} \quad ps.nm^{-1}.km^{-1} \quad (23)$$

Therefore the zero-dispersion wavelength λo and dispersion slope So at this wavelength are given by:-

$$\lambda o = (B/(3C))^{1/4} \quad nm \quad (24)$$

$$So = 2.B.\lambda o + 6.C.\lambda o^{-3} \quad ps.nm^{-2}.km^{-1} \quad (25)$$

This fit has been proposed for wide range dispersion data on un-shifted (Class B2 / IEC) fibers.

4.4 Sequence Of Operation for Dispersion Measurements.

This section briefly describes the sequence of operation of the FD440 when it is collecting data at a particular wavelength point.

The function of the COMMS up-link is to carry the 70MHz main oscillator signal all the all way from the Receiver unit to the Transmitter unit. At the Transmitter unit, the COMMS up-link detector detects the presence of a 70MHz modulation signal in the light exiting the COMMS up-link fiber, coming from the 1550 nm laser installed in the Receiver unit. The detector uses a phase-locked loop to “lock-on” to this signal. When the signal is detected and a good lock-is achieved, the green “LOCKED” LED on the Transmitter unit front panel will light. The loop produces a replica of the incoming 70MHz modulation, which is used to drive the LED source(s) at 70MHz. The modulated broad-band light from the LEDs is injected in to the test fiber. As long as the COMMS up-link is connected, the Transmitter will lock-on and correctly modulate the LEDs. This occurs continuously, whether the Receiver is performing measurements, or is “idling”.

In the Receiver unit, there follows a sequence for each measurement wavelength, as follows:

1) The detection wavelength modulation using the solid-state monochromator is switched on at the beginning of the measurement cycle for the dispersion point, at the appropriate values of $\square_1$ and $\square_2$.

2) The next stage of the measurement cycle is to set an input RF attenuator inside the phase detection system, so that the receiver signal is within the permissible range of the phase detection system, but not in overload condition.

3) Finally, the actual data acquisition cycle begins. Additional noise filtering is achieved on the outputs by increasing the phase/power detection time constants. After allowing these to “settle", the computer data acquisition system takes simultaneous digital readings of the outputs of the phase detection system and the DSP Lock-in Amplifier output. The computer calculates the differential phase taken and averages the result over many readings to achieve further noise reduction.

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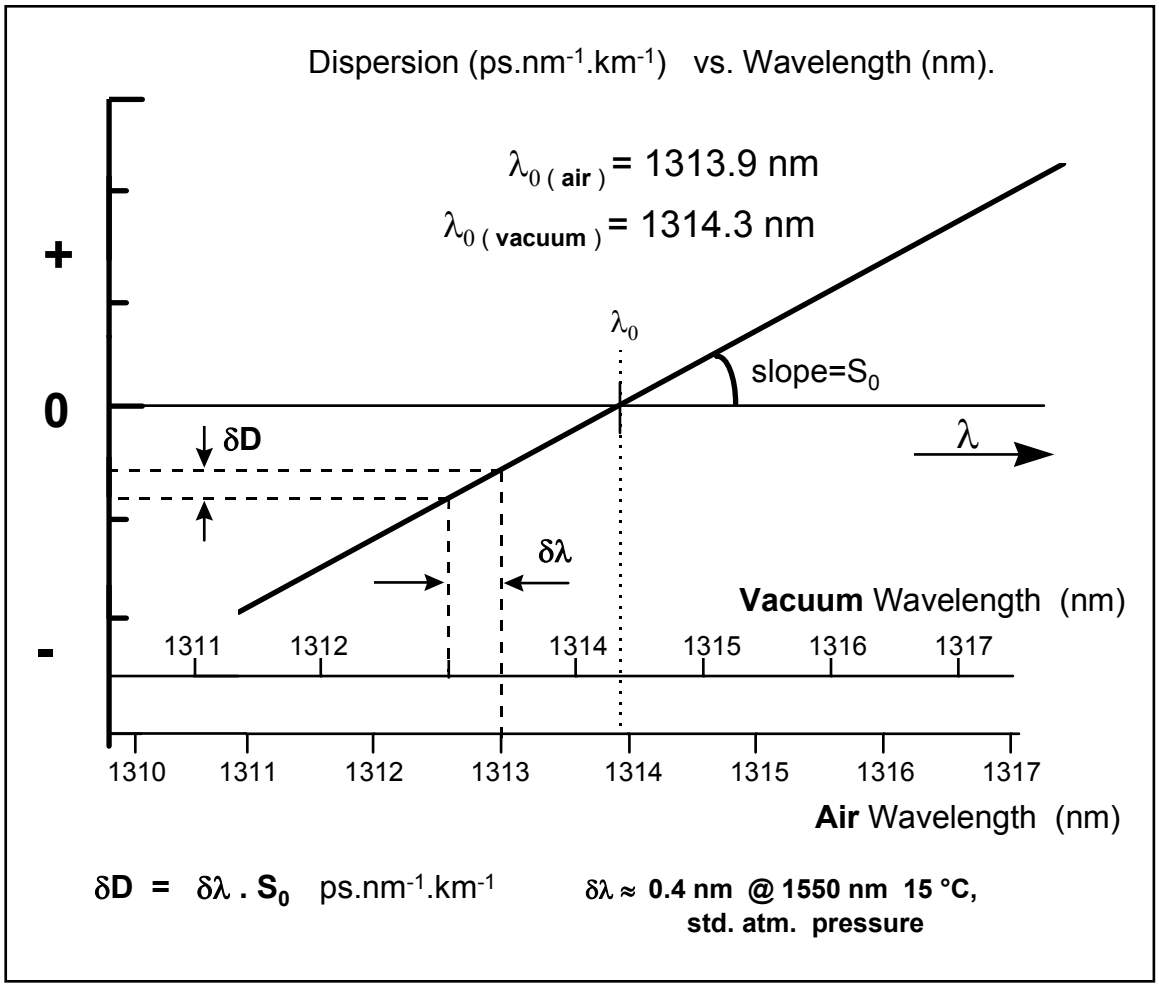
4.5 Correction of Air and Vacuum Wavelength.

Normally, the wavelengths used by the FD440 solid state monochromator are based on the wavelength in air. However, in some applications, it may be necessary to specify and use the wavelength in vacuum. This differs from the air wavelength. This section provides explanation.

In vacuum, the wavelength of light is related to the optical frequency, υ, by the speed of light, c in vacuum. However, in air the speed of light is altered by the refractive index of the air. In air, the refractive index is dependent on the air temperature, pressure and humidity. Therefore air wavelengths vary slightly with ambient. The variation is less than 0.05nm over the normal range of atmospheric pressures and normal room temperatures. However, since any such variation is un-desirable when wavelength accuracy is important, some applications may demand the use of vacuum wavelength. Typical cases are for long-haul high-bit rate systems where dispersion management is critical at the operating wavelength(s), trans-oceanic submarine systems and dense WDM systems where optical channels are dictated by optical frequency or vacuum wavelength. In the case of vacuum wavelength, the speed of light is unchanged and vacuum wavelength is constant for all environments.

Figure 4-4. Dispersion and Air and Vacuum Wavelength.

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The FD440 provides the possibility to measure dispersion in fibers using vacuum wavelengths instead of the more regular air wavelengths. The most important thing to remember is that vacuum wavelengths are approximately 0.4 nm longer than the corresponding air wavelength. This can lead to apparent lambda zero discrepancies if the air-vacuum difference is not taken into account.

The other important thing to remember is that the fiber dispersion characteristic is unique- there is only one fiber dispersion curve. The change from air to vacuum is simply a change of the x-axis scale. Unfortunately, the scales are not merely shifted by ~0.4 nm, but the shift is slightly different at each wavelength. The other point is that while lambda zero (in air) is ~0.4nm shorter than lambda zero (vacuum), the dispersion at a given wavelength in air will differ from that in vacuum by an amount dependent on the dispersion slope. This is illustrated in Figure 4-4.

The following formulae may be used to calculate the wavelength or zero-dispersion wavelength in vacuum, λ_{vac}, from wavelength in air, λ_{air}. Following the Tables of Physical and Chemical Constants [10], the corrections are conducted as a series of refinements to the refractive index, n, which is a function of wavelength, temperature, pressure, and humidity.

The basic relationship is:

$$\lambda_{vac} = n_X \lambda_{air} \qquad (26)$$

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where n_X is a refractive index computed with varying levels of refinement, indexed by X, as follows:

X	Corrected for:
g	Standard air
tp	Temperature and pressure
tpf	Temperature, pressure, and humidity

Vacuum wavelength is represented by the following, to simplify the notation:

$$\sigma = \frac{1}{\lambda_{vac}} \text{ with } \lambda_{vac} \text{ in } \mu m \qquad (27)$$

Standard air correction (dry air at 15° C and pressure of 101325 Pa, containing 0.03% by volume of carbon dioxide):

$$(n_g - 1).10^8 = 8342.13 + 2406030.0\left(130.0 - \sigma^2\right)^{-1} + 15997.0\left(38.9 - \sigma^2\right)^{-1} \qquad (28)$$

Note: Given the wavelength in air, equation 26 and 28 must be solved iteratively. However, the wavelength in vacuum can be derived from the wavelength in air using equations 29, 30 and 26, with better than 10^{-5} nm accuracy *without* the need for iteration:

$$\sigma_a = \frac{1}{\lambda_{air}} \qquad \text{with } \lambda_{air} \text{ in } \mu m \qquad (29)$$

$$(n_g - 1).10^8 = 8342.13 + 2406030.0\left(130.0 - \sigma_a^2\right)^{-1} + 15997.0\left(38.9 - \sigma_a^2\right)^{-1} \qquad (30)$$

Correction for temperature, *t* (° C), and pressure, *p* (Pa):

$$n_{tp} - 1 = (n_g - 1).\frac{p.\left[1 + p.(61.3 - t.).10^{-10}\right]}{(96095.4).(1 + 0.003661.t)} \qquad (31)$$

Correction for humidity- partial pressure H_2O, *f* (Pa):

$$n_{tpf} - n_{tp} = -f.\left(4.2918 - 0.0342.\sigma^2\right).10^{-10} \qquad (32)$$

Note: Equation 32 is indicated as appropriate in the visible region (0.405 μm – 0.644 μm) only for conditions not deviating very much from the normal laboratory conditions (*t*=20° C, *p*=100000 Pa, *f*=1500 Pa).

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Chapter 5

Attenuation Background.

5.1 Fiber Relative Attenuation Measurement.

The FD440 also has optional facilities to measure the relative spectral attenuation of the test fiber using the same fiber interface and measurement apparatus as for dispersion. This measurement is applicable to only single-mode fibers and cables. The FD440 is therefore potentially able to measure many vital fiber parameters using one instrument.

For attenuation measurement, the FD440 uses the power detection capabilities of the high frequency digital phase detection system. In this case the phase (delay) information is not used. Refer to Chapter 3 for a basic schematic block diagram.

A 70MHz master oscillator signal in the Receiver Unit is sent via the COMMS fiber up-link to the FD400 Transmitter Unit. The 70MHz signal is used to drive the LED so that the light intensity is sinusoidally modulated. This modulated light is injected into the test fiber or cable and the output from the fiber detected at the Receiver unit. The modulation waveform is reconstructed in the Receiver Unit and passed to the digital phase detector system. The original undelayed LED drive signal is used as the reference phase for the phase meter. The phase meter outputs are two digital bit streams representing the In-phase (I) and Quadrature (Q) components of the signal respectively:-

$$I = A.\cos\phi \quad \text{Volts} \qquad (1)$$

$$Q = A.\sin\phi \quad \text{Volts} \qquad (2)$$

where ϕ is the signal phase relative to the reference phase and A is the signal amplitude (in turn proportional to the light intensity at the detector).

Thus by detecting I and Q together and using data averaging, the light power may be detected. The algorithm for calculating the power, P is:

$$P = 10 \log_{10} [(I^2 + Q^2)^{1/2}] \quad \text{dB} \qquad (3)$$

The spectral attenuation is now measured as follows:

During a measurement of the system attenuation reference, the FD440 can record light power information at several user-selected wavelengths using the high- frequency phase detection system. The light power data Pr (λ) measured at a modulation frequency of 70 MHz is then available for use as a reference. By inserting and measuring the test fiber, the FD440 will compare the power transmitted by the fiber at each of the wavelengths used with the reference powers. The light power transmitted by the fiber Pf (λ) is measured at these wavelengths and the fiber attenuation a(λ) per unit fiber length is given by:

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$$a(\lambda) = 10/L.\ \log_{10}.[Pf(\lambda)/Pr(\lambda)] \quad dB/km. \qquad (4)$$

However, this measurement is subject to some error arising from loss at the extra fiber splice used when measuring the test fiber compared to when measuring the reference loop alone. This error may be quite small for long fibers. In order to reduce this error to a minimum, facilities are provided to use a cut-back technique (e.g. ITU-T recommendation G.650, or IEC 793-1), where, after measuring the total fiber transmission, the fiber is cut back to a short length and fixed bend radius placed in this short length, the second optical splice is retained and the resultant transmission $Pc(\lambda)$ used as the reference power data. The fiber relative attenuation per unit fiber length, L, is now given by:

$$A(\lambda) = 10/L.\ \log_{10}\ [Pf(\lambda)/Pc(\lambda)] \quad dB/km. \qquad (5)$$

Because the Receiver has a single-mode fiber pigtail (for optimum dispersion performance), the accuracy of this procedure is dependent on the repeatability of the fiber splices or connectors.

The FD440 can measure spectral attenuation in the range 1150nm to 1700nm using the standard LEDs fitted. The high power of the LEDs in the 1310nm and 1550nm region allows for high dynamic range measurements.

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