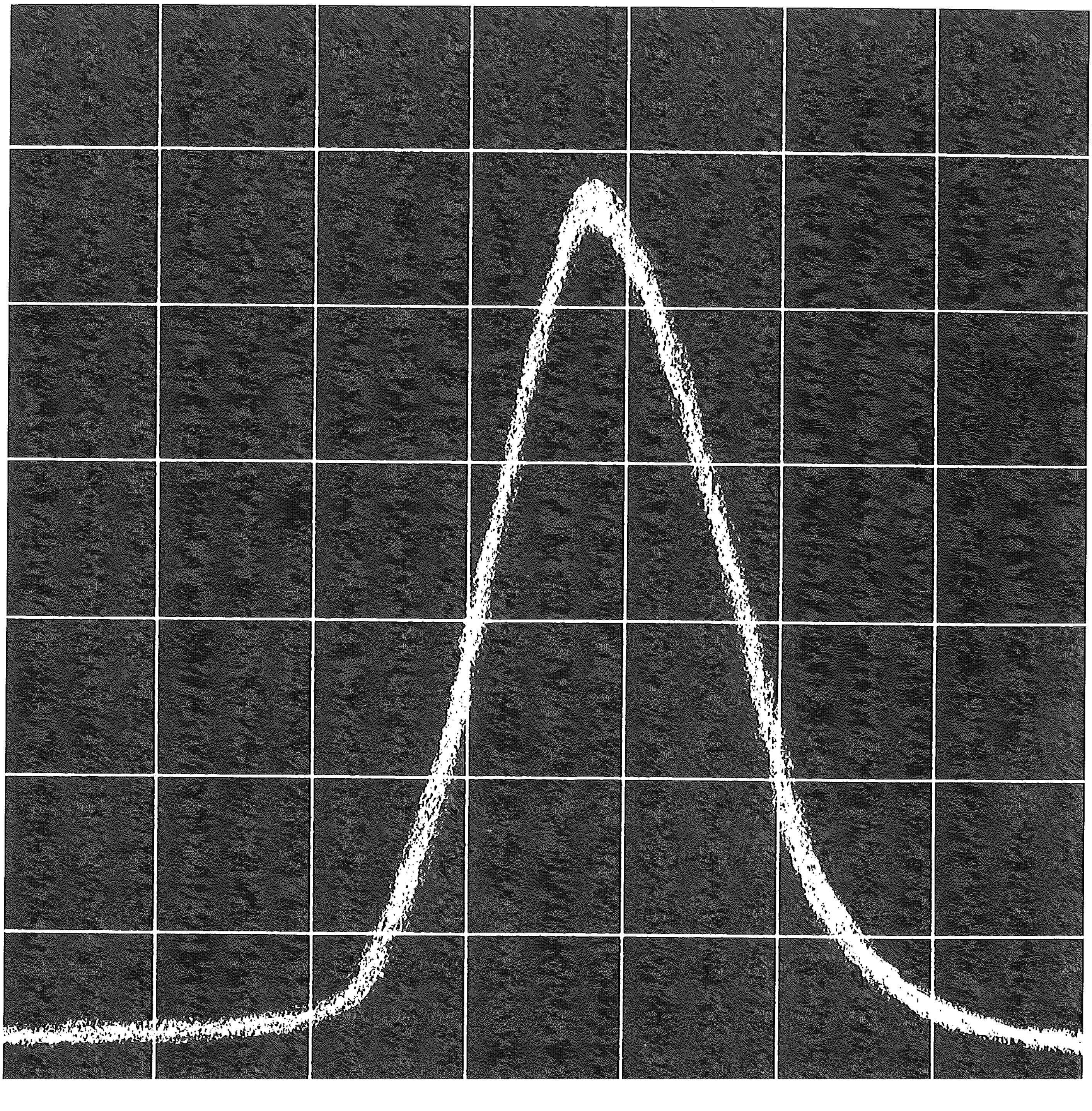
OPTO-ELECTRONICS INC.

RESEARCH IN ELECTRO-OPTICS

REFERENCE MANUAL

MILLIMETER RESOLUTION

OTDR SYSTEM



REFERENCE MANUAL

MILLIMETER RESOLUTION

OTDR SYSTEM

This reference manual is designed to explain the general theory and operation of the OTDR system and its components along with the TDR Processor and its functions. For a step by step explanation of the various measurement procedures consult the Training manual.

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1 GENERAL DESCRIPTION

The Opto-Electronics MILLIMETER RESOLUTION OTDR SYSTEM is an ultraprecise reflectometer designed to detect and measure reflective features and Rayleigh backscattering in fibers and fiber cables. It is also well suited to make measurements in air or other media in reflection or in transmission mode.

This system is designed to detect Fresnel reflections and Rayleigh backscatter at most wavelengths from 0.4 μm to 1.6 μm. This combination provides advantages over conventional OTDR's for a number of applications and makes possible many new applications. The uniqueness of the system stems from the use of 100 picosecond wide optical pulses, a fact which enables millimeter resolution to be routinely achieved. Furthermore, high power pulses coupled with high sensitivity detectors provide a much wider dynamic range than can be achieved with conventional OTDR's.

The modular construction provides a great flexibility for the system. An interchange of modules allows for operation over the wavelength range of 630 to 1550 nanometers. A trade-off in sensitivity for resolution allows for operation from literally counting photons with several centimeters of resolution to utilizing detectors with lesser sensitivity but providing submillimeter resolution. Any particular system can work into all fiber sizes, although a dynamic range penalty must be paid for mismatching fiber size. For the ultimate performance, the relevant modules are all designed to operate into the designated fiber size. As indicated above, the system is not limited to OTDR applications but can be utilized in transmission and scattering measurements as well.

Applications for the MILLIMETER RESOLUTION OTDR system are very wide ranging. The system is ideally suited for measuring absolute and relative distances in SM or MM fibers from 1 mm to 30 km without lead-ins or masking; for locating the precise position of connectors, couplers, splices and breaks or other faults in fibers and cables; for measuring insertion and return losses of components or links; for testing, mapping and monitoring LANS in buildings, ships or airplanes; for measuring the performance of sensors, connectors, couplers, attenuators, switches and integrated optics; for measuring the precise strain, time delay changes, and loss changes of fibers in cable pull testing, cable installations, fiber spooling and fiber payouts; for measuring precise group index variations, strain and temperature coefficients of fiber effective group index, and; for many other applications where picosecond or millimeter resolution and accuracy is required.

The MILLIMETER RESOLUTION OTDR system requires an external, single channel, low frequency display oscilloscope to provide visual read-out of the signal pulse. The system can be rack mounted in three parts; the Mainframe holding the various modules, the Processor and the Display oscilloscope.

2 SPECIFICATIONS and PERFORMANCE

The specifications given here are for several of the standard systems and do not include custom built systems or the performances attainable by special techniques. The number and variation of applications are very high so only generalities can be dealt with in this manual. The information given is believed to be accurate at the time of publication but Opto-Electronics reserves the right to change these specifications and performance data as new improvements are implemented.

Distance accuracy and resolution are primarily receiver speed dependent as the transmitters tend to be faster than the receivers. The specifications are given for various types of receivers so that tradeoff choices can be made between resolution and sensitivity. Dynamic range, on the other hand, is transmitter dependent, fiber dependent and receiver dependent.

Standard singlemode fiber, here, implies 9/125 μm core/clad fiber for 1300 nm operation and 4/125 μm fiber for 850 nm operation. Other singlemode fiber sizes and polarization maintaining fiber are considered nonstandard.

Standard multimode fiber includes 50/125, 62.5/125, and 100/140 μm core/clad. Note that 200 and 400 μm core fiber is available but this and other sizes are considered nonstandard.

2.1 DEADZONE

This is a conventional OTDR term and is not applicable to the Opto-Electronics reflectometer. See singlepoint and two point resolution below.

2.2 DISTANCE ACCURACY

Time of flight accuracy: 0.1% or 10 ps, whichever is largest. This translates to 0.1% or 1 mm, whichever largest, assuming an effective index of refraction of 1.5.

2.3 DISTANCE RANGE

Delays in excess of 300 μs are possible. This represents a fiber length of approximately 30 km. Note, however, that this distance can rarely be realized due to losses and/or pulse dispersion.

2.4 DISTANCE RESOLUTION, Single Point

Single point resolution is defined as the minimum length change which can be measured and displayed. The pulse shift in time is used to make this measurement. Values shown are for negligible pulse dispersion and are given in units of ps and calculated values in mm assuming n = 1.5.

SINGLE POINT RESOLUTION, ps (mm)

	Signal to Noise Ratio (SNR)			
RECEIVER	50	20	10	5
PPD	1 (0.1)	2 (0.2)	4 (0.4)	10 (1.0)
PAD	3 (0.3)	5 (0.5)	10 (1.0)	25 (2.5)
PPC10:	------------	------------	------------	------------
LOW	3 (0.3)	5 (0.5)	10 (1.0)	25 (2.5)
MED	6 (0.6)	12 (1.2)	24 (2.4)	60 (6.0)
HI	20 (2.0)	40 (4.0)	80 (8.0)	200 (20)
PPC20:	------------	------------	------------	------------
NORMAL	3 (0.3)	5 (0.5)	10 (1.0)	25 (2.5)
HIGH	6 (0.6)	12 (1.2)	24 (2.4)	60 (6.0)

2.5 DISTANCE RESOLUTION, Two Point

Two point resolution is defined as the minimum separation which can be measured between two identically reflective features. Normally, these values would be approximately one half the system pulse width. However, the Opto-Electronics *deconvolve* feature allows for even better resolution. Values shown for various pulse height ratios (PHR) and signal to noise ratios (SNR) are given in units of ps and (mm), the mm calculated for n = 1.5.

TWO POINT RESOLUTION, ps (mm)

PULSE HEIGHT RATIO	Signal to Noise Ratio (SNR)			
	50	20	10	5
1:1	2 (0.2)	3 (0.3)	5 (0.5)	12 (1.2)
2:1	3 (0.3)	5 (0.5)	11 (1.1)	25 (2.2)
5:1	5 (0.5)	10 (1.0)	22 (2.2)	50 (5.0)

RECEIVER	Two Point Resolution
PPD	Above figures apply
PAD	Multiply above figures by 3
PPC10:	
LOW	Multiply above figures by 3
MED	Multiply above figures by 6
HI	Multiply above figures by 20
PPC20:	
NORMAL	Multiply above figures by 3
HIGH	Multiply above figures by 6

2.6 LOSS ACCURACY

Loss measurements made with the TDR Processor are accurate to ±5% or ±0.02 dB whichever is largest. Loss measurements with the POA calibrated Attenuator are accurate to ±1% or ±0.02 dB whichever is largest.

2.7 DYNAMIC RANGE, Return Loss

This is defined as the spread in dB units between the output signal and the minimum detectable return signal (SNR = 1), including averaging.

RETURN LOSS (dB)
REAL-TIME, 4 averages, 30 updates per second.

Fiber Type		Multimode			Singlemode		
Receiver		PPD	PAD	PPC	PPD	PAD	PPC
Transmitter	850 nm	39	55	86	31	47	80
Transmitter	1300 nm	22	38	68	15	31	61
Transmitter	1550 nm	20	36	66	13	29	59

RETURN LOSS (dB)
AVERAGED TIME, 16,384 averages, 2 minutes.

Fiber Type	Multimode			Singlemode		
Receiver	PPD	PAD	PPC	PPD	PAD	PPC
Transmitter 850 nm	57	73	104	49	65	98
Transmitter 1300 nm	40	56	86	33	49	79
Transmitter 1550 nm	38	54	84	31	47	77

AVERAGED TIME, 65,536 averages, 8 minutes.
This will add 3 dB to the values immediately above.

2.8 <u>DYNAMIC RANGE</u>, Insertion Loss

This is defined as the spread in dB units between the output signal and the minimum detectable signal (SNR = 1), including averaging, from a 4% reflecting surface on the far side of the loss feature. In the event that the reflection can be increased to 100%, 14 dB can be added to the values given below. Values are given for real-time, (no averaging) and for 2 minute averaging.

INSERTION LOSS (dB)
REAL-TIME, 4 averages, 30 updates per second

Fiber Type	Multimode			Singlemode		
Receiver	PPD	PAD	PPC	PPD	PAD	PPC
Transmitter 850 nm	12	20	36	8	16	32
Transmitter 1300 nm	4	12	27	0	8	23
Transmitter 1550 nm	3	11	26	0	7	22

INSERTION LOSS (dB)
AVERAGED TIME, 16,384 averages, 2 minutes.

Fiber Type	Multimode			Singlemode		
Receiver	PPD	PAD	PPC	PPD	PAD	PPC
Transmitter 850 nm	21	29	45	17	25	41
Transmitter 1300 nm	13	21	36	9	17	32
Transmitter 1550 nm	12	20	35	9	16	31

<u>Note:</u> The flexibility of this system allows for two-ended loss measurements in transmission, thereby bypassing the Coupler. In this instance double, then add 14 dB to the above figures.

AVERAGED TIME, 65,536 averages, 8 minutes.
This will add 3 dB to the values above.

2.9 MECHANICAL

	MF20 Mainframe:	TDR Processor:
Size	19"W x 14 1/4"L x 7"H	12"W x 13"L x 5 1/2"H
Weight	6 1/4 kg (14 lb)	4 kg (9 lbs)
Capacity	11 Single module bays	---
Mounting	Standard 19" rack or bench top	Standard 19" rack or bench top

2.10 ENVIRONMENTAL

Temperature	+10C to +40C operating
	-15C to +60C storage
Laser Safety	Meets Class I laser product safety

2.11 ELECTRICAL

Power	110/220 V, 50/60 Hz line

2.12 OPTICAL CONNECTORS

Standard	ST
Custom	Biconic, FC, D4, SMA

2.13 INTERFACES

Display	
Oscilloscope	Requires a single channel low frequency lab type oscilloscope.
Printer	Auxiliary Epson style dot matrix with graphics capability.
RS232	Data port to dump stored data from TDR20 Processor.
GPIB	Enables fully automatic remote operation of OTDR and data transfer.

3 OPERATING PRINCIPLES

The Opto-Electronics MILLIMETER RESOLUTION OTDR is designed to detect and measure Fresnel reflections and Rayleigh backscattering for most wavelengths from 0.4 μm to 1.6 μm. It makes three measurements and uses these three results to calculate all the other quantities. These three measurements are outlined in more detail below. There are fundamental differences between conventional OTDRS and the Opto-Electronics MILLIMETER RESOLUTION OTDR which offers new and unique measurement methods. To help point out some of these features a series of definitions is also given below.

3.1 <u>THE THREE MEASUREMENTS</u>

The three basic measurements performed by the system are *time of flight*, *energy loss* and *pulse width*. The calculations performed with these measurements provide accurate values for distance, return loss, insertion loss, dispersion and bandwidth. In addition, the accuracy of this instrument makes feasible a host of sensor applications.

3.1.1 <u>TIME OF FLIGHT</u> The Opto-Electronics MILLIMETER RESOLUTION OTDR measures the time of flight of an optical pulse launched into the near end of the fiber and returned to the same end from the far end or from a feature along the fiber, having Fresnel reflection. This measurement allows for the calculation of absolute length or of small length changes, as shown in Equation 3-1.

$$d = ct/2n \qquad (3\text{-}1)$$

where d is the distance, c is the velocity of light in vacuum, t is the time of flight measured and n is the effective group index of the fiber or the medium.

3.1.2 <u>ENERGY LOSS</u> The loss caused by a feature can be measured by taking the ratio of two known Fresnel reflections; one at the input end, the other at the output end, of the test piece. If the two reflectors are identical and the areas under the curves of the reflected pulses are I1 and I2, then the loss (L) in decibels is calculated from

$$L = ½ \cdot 10[\log(I_2/I_1) \qquad (3\text{-}2)$$

Alternatively, the loss caused by a feature or the loss of a segment of fiber can be measured using the Rayleigh method. In this case, the backscatter curve is taken from a small length of fiber, one upstream and one down stream from the feature or the segment. If the fiber length is the same for both measurements, then the insertion loss is calculated by the TDR processor according to equation 3-2. Here again I_1 and I_2 are the up and down stream areas under the curves.

3.1.3 <u>PULSE WIDTH</u> Measurement of the input and reflected pulse widths can be utilized in calculation to determine the dispersion of the test piece at the measured wavelength. The Equation 3-3 will give this.

$$D = \{W_R^2 - W_I^2\}^{½} \qquad (3\text{-}3)$$

Where D is the dispersion, W_R is the reflected pulsewidth and W_1 is the input pulsewidth. This can be used to provide an approximate bandwidth calculation for a length of fiber. More precise calculations are accomplished with the Opto-Electronics Fast Fourier Processor Model FPS10.

3.2 <u>FRESNEL vs RAYLEIGH</u>

The Rayleigh backscatter method offers advantages in measuring and analysing long lengths of fiber typical of long haul communications. When shorter lengths are measured difficulties are encountered. These difficulties stem from deadzone (due to Fresnel reflections) and lack of sensitivity (due to the very low level of scattering from a short segment of fiber). The strong Fresnel reflection , on the other hand, comes from an interface so that it can be probed with a very short optical pulse. This also means high resolution (submillimeter) is a reality. This high resolution combined with new analytic techniques makes possible a whole new range of measurements.

One can view the Rayleigh backscattering machine as a telescope. The operator views the entire picture at once but can zoom in on specific features. Still the Telescope cannot perform as a microscope. The Fresnel machine, on the other hand, is a microscope which can look at features in some detail and locate them with great precision. Again, one can demagnify and look at the large picture but not quite as well as with a telescope.

3.2.1 <u>FRESNEL REFLECTION</u> A Fresnel reflection is caused by a discreet discontinuity in the fiber, causing a sharp step in the index of refraction. This occurs at fiber-air interfaces such as can be found in fiber connectors, fiber breaks, fiber cleaves, pigtailed detectors or lasers, fiberoptic switches, attenuators, etc. Fresnel reflections do not occur at fusion spices, macro and microbends, fused-tapered couplers and angle polished singlemode connectors. The approximate value of reflected power from a good cleave or a flat polished connector for standard glass fibers is 4% of the incident power, or -14 dB.

3.2.2 <u>RAYLEIGH BACKSCATTER</u> Rayleigh backscatter is caused by small density variations or impurities which are much smaller than the wavelength of the probing light and which extend throughout the entire length of the fiber. The scatter power is wavelength dependent and it is approximately 50% or 3 dB per kilometer of fiber at 850 mm and 7% or 0.3 dB per kilometer at 1300 nm of the incident power. The Rayleigh backscattered light from the 1-2 cm wide Opto-Electronics laser pulse at 850 mm is approximately 40 dB below the Fresnel signal of a 4% cleave.

3.3 <u>DEFINITIONS</u>

Some of the common terms associated with the conventional Rayleigh OTDR system are defined below. Where relevant, these definitions are explained as they pertain to the Fresnel system. In addition a few new terms, peculiar to the Fresnel system are introduced.

3.3.1 <u>ACCURACY</u> In the conventional system this is called distance measurement accuracy and refers to how accurately the OTDR can measure distance to or between items such as connectors, splices or the fiber end. This implies knowledge of the index of refraction. For the Opto-Electronics OTDR the accuracy is stated in terms of time.

3.3.2 <u>DEADZONE</u> In the conventional system this is the displayed distance between the departure from the backscatter trace and the point where the signal returns to the backscatter trace within a given error band. This departure is usually caused by a strong Fresnel reflection. The deadzone is made up of two parts; the duration of the light pulse plus the recovery time of the detector. In the conventional system detector recovery time can be minimized by masking the light for the duration of the pulse. In the Opto-Electronics system, this cannot be done due to the very short time scale. Hence the deadzone depends on signal strength as recovery time depends on this parameter. Even so, in the Rayleigh mode, the PFOS OTDR system deadzone is measured in centimeters as opposed to meters or tens of meters for the conventional systems.

In the Fresnel mode the system measures Fresnel reflections which are much stronger than the Rayleigh backscatter. Here the deadzone phenomenon is absent. However, one Fresnel reflection can interfere with another, a difficulty which is dealt with under two point resolution below.

3.3.3 DYNAMIC RANGE In the conventional system the dynamic range is the difference between the (extrapolated) start of the backscatter trace and the noise level, expressed in decibels one-way loss. The noise level is calculated so that 98% of all data points fall below this level. The dynamic range is specified for a three minute averaging period. This definition fits for the Rayleigh mode of operation but in the Fresnel mode another definition is required.

For Fresnel mode the dynamic range is stated to be the difference in decibels between the outgoing signal amplitude and the minimum detectable returned signal (SNR = 1) with two minutes of averaging.

3.3.4 EFFECTIVE GROUP REFRACTIVE INDEX This is the factor by which the speed of light has to be divided to yield the propagation velocity of light pulses on the fiber. This must be entered into the OTDR to give distances.

3.3.5 SINGLE POINT RESOLUTION This is the minimum length change which can be measured and displayed. The actual measurement is done in time with the distance being calculated from the time measurement and the index of refraction. For this calculation the value of n is taken as 1.5.

3.3.6 TWO POINT RESOLUTION This is the minimum separation which can be measured between two identically reflective features. The Opto-Electronics deconvolve feature enables separation of composite pulses of equal or unequal size. This feature enhances the resolution considerably.

3.3.7 LOSS ERROR This is the deviation between the OTDR measured loss of a fiber component and the true loss of the component, divided by the true loss of the component, as a function of the displayed power level, in dB/dB.

3.4 TYPICAL RETURN LOSS VALUES

In Figure 3-1 below, return loss measurement capability for various standard Opto-Electronics OTDR's is compared with return loss values of typical features and components commonly found in most fiberoptic systems. This figure gives a good idea of how far "down" the Opto-Electronics MILLIMETER RESOLUTION OTDR can reach to detect and measure these features.

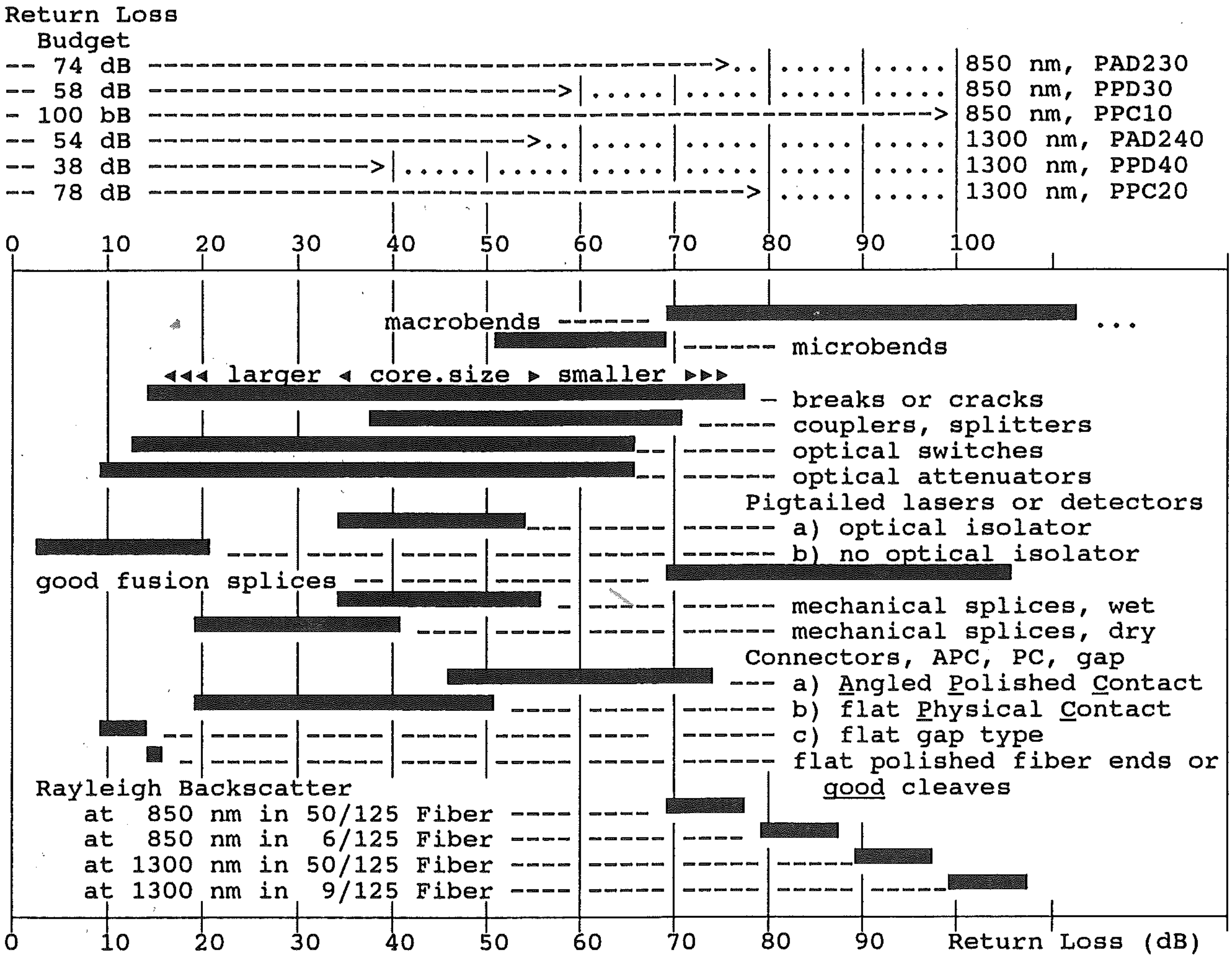


Figure 3-1

The dynamic range for return loss of four typical configurations of the Opto-Electronics MILLIMETER RESOLUTION OTDR is compared with the return loss values for common fiberoptic features, components and faults, as well as with the Rayleigh backscatter signal for the 100 ps wide probe pulse used by the system. It is seen that some models have limited capabilities while the photon counting configuration can detect every feature that is commonly found in a fiber optic link or system. The loss values shown are at SNR = 1, with 2 minute averaging.

4 OTDR SYSTEM AND COMPONENTS

The OTDR system consists of the Components and Outputs as shown in Figure 4-1 below. The Mainframe and its various plug-in modules are described here, while the Outputs and the Processor are described elsewhere.

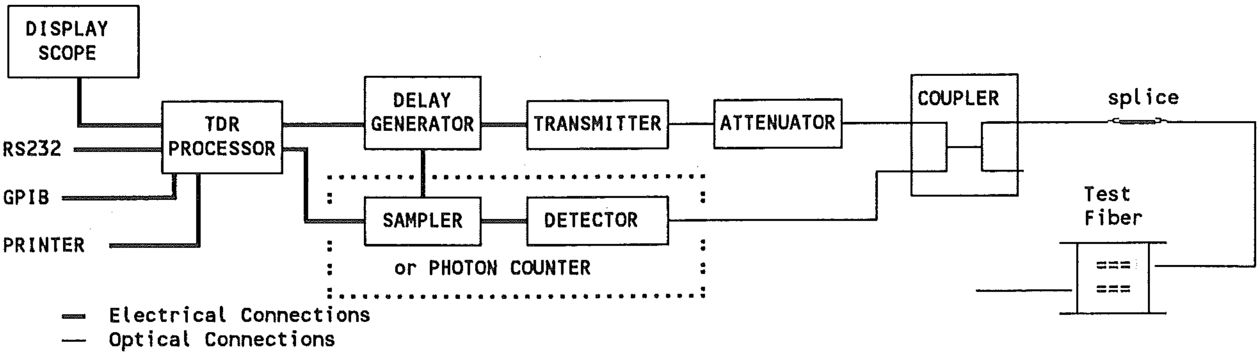


Figure 4-1
Components and outputs of the OTDR system

4.1 THE OTDR SYSTEM

The typical OTDR system is made up of the components shown in Figure 4-1. Some of the components are common to all systems and some are optional. Variations are possible in the laser, detector, coupler and attenuation modules depending on the required wavelength, fiber size, resolution and sensitivity. How the system and some of the components work is described here.

4.1.1 HOW THE SYSTEM WORKS The heart of the OTDR system is the Delay Generator, which operates at a predetermined repetition rate. For short distances this repetition rate is 33 KHz. The trigger out causes the Laser Transmitter to fire at this rate providing the short optical pulse. The returning optical signal is sensed by the Receiver which transforms the short optical pulse into a fast electrical pulse. The fast electrical pulse is detected with the sampling system which is also triggered by the Delay generator. The Sampler passed the pulse data to the Processor. In the case of the Photon Counting Receiver, the individual returning photons are counted when the Photon counter is triggered and this data is passed over to the Processor. The Processor does the averaging and the relevant calculations. All of this is displayed or channelled to the outputs as desired.

The optical signal leaves the Transmitter and can pass through an optional calibrated Attenuator or directly into a Fiber Optic Coupler. At this point the Coupler acts as a splitter providing a signal to the two outputs which can be utilized individually or together. The signal is launched from one or both of these outputs into the test fiber. The returned signal from some fiber feature, is then directed back through the Coupler to the Receiver where it is converted into an electrical signal.

The system launches a short light pulse and measures the time of flight, the energy loss and the change in pulse width. All other information is calculated on the basis of these three values.

4.1.2 <u>HOW THE DELAY GENERATOR WORKS</u> This is easiest understood by referring to Figure 4-2 below. The Delay Generator runs at a set repetition rate. If the time of the Trigger Out is taken as zero, then a Reference value can be set to any point in time within the *Operating Range*. The Delay can be positive or negative but the Reference plus Delay must fall within the *Operating Range*. The Delay is measured from the Reference point to the left side of the scope Window position. The Window Size is determined from the Delay Generator T/DIV value, (Window Size = 10 x T/DIV). Again, Reference plus Delay plus Window Size cannot extend beyond the *Operating Range*. An attempt to do so will cause the error indicator, (E), to light. Press CLR and re-enter. The Window position, (Delay), can be moved by direct entry or stepped by the Delay Generator STP size value. When FN-REF-ENTER is pressed, the current Delay is added to the current Reference to give a new Reference and a Delay equal to zero while the Window position remains unaltered in the *Operating Range*. For delay times of less than 2 μs the Delay Generator operates at about a 33 kHz repetition rate. This is the rate at which the laser is triggered. For longer delay times the rate slows down as required.

```
Trigger Out                              Window Size |←      →|
|                                                    ┌────────┐
|────────────────────────────────────────────────────│        │──────────>
0<--------- Reference ----------> <------- Delay ------>└────────┘   319995 ns
 <----------------------------- Operating Range ----------------------------->
```

Figure 4-2

4.1.3 <u>HOW THE SAMPLING UNIT WORKS</u> The electrical signals are too short to be displayed in real time even with the fastest of oscilloscopes. Thus, a sampling technique is employed. To understand how this works, imagine the Display scope screen divided into 256 points. If the entire screen represents 500 ps (50 ps/Div) then each point represents about 2 ps, (500-256). While it is not possible to follow a pulse in this time frame it is possible to sample the pulse voltage at point one, say, of the first pulse, then at point two, (one pulse plus 2 ps later) of the following pulse and so on. With this sampling technique, one sweep can be built up with 256 samples. It is obvious that the repetitive pulses must be identical and that one must have a delay generator with very low jitter. With a Delay generator repetition rate of 33 kHz, a display screen update of approximately 30 Hz is possible.

4.1.4 <u>HOW THE PHOTON COUNTER WORKS</u> There are 256 horizontal points on the Display screen. Each point represents a sequential point in time at which the photon counter is turned ON. The length of the Photon Counter ON time is a function of the SENSITIVITY setting on the PPC10. For example, with the SENSITIVITY setting at MED the photon counter ON time is 0.8 ns.

The delayed electrical pulse triggers the photon counter at a precisely determined time. The PPC10 will look for and count, if present, a photon return from each pulse. The count is one or zero. If two or more photons arrive at the same time the count is still one. At each of the 256 points the PPC10 sits for four pulses. Thus the display has five levels. The baseline represents zero counts out of four pulses. The first level represents one count out of four and so forth. When a solid line is observed at the four count level, this indicates that the counter is being saturated: i.e. more than one photon is arriving at each count.

In real time, one sees a lot of dots on the screen. If the TDR30 is used on 512 averages for example, then it takes 512x256 or 131,072 pulses to construct a sweep as displayed on the scope after a measurement or reference is taken.This represents a little over 4 seconds in time. As there are 256 points in the vertical sense as well, a reasonable number of averages will produce a well defined pulse shape.

For best results, the light should be attenuated with the calibrated Attenuator or at the laser-jumper interface until the feature being viewed shows 1 to 3 counts in real time. This indicates a return of photons, but prevents saturation.

4.2 THE OTDR COMPONENTS

The front panel features and functions of the various modules and components making up the system are explained here.

4.2.1 THE MAINFRAME The Mainframe function is twofold; first, it houses the operating modules and second, it provides power to the modules. Power is provided by depressing the POWER button on the left side of the Mainframe. Note that it is recommended to power down to remove or replace any of the modules.

4.2.2 THE TRANSMITTER The PPL30K is the optical laser source for the system. It will be of the chosen wavelength, pigtailed with the chosen fiber size, and normally connectorized with an ST style optical connector. Front panel connections and functions are explained below.

"TRIGGER IN" When the laser is to be triggered externally, the trigger is supplied through this BNC connector. " TRIGGER IN" is used as the input from the Delay Generator.

"PRETRIGGER OUT" Whether the laser is triggered internally or externally, a low jitter pretrigger out is provided. This pretrigger is about 80 ns before the laser pulse.

NOTE The Transmitter can be used as an independent source in one of two ways. On "INTERNAL TRIGGER" the Transmitter will operate at a fixed 33 KHz repetition rate while on "EXTERNAL TRIGGER", it can be triggered externally from single shot to a 33 KHz repetition rate. In either case, there is a low jitter "PRETRIGGER OUT" provided to facilitate triggering of an oscilloscope or other device.

"READY" This indicator comes on as soon as the laser has reached its operating temperature. This is factory set at about 23 °C, thus it will normally come on quickly unless the operating area temperature is excessively high or low.

"LIGHT OUT" The laser light pulse comes out here. This connector should always have a dust cap on when not in operation or there is no jumper connected. The average light power emitted by this laser is much below the Class I power level. Nevertheless, it is suggested that the operator not stare directly into the output when the laser is operating.

"INTERNAL/EXTERNAL" This refers to the Transmitter trigger source. When the module is being used in the OTDR system the trigger must be on external and must come from the PDG Delay Generator to operate.

4.2.3 OPTICAL ATTENUATOR The calibrated Optical Attenuator is a very useful addition to the sampling system as it provides a convenient way to measure attenuation. It is a necessary component for the photon counting system as the dynamic range of the Photon Counter is inherently very small.

"LIGHT.IN/LIGHT.OUT" While the Attenuator will operate in either direction, it has only been calibrate for operation with the light in the direction indicated. Keep dust covers on the ports when not in use.

"ATTENUATION" The window displays the software version in use, the wavelength for which the Attenuator has been calibrated and the attenuation at the calibrated wavelength. The attenuation can be displayed in absolute terms or relative to a chosen reference.

Variable Control This controls the attenuation value as indicated in the display.

"SET ZERO" This key toggles the attenuation read-out between the absolute attenuation and the attenuation relative to a chosen reference.

"WAVE-LENGTH" This key causes the display to show the calibrated wavelength in operation. Two or more quick depressions will cause the operational wavelength to change in cyclic fashion though each wavelength for which the unit has been calibrated. Holding down this key, while depressing the SET ZERO KEY will cause the default calibration to change. For details, see the Attenuator section of the PFOS manual.

4.2.4 THE OPTICAL COUPLER The Coupler is required for normal OTDR applications and it is recommended that the ports be used as indicated in the PFOS Operating Manual; normally, light from the Transmitter into P2, light to the Receiver from P3, light to the test piece from P1. The Coupler can be bypassed in transmission measurements or through the air measurements. Keep dust covers on the ports when not in use.

4.2.5 THE RECEIVER; Sampling System There are basically two types of detectors utilized as Receivers in the OTDR system. The first, allowing for the highest spatial resolution, is a detector employing an avalanche photodiode. The second, an amplified avalanche photodiode, provides an improvement of about 16 dB in sensitivity at the expense of some resolution. Both detectors convert the short optical pulses to short electrical pulses which must be analyzed with sampling techniques. Thus the Sampling module forms part of the Receiver.

4.2.5.1 AVALANCHE DETECTOR - (Amplified and Nonamplified) Both types of detectors have similar front panels and operate identically. They differ only in sensitivity and time response. Generally, the detectors are more sensitive and faster at 850 nanometers than at 1300 nanometers.

"LIGHT IN" Normally an ST style connector with 100/140 core/cladding fiber is provided for the optical input. A dust cap should always be in place when the module is not being used.

"SIGNAL OUT" The electrical signal out is connected to the sampling module. The detector can be used independently from the OTDR system if desired.

"OVERLOAD" This light comes on when there is too much light falling on the detector, causing excessive current, ($>150\,\mu$A), through the diode. The diode is current limited to prevent damage but if operated in this region erroneous results must be expected.

"GAIN ADJUST" This is a ten turn potentiometer which allows fine adjustment of the bias voltage and hence the avalanche gain. Adjustment from breakdown voltage to about 85% breakdown voltage is provided for.

"HIGH-GAIN/LOW-GAIN" In the LOW GAIN position the diode operates as a pin diode with no avalanche gain. The variable voltage adjust has no effect in this position. In the HIGH GAIN position the voltage can be varied from breakdown voltage to about 85% of breakdown voltage. This allows a variation in gain from maximum to about 10% of maximum.

4.2.5.2 SAMPLER The PSU20 Sampler module is required to measure the very fast electrical signals generated by the high speed detectors.

"SIGNAL IN" The signal from the detector is fed in here. Care should be taken to use a high quality coaxial cable for this connection.

"TRIGGER IN" The trigger in comes from the Delay Generator and tells the Sampling Unit when to sample.

"PULSE OUT" This connection provides a timing signal to the TDR Processor.

"PULSE OUT" This connection provides a timing signal to the TDR Processor.

"VERTICAL SIGNAL OUT" This is the measured signal level which is passed on to the TDR Processor.

"VERTICAL POSITION" The vertical position of the display scope signal can be adjusted with this ten turn potentiometer.

"SENSITIVITY" The sensitivity of the displayed signal can be adjusted from 200 to 2 mV/Div. When the display scope is properly calibrated, it will display (in mV/Div) values to match the scale of the Sampling unit.

4.2.6 THE RECEIVER; Photon Counting System The photon counting receiver consists of a special avalanche photodiode in a proprietary circuit designed to provide the ultimate in sensitivity. When the Photon Counter is used, it replaces the Detector and Sampler in the Mainframe.

"LIGHT IN" Normally an ST style connector with 100/140 core/cladding fiber is provided for the optical input. A dust cap should always be in place when the module is not being used.

"TRIGGER IN" The trigger in comes from the Delay Generator and tells the Photon Counting Unit when to test for a photon return.

"PULSE OUT" This connection provides the timing signal to the Processor.

"SIGNAL OUT" The photon count information is passed on to the Processor.

"SENSITIVITY" The PPC10 has three sensitivity settings from which to choose; HI, MED, and LOW, while the PPC20 has two; HIGH and NORMAL. The choice determines the widow size during which the Photon Counter is on. This is factory set to the following values;

PPC10 SETTING	PPC20 SETTING	SENSITIVITY
HI		3.0 ns window; Highest
MED	HIGH	0.8 ns window; lower by a factor of about 4
LOW 0.3 ns window; Sensitivity lowest by a factor of about 100		

4.2.7 DELAY GENERATOR The delay generator has three main functions when used in the OTDR system. First, it provides a free running 33 kHz trigger to the transmitter. Second, it provides an ultra low jitter, variable delay signal to trigger the receiver. Third, it provides the time sweep for the delayed window. Within this framework there are several programmable functions which are outlined below.

"TRIGGER OUT" This is connected to the Transmitter "EXTERNAL TRIGGER IN" to provide the laser trigger.

"DELAY OUT" This is connected to the Receiver TRIGGER IN to provide the correct timing for the CRT display window.

"J1" This connection to the Processor allows the two unit to communicate as required.

Display The display shows the current value of the chosen function. The function under display is marked with an LED. All times are displayed in units of nanoseconds while distance is displayed in units of centimeters.

Keyboard The keyboard serves two purposes. It is used to chose the desired functions and to enter their values. The functions are described below.

"DLY" The delay can be entered directly in ns or us or stepped by predetermined values, forward or backward in time. The stepping is actuated with the INC/DEC keys when in the delay mode by step sizes set by "STP".

"STP" The step size can be entered directly or can be toggled though a series of installed values by actuating the INC/DEC keys when in the step mode.

"REF" The reference value can be entered directly, or set at the current delay. The latter will not change the total delay so that the current time position is not lost.

"T/DIV" The time per division, which controls the scope window size, can be entered directly or toggled through a series of installed values by actuating the INC/DEC keys when in the time per division mode.

"LEN" The length is calculated from the delay value and the entered index of refraction on the assumption that the distance is half the optical path length.

"n" The correct index of refraction must be entered to provide accurate length measurements. Values from 1 to 9 can be entered.

"INC\DEC" These two keys may be used to change the delay in steps equal to the value entered in STP. When in the STP or the T/DIV mode they may be used to increment these values up or down.

"CLR" This may be used to clear an incorrect numerical entry.

4.2.8 THE PROCESSOR The Processor functions as the manager for the time delay generator and the receiver in the OTDR and as well, it performs signal averaging, calculating, data storage, the management of inputs from the front panel or from the GPIB port, and the management of outputs to the display scope, the external dot matrix printer or the external PC via RS-232 or GPIB ports. The details concerning the Processor are given in Section 5.

4.2.9 THE OUTPUTS The various outputs are described in section 6, System Interfaces.

5 THE TDR PROCESSOR

This section serves as the Operating Manual as well as part of the Reference Manual for the TDR processor. The individual keys, toggles and connectors as found on the front and back panels are described in detail. In addition, the various calculations performed by the Processor are described.

5.1 <u>FRONT PANEL and FUNCTIONS</u>

The various buttons, toggles and features of the TDR Processor are explained here. The Processor front panel is shown in Figure 5-1. To operate, the TDR Processor must be fully connected and the POWER switch must be ON.

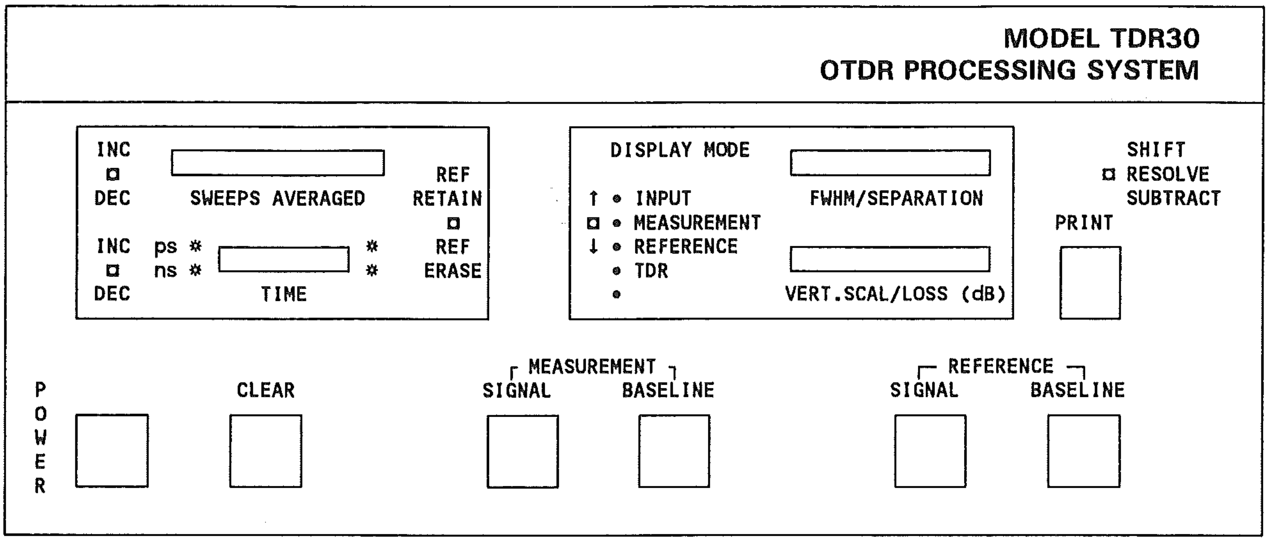


Figure 5-1
Front Panel of the TDR Processor

5.1.1 <u>MODES OF OPERATION</u> There are three modes of operation for the Processor. These are controlled with the toggle switch in the upper right corner of the front panel.

"SHIFT" This is used to measure absolute length and small length changes. Longer lengths usually involve a REFERENCE pulse and a MEASURED pulse and the length is determined by using the Delay Generator delay with correction from the Processor. Length changes usually involve a shift of the same pulse from a REFERENCE position to a MEASURED position and the shift is measured in time using the Processor read-out directly.

"RESOLVE" Two overlapping pulses which have been MEASURED can be resolved into their component parts in this mode. It requires that the two pulse be identical in shape but not amplitude. The REFERENCE pulse must also be of identical shape to the individual pulses.

"SUBTRACT" This is a straight forward subtract function. The REFERENCE Display screen is subtracted from the MEASURED Display screen.

5.1.2 <u>DISPLAYS AND TOGGLES</u> The meaning of the values displayed in the windows and the function of the various toggles are explained below.

"SWEEPS AVERAGED" When in CLEAR the number of averages can be chosen from 4 to 65,536 in powers of 2. Choosing the number of averages is usually a trade-off between the SNR improvement desired and the averaging times needed. It is useful to note that most signals which have a useful SNR at 65,536 averages will become detectable with 4,096 averages, which only takes 35 seconds at the maximum repetition rate. When powered up the default value is 4 averages.

When in the CALIBRATE mode for the Display scope , the SWEEPS AVERAGED can be chosen for continuous averaging. This can be set at values from 4 to 256 in powers of 2. This feature does not affect the normal operation of the SWEEPS AVERAGED and can only be adjusted when in the DISPLAY SCOPE CALIBRATE mode. See Display Scope Calibration.

"TIME" In order to calculate correctly, the TIME window value must coincide with the Delay Generator T/DIV value. Whenever the Processor TIME base is changed, the Delay Generator time base (T/DIV) is automatically set to the same value. This provides a convenient way of insuring that the processing is carried out using the correct time base. This feature can be defeated by entering Processor incompatible time base values directly into the Delay Generator. This may be useful to examine certain features more closely but care should be taken to revert back to Processor compatible values before processing. The TIME toggle adjusts T/DIV only when in CLEAR.

After taking either a MEASUREMENT or REFERENCE the TIME toggle will adjust the scaling factor which allows the operator to view features in more detail. If a MEASUREMENT is taken, then a REFERENCE only the REFERENCE can be scaled and vice versa. REFERENCE and MEASUREMENT must be taken on the same TIME scale or calculations will not proceed.

"DISPLAY MODE" This toggle enables the operator to view or select for print several different pieces of information. The input mode shows the real time pulse on the display scope. MEASUREMENT, REFERENCE, or TDR can be viewed or printed. The data is displayed in the two windows on the right side of the panel. The information is stored until updated by another measurement. The operator can output the three sets of data via the RS-232 or GPIB port. The values displayed are outlined immediately below and Table 5-1.

INPUT MODE:	The windows are blank
MEASUREMENT and REFERENCE MODE:	The windows display the left hand parameter; FWHM, top and Scaling Factor, bottom.
TDR MODE:	The windows display the right hand parameter; Separation, top and Loss (dB), bottom.

"FWHM/SEPARATION" The calculated values shown here depend on the mode of operation and are outlined in the table below.

"REF. RETAIN / REF. ERASE" This toggle enables the operator to retain a REFERENCE measurement for a series of MEASUREMENTS. This is useful where the reference pulse is unlikely to change. When the Processor powers up there is no reference pulse stored so that it is necessary to run the REFERENCE the first time through. Also, in the REF. ERASE position a the calculations are prevented from going forward until another REFERENCE is taken. This prevents the screen from blanking or displaying calculated data which may not yet be desired.

"VERT.SCALE/LOSS (dB)" The calculated values shown here depend on the mode of operation and are outlined in the table below.

DISPLAY MODE	OPERATION		
	SHIFT	RESOLVE	SUBTRACT
INPUT MEASUREMENT REFERENCE TDR	Blank FWHM FWHM Separation	Blank FWHM FWHM Separation	Blank FWHM FWHM Separation
Upper Window	FWHM/SEPARATION	FWHM/SEPARATION	FWHM/SEPARATION
INPUT MEASUREMENT REFERENCE TDR	Blank Scaling Factor Scaling Factor Loss	Blank Scaling Factor Scaling Factor Scaling Factor	Blank Scaling Factor Scaling Factor Scaling Factor
Lower Window	VERT. SCALE/LOSS (dB)	VERT. SCALE/LOSS (dB)	VERT. SCALE/LOSS (dB)

Table 5-1

The pulse FWHM or the time Separation between the peak positions of measured pulses is given in ps/ns (as indicated by the TIME window LED). The window is blanked if calculations cannot be reliably made.

The toggle beside the TIME window can be used to adjust the vertical scaling factor of the last taken MEASUREMENT or REFERENCE.

5.1.3 KEYS The series of keys located along the bottom of the panel initiate the measurements and are used for several other functions as outlined below.

"CLEAR" This is the start point in the operation of the Processor. CLEAR allows the real-time signal to be observed on the Display scope. Depressing CLEAR when using REF. RETAIN will clear the MEASUREMENT information but will retain the REFERENCE data for the next MEASUREMENT. CLEAR can be depressed at any time and will interrupt any proceedings.

"MEASUREMENT/SIGNAL/BASELINE" Assuming the correct settings and the presence of a pulse on the display scope, pressing the SIGNAL button will start the processing. The LED will blink while the data is gathered, then the Processor will calculate the relevant information depending on the functions set. Occasionally, especially when attempting to detect very weak optical signals the baseline may contain coherent electrical noise, which should be subtracted from the signal. To do this the optical signal must first be blocked. The blocking may be accomplished by switching the laser from EXTERNAL TRIGGER to INTERNAL TRIGGER, by pulling the output connector from the optical coupler module, or by pinching the output pigtail or sample fiber until the pulse peak decreases to near zero value. Now the BASELINE may be pressed. The LED will blink while the data is gathered, then the Processor will subtract the baseline from the signal and recalculate the relevant information. When ready MEASUREMENT-BASELINE, MEASUREMENT-SIGNAL or REFERENCE-SIGNAL may be pressed or the system may be reset by pressing CLEAR.

"REFERENCE/SIGNAL/BASELINE" These two buttons operate in the same fashion outlined above. It should be noted that the BASELINE must be taken after the SIGNAL in both cases. Remember to set REF.RETAIN if needed for the next measurement.

NOTE: The MEASURE and REFERENCE buttons may be pressed in any order. Baseline taking is optional. One may move freely from baseline back to signal. However going from MEASURE to REFERENCE or back to MEASURE from REFERENCE, causes the baseline to be cleared.

"**PRINT**" When the print button is pushed, the TDR will initiate printing of the data from the DISPLAY MODE indicated by the lighted LED. More details and an sample printout can be found in Section 6.3.

Display Scope Calibration To obtain the calibration pattern, press the Processor keys in the sequence indicated below. The calibration procedure is outlined in the Training Manual.

1. Press and hold the MEASUREMENT-SIGNAL button.
2. Press and release the CLEAR button.
3. Release the MEASUREMENT-SIGNAL button.

5.2 REAR PANEL

The Processor rear panel contains interface connectors, control switches and the power fuse. The panel configuration is shown in Figure 5-2 and described below.

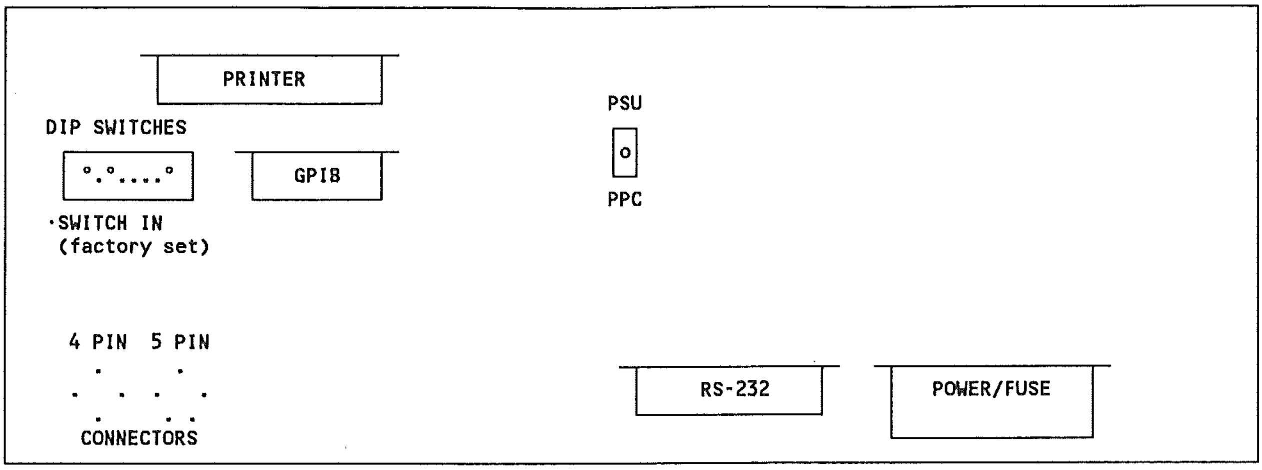


Figure 5-2
Processor Rear Panel

5.2.1 PRINTER Connections to the printer are made by a standard 36 pin Centronics printer cable. The data selected to appear on the Display scope screen may be printed on an Epson style dot matrix printer (with graphics capabilities) by pushing the PRINT button on the front panel of the TDR Processor. Printing details are given in Section 6.

5.2.2 GPIB The Processor can be interfaced to any PC with the proper GPIB card via the standard GPIB output port. The OTDR system can be controlled from the PC keyboard or by program. In addition, data can be transferred for storage or further processing. The GPIB operation is described in detail in Section 7.

5.2.3 RS-232 An RS-232 (25 pin D type) connection may be made between the back panel of the TDR and any desktop PC equipped with this interface. Code letters sent from the keyboard to the TDR will activate data transfer to the PC from the memory location addressed. These data (MEASUREMENT, REFERENCE and TDR) can be stored in the PC, or on a disc or be further processed. Relevant details can be found in Section 6.

5.2.4 DIP SWITCHES These are utilized in the GPIB operation and are factory set. Positions and meaning are given in the GPIB Section 7. The switches are factory set as shown above.

5.2.5 PSU\PPC SWITCH This switch (On the TDR30 only) is used to convert between operation with the Sampling system and the Photon Counting system.

5.2.6 4-PIN CONNECTOR This connector is used to interface with the Delay Generator

5.2.7 5-PIN CONNECTOR This connector is used to interface with the system Receiver and the Display Scope.

5.2.8 POWER/FUSE The power cord is connected here. This is a combination 110/220 Volt connection. Conversion is accomplished by removing and replacing, in the correct orientation, a small printed circuit card. The fuse is included in this receptacle.

5.3 INTERNAL SETTINGS

The Processor has three internal settings made on the main circuit board, as shown in Figure 5-3. To access these settings the Processor cover must be removed. This requires the four screws, two each side, to be removed.

5.3.1 BEEPER SWITCH On the dual switch located on the back of the circuit board, the switch closest to the rear of the unit controls the beeper. If ON, the beeper will beep when there are 1024 averages remaining if 4096 or more averages were selected. If OFF, the beeper is disabled. Factory setting; ON.

5.3.2 SMOOTHING CONTROL The second switch, beside the beeper switch, controls a smoothing function which connects the dots on the Display Scope. If OFF, discrete dots will be displayed. Factory setting: OFF.

5.3.3 THE BAUD RATE The baud rate for the digital output port is selected by a jumper pair near the front of the circuit board. Factory setting: 9600.

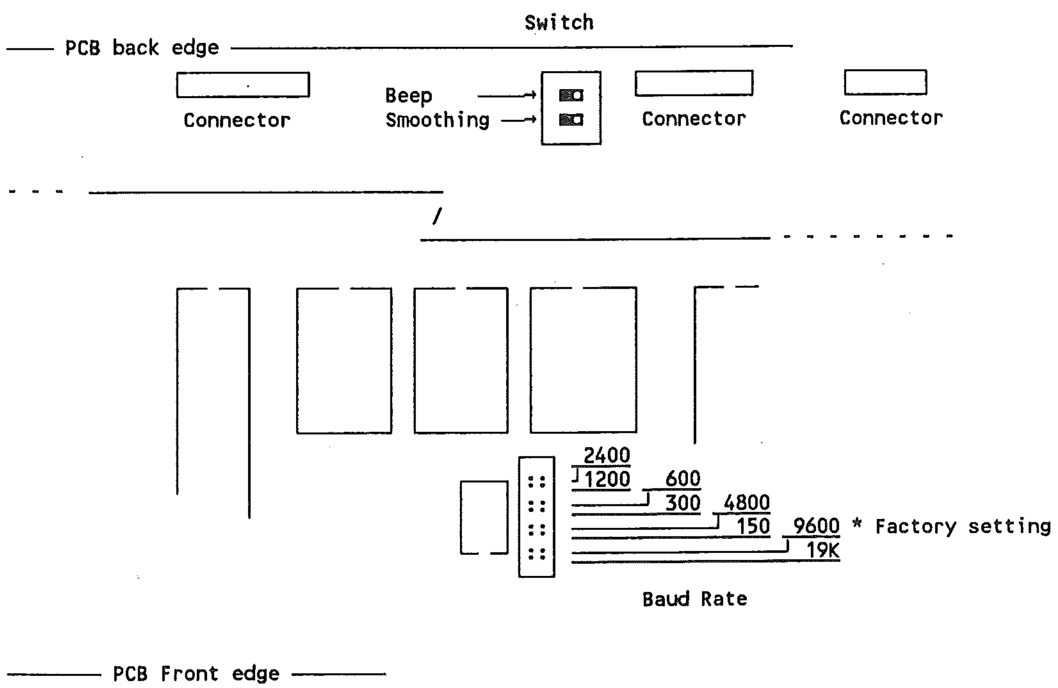


Figure 5-3
Main Circuit Board

5.4 PROCESSOR CALCULATIONS

The Processor has been designed to complete specific calculations at considerably higher speed than one could hope to achieve with general purpose programs used with desktop computers. The various calculations are outlined below.

5.4.1 SIGNAL AVERAGING Part of the Processor is a digital instrument with analog interfaces designed specifically to mathematically average low level signals from a sampler. Signal averaging is a conceptually simple yet very powerful technique that can be used to improve the SNR of repetitive signals as used with a sampler. Signal averaging works because the repetitive signal of interest has the same fixed amplitude each sweep and the accumulation process reinforces the signal, while the random noise will vary about the mean, averaging to zero. The Processor uses linear summation averaging which gives the largest improvement possible in SNR for a given number of averages. For linear summation averaging, the signal Y(N) at a given point after N averages is given by,

$$Y(N) = S \cdot \sum_{J=1}^{N} Y(J)$$

where S is the scaling factor and Y(J) is the Jth sample taken at this point. For a white noise background, the SNR improvement is theoretically the square root of N and the Processor achieves better than 90% of the theoretical improvement. In order to correct for coherent background noise, such as repetitive variation in the sampling baseline, the Processor takes a background average which is subtracted from the signal before display. The combination of these two techniques enables expansion of the effective sensitivity of the sampling unit from 2mV/cm to less than 8uV/cm for a similar displayed noise level.

5.4.2 FWHM CALCULATIONS The FWHM display on the Processor can be a very useful feature. However, to get reliable results it is necessary to know something about how the calculations are done. The algorithm used was designed to give accurate results with the widest possible range of pulses and step functions. All the risetime and pulsewidth calculations are done on the same data which is fed to the display scope.

To calculate pulsewidth (full width at half maximum) it is first necessary to have values for the 0% and 100% level. To obtain a 0% level, the Processor averages the fifth through eighteenth points from the left hand edge of the scope screen and calls this the zero level. The first few points are skipped to avoid any error due to the scope retrace. To obtain the 100% value, the Processor now searches the display data for the maximum value on the screen. It then does a thirteen point parabolic fit about this point, and determines the 100% value from this fit. The combination of the thirteen point baseline average and the parabolic fit to the peak gives accurate results on signals that still have some degree of noise. The Processor now calculates the FWHM by doing an eight point running average starting at the baseline, looking for the 50% value. If the displayed signal is especially noisy, the FWHM will not be calculated.

Once a valid MEASUREMENT and REFERENCE set of data become available, the Processor proceeds according to the setting of the calculation mode switch.

5.4.3 CALCULATIONS IN SHIFT MODE In the shift mode, the peaks of the MEASUREMENT and REFERENCE are found by doing a parabolic fit around the maximum as described for the FWHM above. The time separation of the two peaks is the calculated and displayed in the units previously set up. In addition, for loss measurements the areas under the curves are calculated from which the loss is determined and displayed.

5.4.4 CALCULATIONS IN **RESOLVE** MODE It is assumed here that the MEASUREMENT data set consists of two pulses, of shape identical to that of the reference pulse. The two pulses may partially overlap. The algorithm then resolves the composite MEASUREMENT pulse into the two component pulses, calculates and displays the time separation. The accuracy of resolution depends on the peak amplitude ratio of the two pulses as well as on their actual separation. The ratio should be better than 10:1 and the separation should be greater than 1/2 FWHM.

Note that the amplitude and position of the reference pulse are irrelevant, since only the functional shape of the pulse is used in the calculation. However as noted earlier it is best to fill the screen especially if the pulse is noisy. The display oscilloscope is switched to show the smaller of the two pulses.

5.4.5 CALCULATIONS IN **SUBTRACT** MODE This mode is used where the signal is a double pulse, but one of the two constituent pulses is available as REFERENCE. Here, the second pulse may be accurately calculated by subtracting the REFERENCE from the MEASUREMENT data. The positions of the peak of the REFERENCE and DIFFERENCE pulses are then calculated, and their time separation is displayed.

Note that here the amplitude and position of the REFERENCE are important. Any drift or amplitude change from acquisition of one set of data to the other will affect the accuracy of the results. This mode is very accurate, allowing separation of pulses with any degree of overlap. The display oscilloscope is switched to show the difference pulse.

6 SYSTEM INTERFACES

The OTDR system can be interfaced with several other systems. The Display Oscilloscope is required in order to "look at" the system under test. The RS-232 and printer interfaces permit retrieval of data while the GPIB interface permits limited control of the OTDR system as well.

6.1 DISPLAY OSCILLOSCOPE

The Processor has output connections for a real-time oscilloscope display. A low frequency, single channel general purpose oscilloscope is required. Depending on the position of the DISPLAY MODE toggle the Processor will send the input signal (real time data) or the stored MEASUREMENT, REFERENCE or TDR data from memory, via a D/A converter, to be displayed on the screen. The connections and setup are described in Section 8.

6.2 RS-232 INTERFACE

An RS-232 (25 pin D type) connection may be made between the back panel of the TDR and any desktop PC equipped with this interface. Code letters sent from the keyboard to the TDR will activate data transfer to the PC from the memory location addressed. These data (MEASUREMENT, REFERENCE and TDR) can be stored in the PC, or on a disc or be further processed.

6.2.1 THE DATA FORMAT The format is Intel hex code with 32 byte records (see Figure 6-1). The data is transmitted as 256, 8 bit hexadecimal numbers. The load address is 1400 hex for the MEASUREMENT data, 1500 hex for the REFERENCE data and 1200 hex for the TDR data. The RS-232 port pin assignment is shown in Table 6-1. The Processor provides DTR and RTS signals. Note that full handshaking is not normally provided.

```
colon (start of field)
record length                                                    chechsum
load address                                           (two's complement)
record type
                                   data
:2013000040404040404040404040404040404040404040404040404040404040404040CD
:2013200041414141424242423434343434445454546565656575857575757575757575404440404040404040404040404040448A9098A0ABAE73
:20134000B2B4B5B6B5B5B4B3B2B0ADAAA8A5A3A19E9A959000008B8882777E79716D6A66625F9325F934040404040404040253F93F93
:201360005C5955524F4DDDD4B4994774644342434141404141403299999404040404040404040404040404040404040000404440404 0C5
:20138000404040404040404040404040404040404040404040400404040404040404040404040404040404040040404 04D
:2012A000404040404040404040404040404040404040404040404040404040404040404040404040404040404040402D
:2013C000404040404040404040404040404040404040404040404040404040404040404040404040404040404040400D
:2013E0004040404040404040404040404040404040404040404040404040404040404040404040404040400404 04ED
:00000001FF
      end of file record
```

Figure 6-1
Intel Hex Code

6.2.2 THE COMMANDS Single letter commands are required to transfer data from the Processor over the RS-232 Interface. An "M" sent to the Processor will cause it to output the MEASUREMENT set of data. Similarly an "R" and "F" will cause the transfer of the REFERENCE and TDR data respectively. If the Processor is in the SHIFT mode, there is no waveform stored in the TDR, therefore, the output of data requested by "F" is not valid.

6.2.3 THE BAUD RATE The baud rate is factory set, internally, at 9600. This can be changed by accessing the Processor circuit board and selecting the correct jumper pair. For more details see "INTERNAL SETTINGS" in Section 5.

TDR20 PIN	NAME
1	Ground
2	Transmitted Data
3	Received Data
4	Requested To Send
5	Clear To Send
6	Data Set Ready
20	Data Terminal Ready

TABLE 6-1
RS-232 Connections

6.3 PRINTER

Connections to the printer are made by a standard 36 pin Centronics printer cable. The data selected to appear on the screen may be printed on an Epson style dot matrix printer (with graphics capabilities) by pushing the PRINT button on the front panel of the TDR. A typical hard copy is shown in Figure 6-2 for a two point measurement with reflective features separated by 144 ps or 14.4 mm. The print outs from the various DISPLAY MODES are described below.

INPUT MODE, for the ... SHIFT, RESOLVE and SUBTRACT FUNCTIONS

Print is inactive for the INPUT mode (realtime display).

MEASUREMENT and **REFERENCE** MODE, for the ... SHIFT, RESOLVE, SUBTRACT FUNCTIONS

The FWHM is printed for a single pulse or in the case of multiplepulses the FWHM is printed for the highest pulse, (pulse with the greatest amplitude). The units for the horizontal scale are printed.

The pulse amplitude (AMPLITUDE(S)) is printed in relative units for the single pulse or for the highest pulse in the case of multiple pulses. The absolute height in mV can be obtained by multiplying the PSU20 mV/DIV times the relative pulse height.

TDR MODE, for the ... SHIFT FUNCTION

The pulse separation is printed with a ± sign; a - sign indicating that the MEASURED pulse appears on the screen before the REFERENCE pulse.

The two pulses will be printed with the highest one "filling the screen" and with the second one in the correct relative position and height to the first. The two relative amplitudes will be printed, MEASURE first, REFERENCE second. Again absolute amplitude in mV will be obtained by multiplying the PSU20 mV/DIV times the relative pulse height, keeping in mind that the PSU20 mV/DIV reading may have been different for the two pulses.

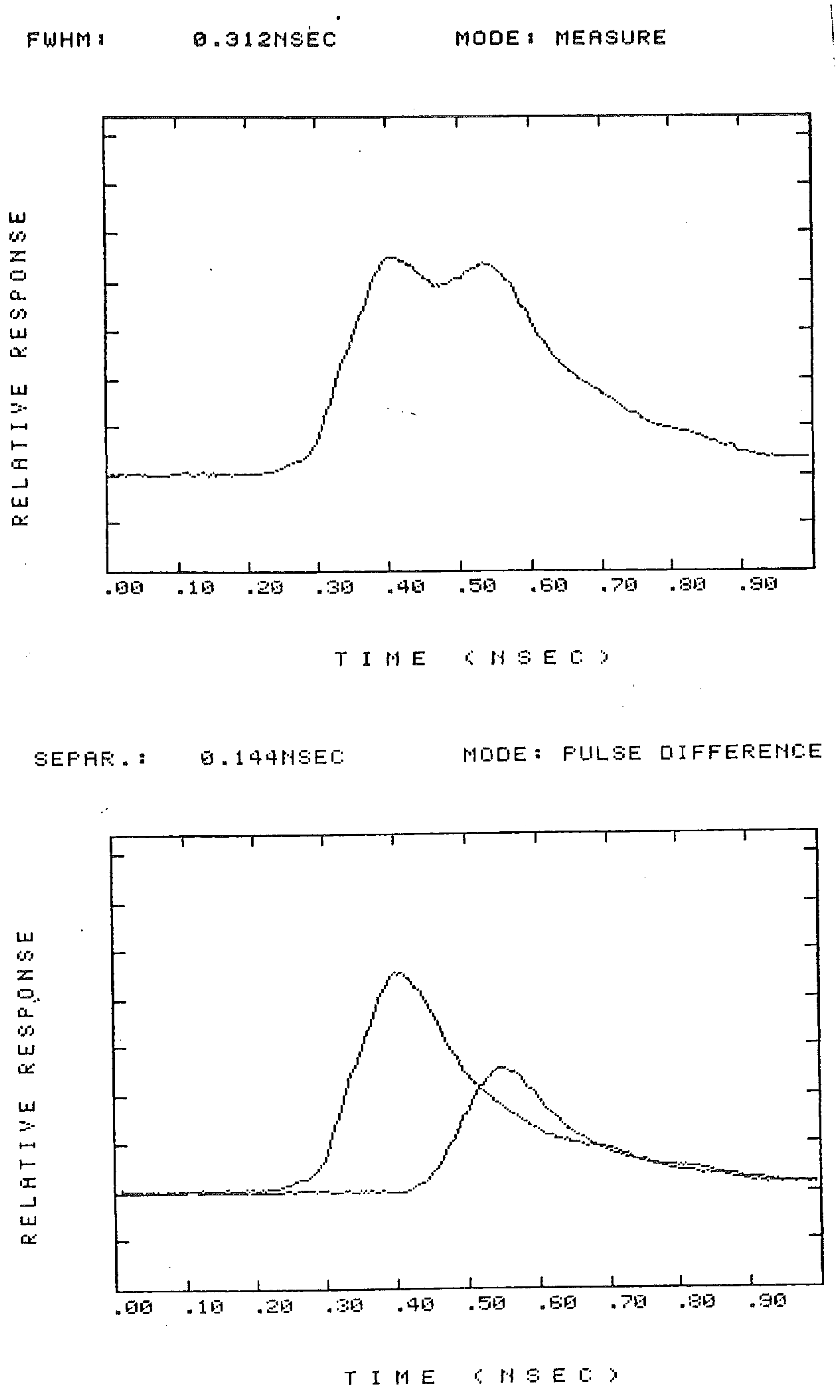


Figure 6-2
Typical printouts from the Processor

The loss is printed as a -dB when the MEASURED signal is smaller than the REFERENCE signal. If it appears as a positive number, then the MEASURED signal was larger than the REFERENCE signal. This can, in fact be the case, if the MEASURED signal was made artificially larger than the REFERENCE signal by changing the PSU20 mV/DIV scale. This must be compensated for.

TDR MODE, for the ... RESOLVE FUNCTION

Here the printout shows the two pulses calculated to make up the measured pulse assuming the reference pulse shape only. The separation of the two calculated pulses is printed.

The relative amplitude "AMPLITUDE(S)" of the two pulses is printed giving the primary (highest) pulse amplitude first. To get absolute values in mV's multiply the relative amplitude by the PSU20 T/DIV.

TDR MODE, for the ... SUBTRACT FUNCTION

Here, the REFERENCE pulse is subtracted from the MEASURED pulse. The printout shows the REFERENCE pulse along with the subtracted result. Again the separation "SEPAR.:" is printed with a ± sign indicating the relative positions of the two pulses.

The relative amplitudes "AMPLITUDE(S)" of the two pulses are printed; REFERENCE first, resulting pulse second. To get absolute values for the pulse heights, multiply the relative numbers by the PSU20 T/DIV setting.

6.4 THE GPIB INTERFACE

The GPIB interface is described in detail in Section 7.

7 GPIB OPERATION

7.1 GENERAL

Connection made from the TDR Processor via the GPIB interface to any computer or PC with the proper GPIB card enables the operator to control the OTDR system from the keyboard or by a program. Data can also be transferred for further processing or for storage. Measurements may also be displayed on the computer screen for easy remote operation.

The talker/listener address of the Processor and assertion of the EOI line at the end of data transmission is user selectable, via the DIP switch on the back of the instrument. The switch arrangement is shown below.

SWITCH NO	FACTORY SET		
1	C	Least Significant Bit.	
2	O	.	
3	C	. (OPEN = 0)	—> TALKER/LISTENER ADDRESS
4	O	.	
5	O	Most Significant Bit.	
6	O	Not Used.	
7	O	Not Used.	
8	C	EOI (Asserted when Switch CLOSED).	

C = Closed, O = Open

The switch settings are read in, when the Processor is powered ON and when a DCL GPIB command is received.

7.2 NOTES ON GPIB TRANSACTIONS

This section lists the commands which can be utilized via the GPIB.

The Serial Poll Status byte is used to inform of the status of the Processor and it must always be consulted before attempting to send data. The bits of this byte have the following significance:

bit7	= 1	TDR "Busy" executing a given instruction. This bit MUST be 0 before any transmission to the TDR takes place.
bit6	= SRQ	SRQ is never asserted at the present time.
bit5	= 1	Data has been placed in the output buffer and are available for reading.
bit4-bit0	= 00h	Machine in Remote mode, last instruction completed successfully.
	= 05h	Machine in Local Mode (LOC).
	= xxh	Error Code (see error code description).

7.3 INSTRUCTION SET

NOTES

* All ASCII data sent to the TDR must have the last byte accompanied by EOI.

* More than one instructions may be sent before EOI and they will be executed sequentially subject to the following conditions:

  a) The instructions are separated by at least one space or control character.
  b) The string does not cause input buffer overflow. In that case the whole string will be ignored.
  c) Any Error will cause termination of the instruction string at the point of error.

Immediately following are the strings and their meaning.

CALC Set Calculation Mode.

Syntax:
- CALC S - SHIFT
- CALC R - RESOLVE
- CALC D - SUBTRACT

CLEAR Corresponds to the TDR "CLEAR" button but the TDR remains in the remote mode.

Syntax: CLEAR

DEC Corresponds to the "DEC" key of the PDG20. Its effects depend on the mode the PDG20 was in when DEC instruction was received.

Syntax: DEC

DELAY Corresponds to the "FN","DLY" key sequence of the PDG20.

Syntax:
- DELAY - Switch PDG20 to the Delay Mode
- DELAY [n] - Set the PDG20 time delay to n; n must end with a U (for Microseconds) or a N (for Nanoseconds)
- DELAY I - Delay is incremented by the current PDG20 "STP"
- DELAY D - Delay is decremented by the current PDG20 "STP"

DISP Set the current display mode of the TDR.

Syntax:
- DISP I - Display Input signal (sampled).
- DISP M - Display "Measure" signal (averaged).
- DISP R - Display "Reference" signal (averaged).
- DISP T - Display "TDR" calculated pulse.

INC Increment quantity in current PDG20 mode. This applies to "DLY", "STP" and "T/DIV" modes only.

Syntax: INC
- If the PDG20 was in DELAY mode then time delay is incremented by the current PDG20 "STP".
- If the PDG20 was in the T/DIV mode then the T/DIV is incremented to the next step in a 2,5,10,... e.t.c. fashion.

INDEX Corresponds to the "FN","n" key sequence of the PDG20.

Syntax:
- INDEX - Switch PDG20 to the Index Mode
- INDEX [n] - Set the PDG20 refractive index to n; n must be entered without a decimal point, which is assumed to be to the right of the first digit. It must also end with a U or a N.

LEN Corresponds to the "FN","LEN" key sequence of the PDG20. Switches the PDG20 to LEN mode for readout. No further operations are allowed since length is a calculated quantity.

Syntax: LEN

MBASE Acquire and average data to be used as "MEASURE" baseline.

Syntax: MBASE

MSIG Acquire and average data to be used as "MEASURE" signal.

Syntax: MSIG

PRINT Print according to current display mode. Printing is done as a background activity, and is interrupted temporarily by subsequent calculations.

RBASE Acquire and average data to be used as "REFERENCE" baseline.

Syntax: RBASE

REF Corresponds to the "FN","REF" key sequence of the PDG20.

Syntax:
- REF - Switch PDG20 to the REFERENCE Mode
- REF [n] - Set the PDG20 time REFERENCE to n; n must end with a U (for Microseconds) or a N (for Nanoseconds).

RRET Set/Reset the TDR "REFERENCE RETAIN" flag.

Syntax:
- RRET Y or
- RRET 1 - REFERENCE RETAIN
- RRET N or
- RRET 0 - REFERENCE ERASE

RSIG Acquire and average data to be used as "REFERENCE" signal.

Syntax: RSIG

SEND Send information through the GPIB.

Syntax: SEND aa - Parameter aa is a two letter string.
SEND a1;a2;..;an- Parameters may be concatenated using ";" as a delimiter.

aa	Information Returned	*
CB	- Clear Output Buffer	T
CM	- Calculation Mode Setting	T
DB	- Db loss (5*log(pulse area ratio))	T
DE	- Delay Time Setting	P
DM	- Display Mode Setting	T
FM	- FWHM of "Measure" pulse	T
FR	- FWHM of "Reference" pulse	T
I8	- Sweep of input (8 bit values)	T
IN	- Index setting	P
LN	- Calculated length	P
M8	- Measure Signal (8 bit values)	T
MA	- Measure Pulse Amplitude in scope divisions	T
MB	- Measure Baseline (24 bit values)	T
MF	- Measure Pulse Data (32 bit F.P.values)	T
MP	- Measure Pulse Peak time position	T
MS	- Measure Signal (24 bit values)	T
PA	- Amplitude in scope divisions of primary pulse	T
PF	- Primary Pulse Data (32 bit F.P.values)	T
PP	- Primary Pulse peak time position	T
R8	- Reference Signal (8 bit values)	T
RA	- Reference Pulse Amplitude in scope divisions	T
RB	- Reference Baseline (24 bit values)	T
RE	- Reference Time Setting	P
RF	- Reference Pulse Data (32 bit F.P.values)	T
RP	- Reference Pulse peak time position	T
RR	- Reference Retain/Erase Flag setting	T
RS	- Reference Signal (24 bit values)	T
SA	- Satellite Pulse Amplitude.	T
SE	- Pulse Separation	T
SF	- Satellite Pulse (32 bit F.P. values)	T
SM	- Scaling Factor of M8 data	T
SP	- Secondary pulse peak time position	T
SR	- Scaling Factor of R8 data	T
ST	- Step Setting	P
SW	- Sweep Setting	T
T8	- TDR Display Signal (8 bit values)	T
TD	- Time/Div Setting	P
TS	- Time Scale Setting	T

* T = TDR Processor
P = PDG20 Delay Generator

All output data are ASCII strings terminated with a CR,LF sequence, with the following exceptions:

M8,R8,T8,I8	Undelimited 256 one byte numbers.
MF,RF,PF,SF	Undelimited 256 four byte floating point numbers. The least significant byte is sent first and is formatted as follows:
byte3 (MSB)	Exponent: Offset by 128 (80h).
byte2,1,0	Mantissa: Shifted left until the most significant bit is 1. This bit is then replaced by the sign of the number.
MB,MS,RB,RS	Undelimited 256 four byte integers, least significant byte sent first.

STEP

Corresponds to the "FN","STP" key sequence of the PDG20.

Syntax:	STEP	- Switch PDG20 to the STEP Mode
	STEP [n]	- Set the PDG20 time RSTEP to n; n must end with a U (for Microseconds) or a N (for Nanoseconds).
	STEP I	- STEP is incremented in a 1,2,5 type sequence
	STEP D	- STEP is decremented in a 1,2,5 type sequence

SWEEP

Set number of Sweeps to average.

Syntax:	SWEEP n	n = positive integer in the range 0-65536 if n is not a power of 2 then the number of sweeps is set to the highest power of 2 less than n.

TDIV

Corresponds to the "FN","T/DIV" key sequence of the PDG20.

Syntax:	TDIV	- Switch PDG20 to the T/DIV Mode
	TDIV [n]	- Set the PDG20 Time/Division to n; n must end with a U (for Microseconds) or a N (for Nanoseconds).
	TDIV I	- T/DIV is incremented in a 1,2,5 type sequence
	TDIV D	- T/DIV is decremented in a 1,2,5 type sequence

TIME

Set Time Scale (Time/Division) for both TDR and PDG20

Syntax: TIME n - Parameter n is a positive integer in the range 1-12 corresponding to the following Time Scale settings:

n	Time/Div.
3	50 ps
4	0.1 ns
5	0.2 ns
6	0.5 ns
7	1.0 ns
8	2.0 ns
9	5.0 ns
10	10 ns
11	20 ns
12	50 ns

7.4 ERROR CODES

(NOTE: All Error Codes are <32 (20h))

00 (00h)	**BMT**	INPUT BUFFER EMPTY. Instruction(s) completed successfully.
01 (01h)	**NER**	NO ERROR - Internal Code.
02 (02h)	**BOV**	INPUT BUFFER OVERFLOW. The number of characters transmitted before EOI exceeded the capacity of the input buffer. The string is discarded.
03 (03h)	**INI**	INVALID INSTRUCTION. Instruction unknown to the system; possibly misspelled.
04 (04h)	**IOS**	INSTRUCTION OUT OF SEQUENCE. Instruction cannot be performed at the present state of the machine.
05 (05H)	**LOC**	MACHINE IN LOCAL MODE. Normal value of serial poll status byte when TDR in Local Mode. The TDR MUST be set to the REMOTE state before any instructions are issued.
06 (06H)	**INE**	INSTRUCTION NOT IMPLEMENTED. Instruction recognized but at the present time no action is taken.
07 (07H)	**MPA**	MISSING PARAMETER. Instruction requires parameter that was not present.
08 (08H)	**IPA**	INVALID PARAMETER. Parameter supplied not valid.
09 (09h)	**POR**	PARAMETER OUT OF RANGE. Parameter supplied not within allowed range.
10 (0Ah)	**WET**	WRONG EQUIPMENT TYPE. PDG20 of improper type (Older version). If this is not the case, powering the TDR OFF and ON or sending a DCL should remedy the fault.
11 (0Bh)	**OBF**	OUTPUT BUFFER FULL. (Same as 12 below.)
12 (0CH)	**OBF**	OUTPUT BUFFER FULL. Data from the last SEND instruction parameter were not placed in the output buffer because of insufficient space.

13 (0DH)	**ARE**	ARITHMETIC ERROR. Calculations resulted in an arithmetic Error.
14 (0EH)	**PRN**	PRINTER ERROR. Printer not ON LINE or not connected.
15 (0FH)	**NRE**	INTERNAL ERROR. No calculation results are valid. A DCL interface command should clear this condition.
16 (10H)	**PDG**	ERROR IN TRANSMISSION TO THE PDG20. Repeat last command.
17 (11H)	**PRB**	PRINTER BUSY. No further printing may be initiated.

8 SETUP INSTRUCTIONS

This section illustrates the correct interconnections for the the OTDR system. The operation and theory are explained elsewhere.

8.1 THE ELECTRICAL CONNECTIONS

The OTDR system is shipped from the factory with the modules positioned as shown in Figure 8-1 or Figure 8-2 below. However, each module can be operated from any available bay should the operator wish to rearrange the order. The electrical connections as made as indicated.

8.1.1 SAMPLING SYSTEM CONNECTIONS

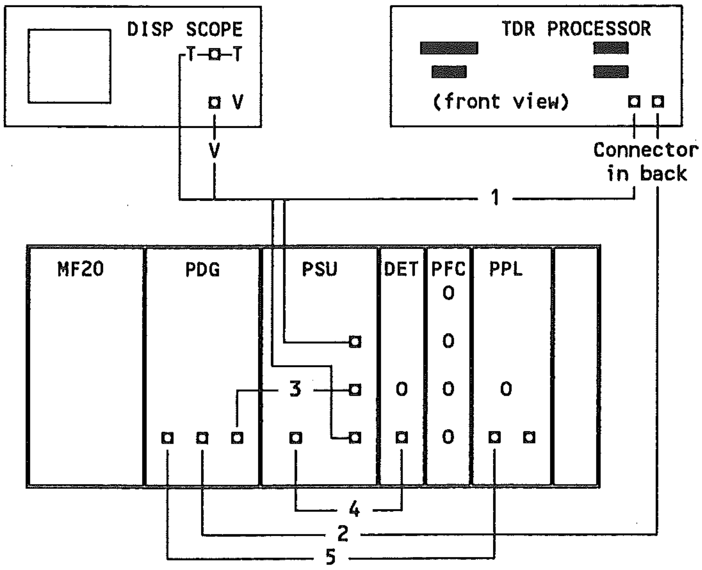


Figure 8-1

a) ELECTRICAL CABLES AND CONNECTIONS

NOTE: On the TDR30, and those TDR10's and TDR20's which have been upgraded to a TDR30, there is, on the Processor back panel, a switch which must be in the position marked PSU or the Processor will not operate properly.

CABLE 1 (1 m, Multiwire Cable)

End 1	5 PIN PLUG	to	5 PIN JACK on the Processor back panel
End 2	SMA(M)	to	SMA(F) "PULSE OUT" on PSU20
End 2	BNC(M)	to	BNC(F) "VERT. SIGNAL OUT" on PSU20
End 2	BNC marked "T"	to	"EXT. TRIG." on Display Scope
End 2	BNC marked "D"	to	"Vert. In" on Display Scope

CABLE 2 (1 m, Coaxial Cable)

PDG20 "J1" to 4 PIN JACK on the Processor back panel

CABLE 3 (40 cm Coaxial Cable, SMA - SMA)

PDG20 "DELAY OUT" to PSU20 "TRIGGER IN"

CABLE 4 (40 cm Coaxial Cable, SMA - BNC)

PDG20 "TRIGGER OUT" to Laser "TRIGGER IN"

CABLE 5 (40 cm Coaxial Cable, SMA-SMA)

Detector "SIGNAL OUT" to PSU20 "SIGNAL IN"

b) PSU20 SETTINGS

- Set Time/Division at 200 mV/cm
- Set the "Vert. Position" at the center position. (5 complete turns from either extreme)

8.1.2 PHOTON COUNTING SYSTEM CONNECTIONS

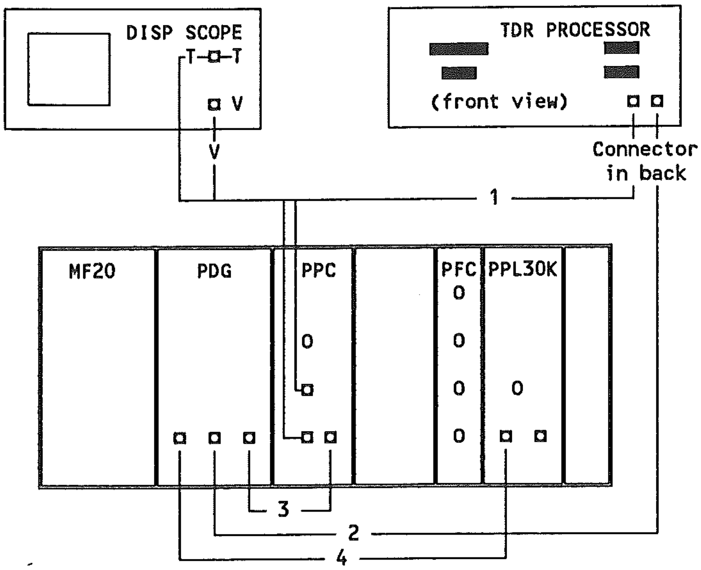


Figure 8-2

The following instructions assume operation of the PPC with a PDG20 and the TDR30 Opto-Electronics Processor. The connection instructions to the Processor are described in TDR30 manual but will be repeated here for convenience.

a) ELECTRICAL CABLES AND CONNECTIONS

CABLE 1 (1 m, Multiwire Cable)

End 1	5 PIN PLUG	to	5 PIN JACK on Processor back panel
End 2	SMA(M)	to	SMA(F) "PULSE OUT" on PPC
End 2	BNC(M)	to	BNC(F) "VERT. SIGNAL OUT" on PPC
End 2	BNC marked "T"	to	"EXT. TRIG." on Display Scope
End 2	BNC marked "D"	to	"Vert. In" on Display Scope

CABLE 2 (1 m, Coaxial Cable)

PDG20 "J1" to 4 PIN JACK on Processor back panel

CABLE 3 (40 cm Coaxial Cable, SMA - BNC)
PDG20 "DELAY OUT" to PPC "TRIGGER IN"

CABLE 4 (40 cm Coaxial Cable, SMA - BNC)
PDG20 "TRIGGER OUT" to Laser "TRIGGER IN"

b) PHOTON COUNTER SETTINGS

PPC10 Set Sensitivity to HI.
PPC20 Set Sensitivity to HIGH.

c) PROCESSOR SETTINGS

TDR30 Back Panel Switch Locate the two position switch on the TDR30 back panel and set for photon counting operation.

8.2 DISPLAY SCOPE CALIBRATION

The Display Scope can be calibrated by following the instructions outlined below once the setup has been completed.

8.2.1 TURN ON The Mainframe, Processor, and Display Scope can be turned on in any order. Allow a few minutes warm up for the oscilloscope, then continue below.

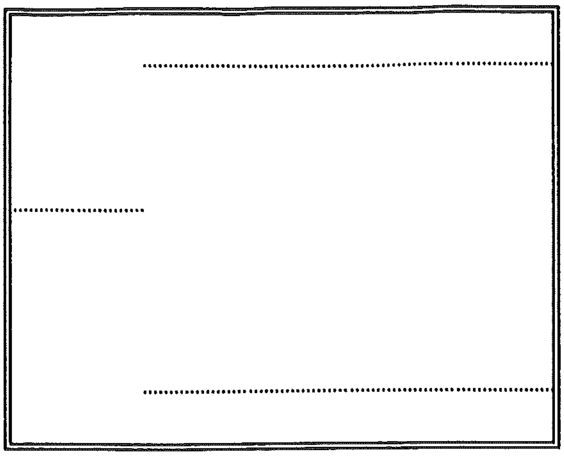
8.2.2 DISPLAY SCOPE SETTINGS

1. SCOPE TRIGGER SETTINGS
   a) external input
   b) negative slope
   c) normal or dc triggering (NOT AUTO)
   d) time/div, 0.33 ms/cm (uncalibrated operation: approximate)

2. VERTICAL AMPLIFIER SETTINGS
   a) dc coupled
      - 50 mV/cm for 50 ohm input impedance
      - 1 V/cm for 1 Mohm input impedance

8.2.3 CALIBRATION STEPS

1. On the TDR20 front panel, hold down the MEASUREMENT-SIGNAL button then press and release CLEAR.
2. A pattern will appear on the scope screen. When the settings are correct, the calibration pattern will appear full screen as shown below. Use the scope vertical control to center the pattern in the vertical sense. Use the scope uncalibrated time base knob to fill the screen with one complete pattern in the horizontal sense. Use the scope horizontal control to center the pattern. The scope will now be correctly calibrated.



3. Press CLEAR to erase the pattern. The VERT. POSITION knob on the PSU20 can now be used to adjust the baseline signal position. The signal should be on the screen if the knob is in the center position. (Five turns from either extreme.)

If the traces do not appear on the screen, check all connections and repeat the procedure.

It remains to make the following optical connections to obtain a reflected optical signal on-screen.

8.3 THE OPTICAL CONNECTIONS

The optical connections for OTDR applications are shown in the figures below. For other applications it may be possible to bypass the optical splitter to gain greater dynamic range.

NOTE: A great deal of care should be taken with optical connectors to prevent dust particles from entering the connector. Small bits of grit can severely damage the mating glass surfaces. Thus connectors should be covered with dust caps when not in use and connectors should be cleaned before mating.

8.3.1 THE STANDARD OTDR CONFIGURATION

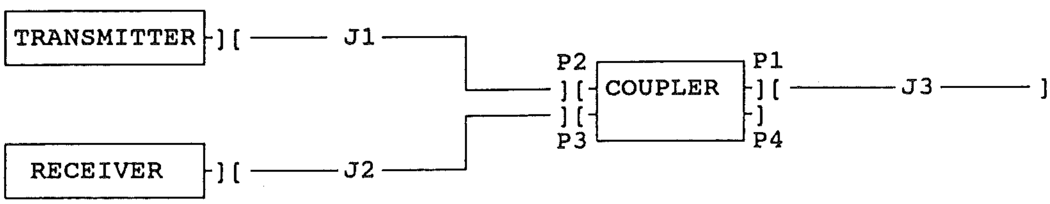


Figure 8-4

Generally, port 1 or port 4 (if available) can be utilized. In either case, connections to the test piece should be made via an additional jumper as shown above. This prevents wear and possible damage to the Coupler connectors which are much more difficult to clean or replace. By using adaptor cables or pigtails it is possible to work into almost any test fiber or cable.

8.3.2 OPTICAL ATTENUATOR, MULTIMODE

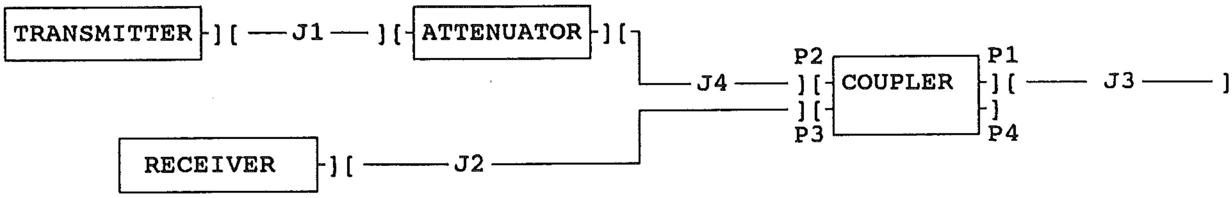


Figure 8-5

This particular configuration with the Transmitter pigtailed with 50/125 core/clad fiber and the Attenuator fiber to match allows operation into any multimode fiber without attenuation penalties. However, care must be taken to fill the fiber when taking loss measurements. This particular choice of Attenuator will also allow operation into singlemode fiber when used as described below.

8.3.3 OPTICAL ATTENUATOR, SINGLEMODE

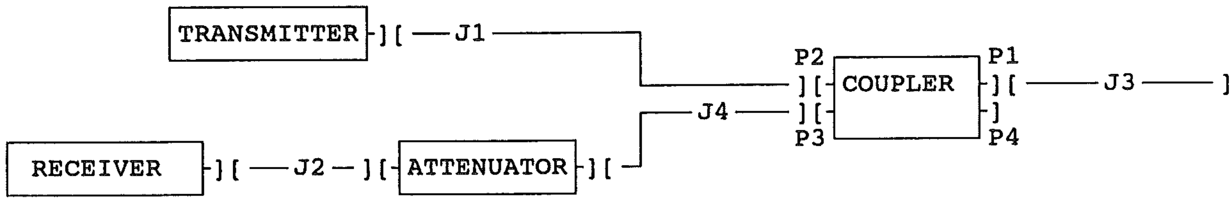


Figure 8-6

Most of the OTDR receivers are pigtailed with 100/140 core/clad fiber so that the Attenuator can be utilised for singlemode systems without loss penalties. Singlemode systems are built from fiber with a core diameter less than 10 micrometer. Thus, one Attenuator with a 50/125 core/clad fiber can be utilized without penalty in all systems. It only requires that the Attenuator be calibrated to the various wavelengths of intended operation.

9 TROUBLESHOOTING

This section has been designed to help the operator locate system faults and where possible to repair the difficulty. While most of the electrical and optical problems cannot be repaired in the field, it is often possible to isolate the faulty module which can then be returned to the factory for repair. The most common system difficulties are described here. Troubleshooting of the individual modules should be done with the help of the PFOS Operating Manual where the individual modules are described in more detail.

9.1 SYSTEM DIFFICULTIES

It is assumed that the system has been set up as described in Section 8, that the system has been powered ON and that all appears more or less normal.

1. Display scope triggering problems.
   As all oscilloscopes are somewhat different it is not possible to anticipate all possible problems. Verify that the connections and settings are as indicated in Section 8. Most difficulties are encountered with the trigger level. Insure that there is no problem with the oscilloscope and adjust carefully.
2. A second flickering pulse is observed on the Display screen.
   This will occur when triggering off the + slope rather than the - slope of the trigger pulse. To rectify change trigger polarity on the Display scope.
3. The pulse is inverted on the display screen.
   Use the display scope invert feature to position the displayed pulse in the desired orientation.
4. The Processors lights up randomly when turned ON.
   Sometimes caused by a partially disconnected ribbon cable connector on the second level PCB in the Processor, this can be checked by removing the cover and inspecting this connection.
5. The Processor "Sweeps Averaged", "Time" and "Clear" all light but all else is non-functional.
   This will occur when timing signals are not getting to the Processor. The Delay Generator "Delay Out" triggers the Receiver which in turn sends a timing signal to the Processor from the "Pulse Out" connector. The relevant cables should be checked for shorts and/or open circuits. A similar problem can occur with a faulty J1 connector on the Delay Generator.
6. No pulse can be found but there are a few random dots appearing on the display screen.
   This can occur when the laser trigger has been switched to internal. In this case the Transmitter fires at a 33 KHz repetition rate but it is not synchronized with the sampling unit. Switch to external trigger.
7. All seems well but the return pulse cannot be found.
   To verify that a pulse is present connect the light from the laser directly to the detector. Set the REFERENCE to 0 ns, DELAY to 50 ns and T/DIV to 10 ns. A strong pulse should be present on the Display Scope. If the system proves functional, difficulties in locating the return pulse may be due to:
   - Faulty Fiber Optic Coupler.
   - Faulty Connectors or Cables.
   - No, or very weak reflection.
   - Searching in the wrong time frame.
8. No pulse apparent but the baseline moves high and low while scanning in time.
   This can occur if the previous operator has left the Delay Generator T/Div set at 0 ns. Change this by altering the Processor "Time" setting.

W WARRANTY AND REPAIR

Opto-Electronics warrants its OTDR Systems for parts and labor in normal operation for a period of 12 months from the time of shipment. The cost of shipment to Opto-Electronics and back to the customer is to be borne by the customer.

IMPORTANT INFORMATION

To insure quick repair turnaround times it is imperative that the following instructions be strictly adhered to.

1. Obtain a <u>Return Authorization Number</u>. To do so call

Telephone	(905) 827-6214
Fax	(905) 827-6216

   U.S. customers may phone Canada, direct, (above number) or via our Buffalo line, (number below),

Telephone	(716) 856-1322

2. The repair facilities are at the <u>Canadian location</u> *only*, thus all repairs must be returned to Canada. (See address below.)

   Opto-Electronics Inc.,
   Unit 9, 2538 Speers Road,
   Oakville Ont., L6L 5K9,
   Canada.

3. It is essential to include the <u>correct customs documents</u>. These include the following;

   A) Those documents required by the customer's country for temporary export and re-import.

   B) A commercial invoice, as required by Canadian customs, which must include the following;

      i An exact description of the return, (part number and serial number)

      ii Value of the goods (Purchase price)

      iii Country of origin (CANADA)

      iv Reason for return

PLEASE NOTE

> Unauthorized returns cannot be accepted. Returns to other than the above address will result in delays and added expenses.