OPTO-ELECTRONICS INC.

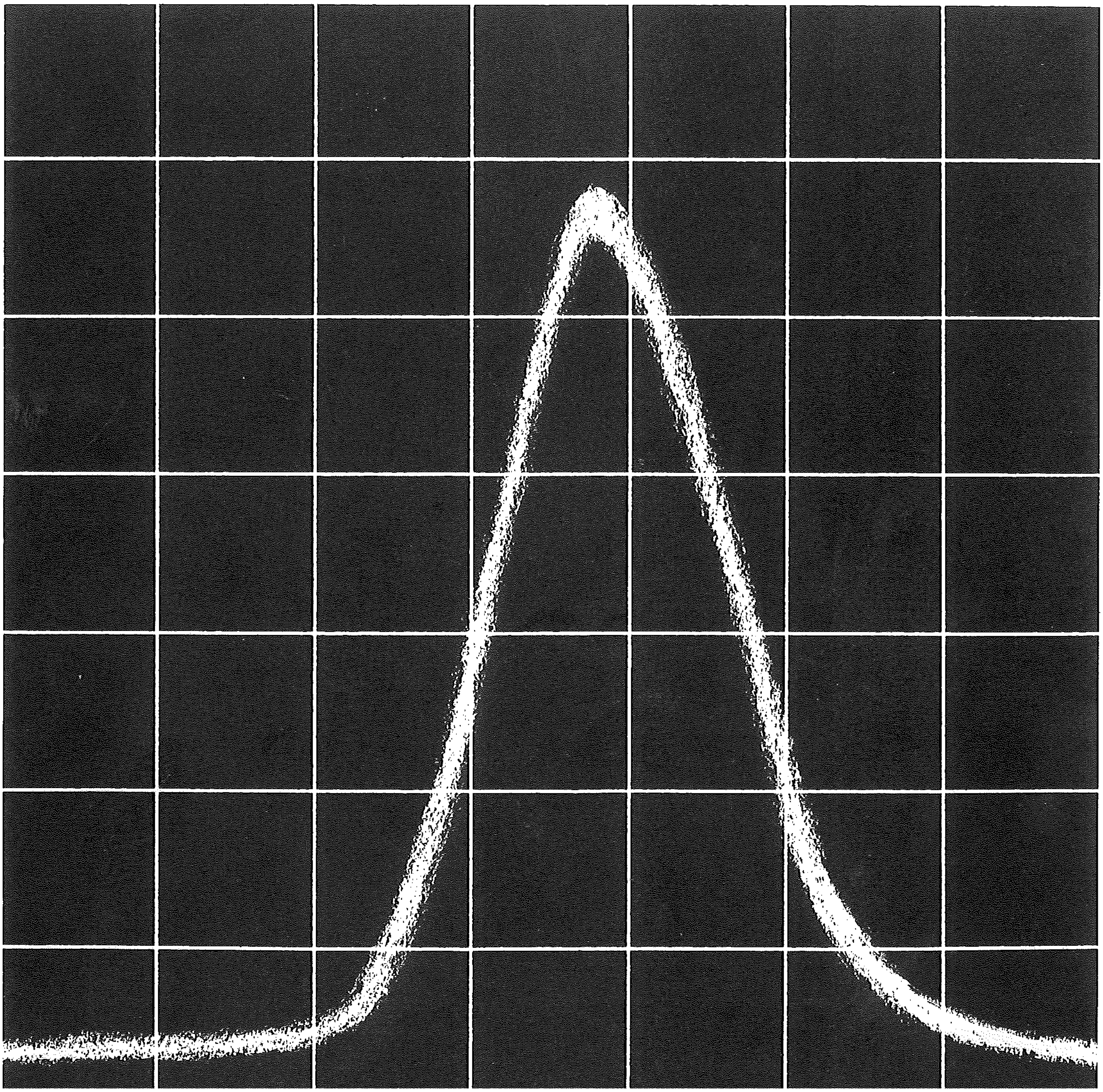
RESEARCH IN ELECTRO-OPTICS

TRAINING MANUAL

for the

OPTO-ELECTRONICS

PHOTON COUNTING OTDR SYSTEM



TRAINING MANUAL

for the

OPTO-ELECTRONICS

PHOTON COUNTING OTDR SYSTEM

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Oakville, Canada
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CONTENTS

1. <u>MAKE THE ELECTRICAL CONNECTIONS</u>

** Set up the OTDR system as shown in Figure 1 below. Make the electrical connections as indicated.

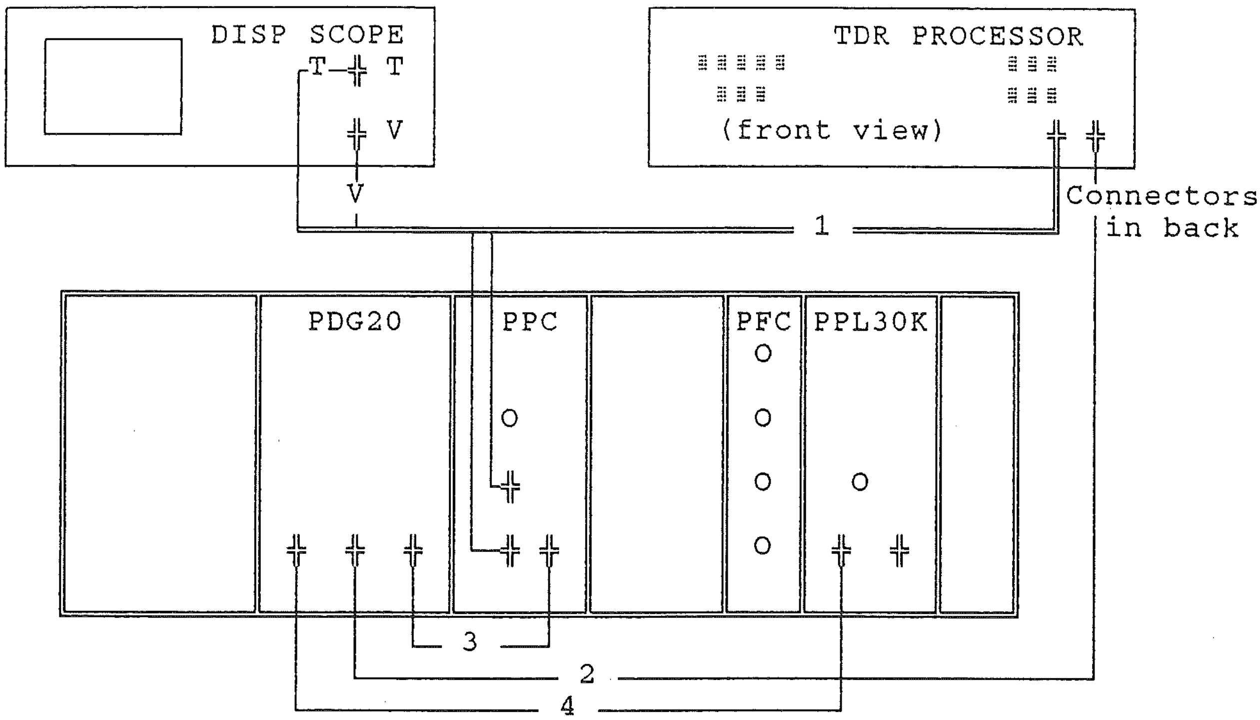


Figure 1

Cable 1: [5 Pin plug ---- 4 Connectors]
: 5 Pin plug to 5 pin jack on back of TDR20
: SMA to SMA "PULSE OUT" on PPC10
: BNC to BNC "SIGNAL OUT" on PPC10
: "T" BNC to External Trigger on display scope
: "D" BNC to Vertical In on display scope

Cable 2: [4 Pin plug ---- 4 Pin plug]
: 4 Pin plug to 4 Pin plug on back of TDR20
: 4 Pin plug to J1 on PDG20

Cable 3: [SMA ---- BNC 15" coax cable]
"DELAY OUT" on PDG20 to "TRIGGER IN" on PPC10

Cable 4: [SMA---BNC 15" coax cable]
: "TRIGGER OUT on PDG20 to "TRIGGER IN" on Laser

**** Set the switch on the Processor back panel to the PPC position.

****

2. CALIBRATE THE DISPLAY SCOPE

** Turn ON:-the Mainframe, Processor, and Display Scope.

Display scope settings:

a) Scope trigger and time base settings
:External input
:Negative slope
:Normal or dc triggering (NOT AUTO)
:0.33 ms/cm (uncalibrated operation; approximate)

b) Vertical amplifier settings
:dc coupled
- 50 mV/cm for 50 ohm input impedance
- 1 V/cm for 1 Mohm input impedance

Calibration steps
:Hold down the MEASUREMENT-SIGNAL button
:Depress and release the CLEAR button
:Then release the MEASUREMENT-SIGNAL button
:Adjust the pattern as in Figure 2A

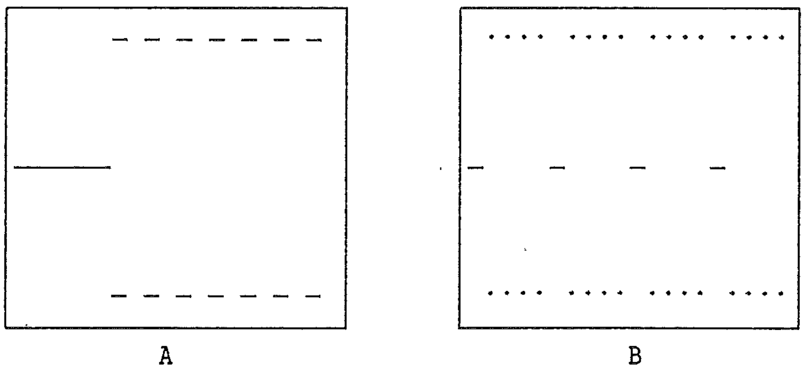


Figure 2

** Adjust the pattern in the vertical sense with the scope vertical position control.

** Use the scope uncalibrated time adjust and horizontal position to fill the screen with one complete pattern as in Figure 2A. Figure 2B shows the pattern repeated four times as it may appear when improperly calibrated.

The scope is now calibrated for use. Do not make any further adjustments to the display scope unless recalibration is required.

** Set the SWEEPS AVERAGED to 4 with the INC/DEC toggle. (This adjustment is only possible with units built after September 1990. With previous systems this is fixed at 4.)

** Press the CLEAR button to clear the calibration pattern. The display scope may now show anything. Ignore at this point.

****

3. MAKE THE OPTICAL CONNECTIONS

** Make the optical connections as shown in Figure 3 below.

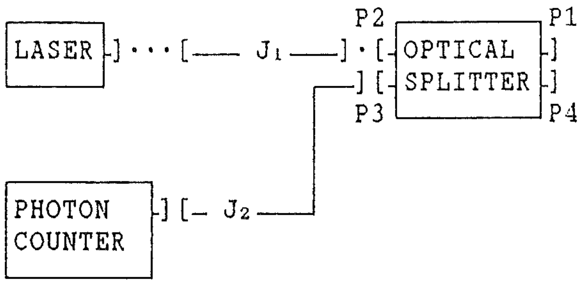
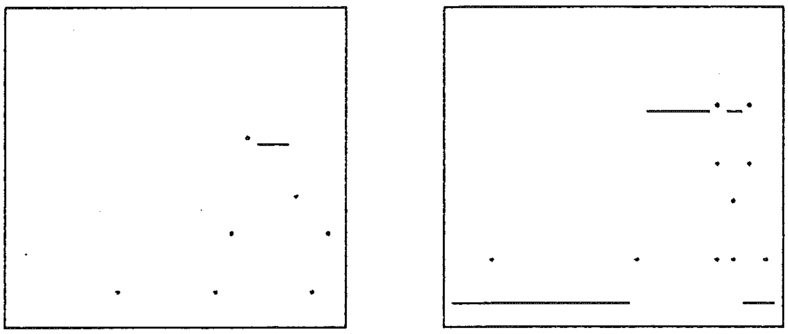


Figure 3

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.

****

4. FIND THE REFLECTED BULKHEAD PULSE



A B

Figure 4

** Go to the Processor and press CLEAR then go to the Photon Counter and set SENSITIVITY to HI

** Go to the PDG20 Delay Generator and ...
:Set REFERENCE to zero, (Press FN-REF-0-ns)
:Set DELAY to 0 ns (Press FN-DLY-0-ns)
:Set for TIME/DIVISION, (Press FN-T/DIV)

If you make an entry error, pres CLR and start the entry over again

** Adjust the TIME/DIVISION by using the Delay Generator INC/DEC buttons. The display will go through powers of 10 times 1,2, and 5. Try this.

** Using the INC/DEC buttons, adjust the T/DIV to 20.00 ns.

The screen should now appear as shown in Figure 4-A but the dots will be jumping around. The pulse, in the second half of the screen is the bulkhead reflection from ports P1 and P4. Partially pull the jumper from the laser and note the reduced pulse width. The detector is being severely saturated at this point, however there is no danger of damage.

The solid line at the bottom is the baseline and represents "no counts". The short solid line at the top represents 4 counts. As it is solid, this implies that more than one photon is arriving at one time, (Saturation). The random dots appearing above the baseline are "dark counts".

How the Photon Counter works!
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. For delay times less than 2 microseconds the delay generator operates at about a 33 kHz repetition rate. This is the rate at which the laser source is triggered and emits optical pulses.

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 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, (the arrival of many photons at one time).

** Change the Sensitivity on the photon counter through HI, MED and LOW. Note the differences. Repeat for different light intensities. (Adjust this by partially pulling and manipulating the Jumper J_1 until the display appears as in Figure 4-B

****

5. <u>MANIPULATE THE BULKHEAD PULSE</u>

** Position the bulkhead pulse on the display screen as in Section 4 above and adjust to look like Figure 4-B.

** Again, adjust the TIME/DIVISION by using the INC/DEC buttons. Do this to find the limits and observe the results of making this change. When finished set T/DIV at 20 ns.

** Set the Delay generator STEP at 5 ns. (Press FN-STP-5-ns, then FN-DLY). Hold the INC button down and observe the pulse move across the screen. Press the DEC button next.

When in DELAY mode, pressing the INC/DEC buttons moves the display window by the step entered in the STP Function. Pressing and releasing the INC/DEC will move the window one step. Holding the button down will cause continuous stepping. Try this. Enter other STEP sizes and repeat.

If you are in the STEP mode and press the INC/DEC buttons, the step size will change by powers of 10 times 1, 2 and 5 ns with the T/DIV mode. Try this. Practice setting the step size and moving the window.

How The Delay Generator Works!
This is easiest understood by referring to Figure 5-A below. The delay generator runs at a set repetition rate. If the time of the Trigger Pulse out is taken as zero, then a reference value can be set to any point in time within the absolute delay range. The DELAY can be positive or negative but the REFERENCE plus DELAY must fall within the ABSOLUTE DELAY RANGE. The Delay is measured from the REFERENCE point to the left side of the WINDOW. 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 ABSOUTE DELAY 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 ABSOLUTE DELAY RANGE.

```
                                                         WINDOW
Trigger Out
0<--------- REFERENCE ----------> <------- DELAY ------>              319995 ns
 <-------------------------- ABSOLUTE DELAY RANGE --------------------------->
```

Figure 5-A

Using the INC/DEC buttons allows only powers of 10 times 1, 2, and 5 ns to be entered in the PDG20. Other values can be entered directly, (Press FN-T/DIV-2.5-ns). Try other values.

The smallest T/DIV entry allowed is 0.05 ns. All T/DIV entries must be a multiple of 0.05 ns. The entry 0.77 ns, for example, will cause the error indicator (E) to light. Press CLR and start over.

Changing the T/DIV value with INC/DEC will cause the step value to change by the same proportion. See this by checking the STP value, changing the T/DIV value using the INC/DEC button and then checking the new STP value.

When changing the PDG20 T/DIV, the left side of the window, (display screen), stays fixed at the indicated delay. The window expands or contracts from the right side. Depending on values entered, then, the pulse will appear from and disappear to the right side of the screen. For large widow sizes the pulse will advance to the left and seem to disappear into the left side when increasing the T/DIV. Indeed, the pulse is disappearing into the first sampling point.

** Go to the Processor. Adjust the TIME/DIVISION by adjusting the INC/DEC toggle switch by the TIME window. Toggle until the pulse returns to the window as it was above.

Note that this adjustment causes the PDG20 window to flash once each adjustment. The PDG20 T/DIV follows the value set in the Processor. Check this. The processor does not follow the value set in the PDG20 and does all calculations on its own value . For this reason all TIME/DIVISION entries should be made through the Processor. Only for special values required for observation should the TIME/DIVISION be entered directly through the PDG20.

****

6. SET UP THE TRAINING REFERENCE PULSE

** Use the procedures learned above to adjust the pulse as shown in Figure 6-A below. Note the settings as you will be asked to return to this display later. There should be only a few counts in the fourth level. Call this the Training Reference Pulse (TRP).

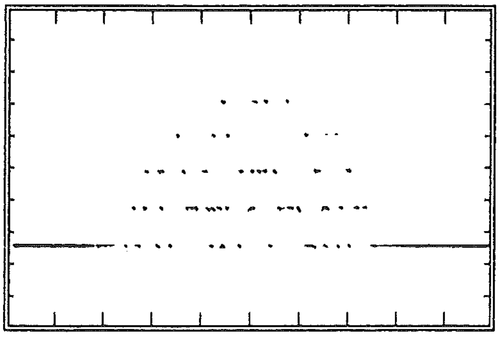


Figure 6-A
Training Reference Pulse (TRP)

****

7. <u>TAKE THE REFERENCE</u>

** Set up the TRP. (See previous section).

** Go to the Processor.
:Set the right hand toggle at SHIFT.
:Set the REF. toggle at REF. RETAIN.
:Press CLEAR.
:Set the SWEEPS AVERAGED at 512 using the nearby INC/DEC toggle.

** Take a Reference. (Press REFERENCE-SIGNAL.) The LED will blink while the Processor is averaging and calculating. When finished the LED will stop blinking and remain ON after which the averaged reference should appear on the Display Scope. Each time the button is pressed the process is repeated and the new data is written over top of the old data. Try this.

If there was data in the MEASUREMENT memory, the Processor will do calculations, the DISPLAY MODE will go to TDR and the Display Screen will blank. To view the Reference pulse go to the DISPLAY MODE and toggle back to REFERENCE. To repeat the procedure press CLEAR and then REFERENCE-SIGNAL.

** Press CLEAR then reduce the signal amplitude to just a few counts in the second level by partially removing J_1. Take a REFERENCE and note how noisy the signal is. Now increase the number of averages to 2048 and take a REFERENCE. Note the improvement. Repeat this for different light intensities and averages to get a feel for the signal required for a good result.

****

8. <u>TAKE THE MEASUREMENT</u>

** Do the following.
:Set the Photon Counter to HI Sensitivity.
:Set up the TRP.
:Set SWEEPS AVERAGED to 1024.
:Set the Processor REF. toggle to RETAIN.
:Set the Processor right hand toggle to SHIFT.

** Press MEASUREMENT-SIGNAL, then when the LED stops blinking Press REFERENCE-SIGNAL.

When the calculation stops the DISPLAY MODE will be TDR. The FWHM/SEPARATION window will show the separation between the REFERENCE pulse and the SIGNAL. Here, since they are the same pulse the separation should be 0.00 ns. The VERT. SCALE/LOSS (dB) window will show the loss in dB between the two pulses. Here again, the loss should read 0.00. These numbers may be significantly different from zero rather than actually reading zero due to noise, rounding, the Photon Counter SENSITIVITY setting and certain other factors.

The DISPLAY MODE toggle allows observation of the averaged Reference, averaged Measurement, the unaveraged Input Signal and the calculated results. Use the toggle to look at these. When in the MEASUREMENT and REFERENCE position the FWHM/SEPARATION window will read the pulse FWHM in nanoseconds while the VERT. SCALE/LOSS (dB) window will indicate the vertical scaling of the display. In these two positions, the display VERT. SCALING can be altered with the TIME window INC/DEC toggle. Try this.

In the INPUT mode the real-time pulse is displayed. This allows inspection of the real-time signal without destroying the averaged data.

The FWHM is calculated on the pulse with the largest amplitude. Here there should be only one pulse so that no confusion should arise.

The scaling allows for enlargement of various features. When scaling the larger features wrap around; that is the display goes off the top and reappears from the bottom of the screen. Try adjusting the Scaling again and observe this feature.

** Set the Photon Counter at Medium SENSITIVITY. Make the signal reasonable by adjusting the jumpers. Take some MEASUREMENT's and note the variance from zero (SEPARATION and LOSS). Repeat at LOW SESITIVITY. Low Sensitivity will give better spacial resolution but does so at the expense of sensitivity.

After the REFERENCE is taken, the TIME must not be changed before taking a MEASUREMENT or vice versa. The Processor cannot and will not calculate when the two time bases have different values.

The REFERENCE and MEASUREMENT can be taken in either order or either can be repeated any number of times.

****

9. <u>USE REF. ERASE</u>

** Do the following;

:Set up the TRP.

:Set the REF. to REF. ERASE.

:Press CLEAR, then MEASUREMENT-SIGNAL.

Note that the REFERENCE is erased so that the Processor now calculates the FWHM, and displays the pulse. The scaling factor can be adjusted with the TIME toggle. This is a useful mode if calculations against the REFERENCE are not desired. It enables the operator to search for, look at and adjust pulse position, number of averages etc. without having the calculations go forth resulting in a blank screen. Try this by taking repeated MEASUREMENTS.

****

10. USE THE CONTINUOUS AVERAGING FEATURE

** Do the following.
:Set up the TRP.
:Use the Processor to obtain the Display Scope calibration pattern.
:Toggle the sweeps averaged to 32.
:Press CLEAR.

Observation of the display scope will show that a number of averages are being taken, (here 32), and the screen is being updated after each series. For 128 averages the screen will update at the rate of slightly more than once per second. Try this. The Processor powers ON at 4. The continuous averaging with update must be entered in the calibrate mode but this can be done at any time.

This feature is useful when searching for a very low signal. It does not interfere in any way with the sweeps averaged set for normal operation.

** Set up a weak signal. Search for it using different averages, T/DIV values and STP values.

** Set the continuous average number at the number with which you feel most comfortable.

****

11. OBSERVE THE PDG VARIABLE REPETITION RATE

** Go to the PDG.
:Set the REF to zero.
:Set the DLY to 1 µs.

** Press the Processor MEASUREMENT-SIGNAL and note the speed at which the LED blinks. Next, set the DLY to 250 µs and again take a MEASUREMENT. Note the reduced rate of blinking. Try some other values.

Below a 2 µs delay the PDG operates at a 33 kHz repetition rate. However, even this relatively slow rate is too fast when the distance of the reflected pulse becomes greater than 200 meters. Thus, there is an automatic reduction in the repetition rate as the delays become larger. This can be seen in the longer times taken for a given number of averages as delays increase.

****

12.A ROUGH LENGTH MEASUREMENT (1 m ±2.5 mm)

** Configure the system as shown in Figure 12-A below.

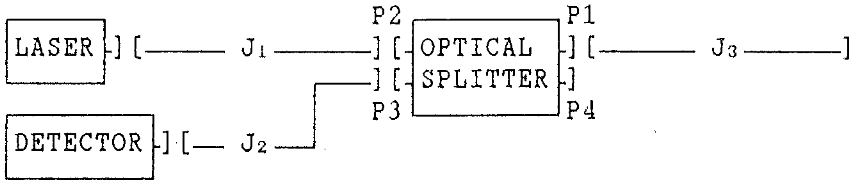


Figure 12-A

** Use the PPC10 LOW SENSITIVITY setting. This is to insure highest resolution for this exercise.

** Locate the pulse from the input end of the Jumper J_3. In this case it will be the bulkhead pulse. Adjust the pulse so it is about 4 divisions wide and 4 to 6 divisions high on the display scope when taking 512 averages.

** Center the pulse using the finest PDG step size, (0.05 ns). It should be possible to center the peak of the pulse within ±0.025 ns.

** Press FN-REF-ENTER, then FN-DLY. This enters the delay time to the input pulse as the Reference Delay. The DLY will read 0.00 ns.

** Locate the pulse reflected from the fiber end. Do NOT adjust the TIME. Again, center the pulse. Read the DELAY from the PDG. Division by ten will give the jumper length, as 10 ns is the time taken for a round trip in a 1 meter piece of fiber.

If the index of refraction for the fiber is known, it can be entered into the PDG. (Press FN-n-146-ENTER, for example). Note that the decimal point is automatically entered. To find the correct length press FN-LEN. The display will indicate the jumper length in centimeters calculated from the Delay time and the entered index of refraction. Enter various index values to see the effect on the calculated length. The system measures the time of flight accurately, but cannot know the index of refraction of the medium through which the light passes. This must be supplied for accurate measurements.

By this method delay times can be measured with an accuracy of ±25 ps which normally represents a distance of 2.5 mm. By using some averages (512 perhaps) and taking MEASUREMENTS, even noisy signal can be fairly well centered.

** Adjust the PPC to MED and HI sensitivity in turn and repeat the measurement. (It will be necessary to adjust the Jumper J_1 to prevent detector saturation.) Notice how resolution falls off when higher sensitivities are used. Try various combinations.

****

13. A PRECISE LENGTH MEASUREMENT (1 m ±0.2 mm)

** Repeat the setup above, to the point where the bulkhead pulse is centered on the display scope screen. Use LOW sensitivity.

** Set the SWEEPS AVERAGED to 1024, set REF. RETAIN and take a REFERENCE.

** As before, locate the reflected pulse and center it on the screen. Now, take a MEASUREMENT.

After the calculations, the DISPLAY MODE will go to TDR and the FWHM/SEPARATION window will indicate the time separation of the two pulses as seen on the display scope window. If the pulses were well positioned this should read less than 25 ps.

The total delay consists of two parts:

The PDG delay	____	ns
The processor separation .... ±	____	ns
	═══	
TOTAL	____	ns

The last contribution is a minor adjustment representing less than 2.5 mm. The ± sign must be determined by the operator. If this accuracy is required, then always position the REFERENCE to the left of center and the MEASURE'd signal to the right of center. In this case the correction may be more than 25 ps but it will always be positive, if the delay is positive.

The small correction in distance can be made using the relationship 10 ps = 1 mm for almost all cases.

The above procedure operates well for returned pulses with FWHM of about 300 ps, (the width for the LOW sensitivity pulse) but will not produce much better results than for the rough measurement described above for wider pulses, (as for 800 ps and 3 ns for the MED and HI sensitivity settings).

** Try the measurements for the MED and HI sensitivity settings. Get a feel for the limitations here.

****

Additional items required for some of the remaining exercises:

:Reel of fiber 500 m to 2.5 km.
:A connector on the fiber input end for use with J_3, OR
A mechanical splice for use with a pigtail, OR
A fusion splicer to splice the fiber to the pigtail.
:A reel of fiber 100 to 500 meters long.
:A calibrated attenuator.

****

14. SEARCH TECHNIQUE

There are two techniques which can be utilized to help find a reflective feature when the delays are long. In the examples below the fiber is assumed to be 1 km in length. If a different length is used to try these search techniques then choose delay times which are of about the same proportion to the expected length as in the examples.

Technique 1. Go out towards the feature but stay well short of it. Next, open the window to cover the suspected feature. For example, suppose the fiber is known to be about 1 km in length and you want to find the end. If your test fiber is a length different from 1 km use numbers proportional to those suggested below.

** Do the following
:Set the PPC to HI SENSITIVITY.
:Set REF to zero, DLY to 8000.00 ns

** Open the window (Use the PDG as the Processor will not open far enough) so that it extends past the expected end position. A T/DIV of 500 ns will give a window of 5000 ns allowing observation of the time from 8000 ns to 13000 ns. This allows observation from 800 m to 1300 m. If a "pulse" is visible it may be in the form of one dot above the baseline. Whether or not the dot can be found try the following:

:Set STP to 0.05 ns
:Use the INC button to step through 20 ns.

IF the dot was found, you will probably see it increase and decrease in height as the delay changes. It may even disappear.

IF there was no dot, one may appear and change in height.

IF no dot appears, there may be a very weak reflection, no reflection or the fiber may in fact be a different length than anticipated.

The reason for the apparent strange behavior is as follows. The photon counting unit counts at each of 256 points across the screen. The results are compiled to compose one sweep on the display scope. The window has been opened to 5000 ns so that each point spans (5000÷256) about 20 ns. The optical pulse is less than 100 ps and the detector response is less than 3 ns on Hi sensitivity, (less than 300 ps on the LOW sensitivity setting). Consequently, the system can sample in a time space within the 20 ns where there is no pulse even though there is one in that 20 ns time span. By stepping through the 20 ns in small steps (0.5 ns) it is insured that the entire span is sampled. The larger the window, the worse this effect. It is advantageous, therefore to move in close to the expected feature so the window becomes relatively small.

** Change DLY and window size (T/DIV) and investigate this phenomenon. It is important to understand this for successful searches.

Technique 2. Open the window an appropriate amount, (Use Processor TIME toggle here), then use the INC button to scan for the feature by stepping perhaps one half a window size at a time. Assume again that the test fiber is 1 km in length.

** Do the following
:Adjust for HI SENSITIVITY.
:Set REF to zero, DLY to 8000.00 ns.
:Open the window to 50 ns, (5 ns/Div).
:Set the STP at 10 ns/Div.

** Scan the delay from 8000 ns to 12000 ns using the INC button. This will take just under 1 minute. The pulse, if it appears, will be narrow but quite readily discernible. Try other window and step sizes but remember to keep the step size less than the window size or the pulse can be easily stepped over and missed.

NOTE. If a REFERENCE has been taken before doing the search it will be cleared if the Processor TIME is adjusted, (Even if it is adjusted back to the original value). This can be circumvented by making all the T/DIV changes through the PDG. However, care must be taken to make the PDG T/DIV match the Processor TIME before valid measurements can be made.

In the event that the signal is quite low, use can be made of the continuous averaging feature. To investigate this, reduce the signal found above to the point where there are just a few one counts and use 32, then 64 followed by 128 continuous averages to look at the effect on the search. Change the T/DIV and STP size to see the effects. When a larger number of averages is used the step may be faster than the update. This could result in missing the pulse. Work with this for a while to become familiar with the advantages and pitfalls.

****

15. A LONGER LENGTH MEASUREMENT (1 to 3 km)

** Set up the optical system as shown below in Figure 15-A. For this measurement a reel of fiber is required. The reel can be connected via a mechanical splice, (wet or dry) or via an optical connector. If a fusion splice is used it may be necessary to take the reference before splicing or else to cut the splice later.

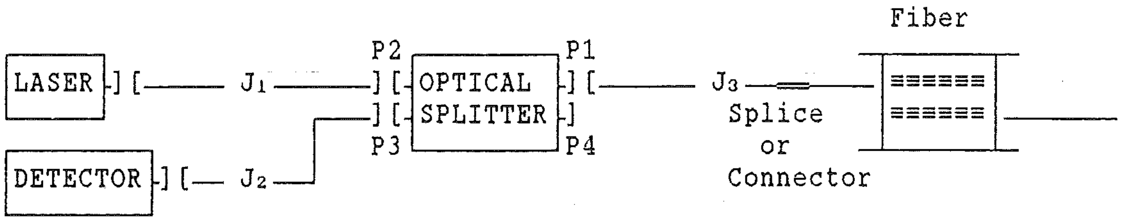


Figure 15-A

** IF a splice or connector is used, make the connection, search for and find the fiber end.

:Take this as the Reference using the techniques described in the previous sections.

:Remove the connection, find the input reflection using the PDG. The Delay will now be negative but that is OK.

The time of flight will be correct to within ±25 ns. This is probably more accurate than the index of refraction is known. Enter the index into the PDG and find the length. Again, try this for different PPC sensitivity settings.

****

16. MULTIPLE REFLECTIONS AND GHOSTS

The Photon Counter is extremely sensitive and thus is susceptible to effects seldom encountered with the Sampling system. Also when a highly reflective feature is encountered the detector becomes blind to tiny features nearby. Some suggestions on how to handle these difficulties are given below.

A multiple reflection resulting in erroneous or confusing results might occur as shown in Figure 16-A below.

Points A and B might be connectors with a return loss of 20 dB. Both A and B would give strong direct reflections as seen by the photon counter. In addition, there would be a multiple reflection as shown, (From B to A, back to B then to the detector, 20 + 20 + 20 = 60 dB.) This would result in an apparent weak, but easily detectable signal at C. An inexperienced operator would see this as a feature at C when in fact it is a ghost cause by multiple reflections.

```
                    A              B                         C
____________________T______________T_________________________|_________
--------------------------------------->                    ghost
                   <---------------
                    --------------->
<-------------------------------------
```

Figure 16-A

HOW DO I DETERMINE WHAT IS REAL AND WHAT IS A GHOST?

This is where operator experience, logic and ingenuity come into play.

In the above case.

:Index matching gel applied to the connectors at A and B will reduce the ghost amplitude significantly. If the feature was real, the amplitude would remain the same or even increase.

:Pinching the fiber between points B and C would affect a feature at C but would not affect a ghost at C.

:For a ghost the distance between B and C would be exactly double the distance between A and B.

Unfortunately, many of the multiple reflections occur within the equipment. For example, there is a strong reflection from the laser-fiber interface, a less strong one between the detector-fiber interface and a 4% reflection from the unused bulkhead connector. Thus a strong reflection from a feature anywhere downstream can go:-

Feature -> Laser -> Bulkhead Connector -> Detector

This would result in a ghost approximately 30 ns later with an amplitude 25 to 30 dB below the feature reflection. What can be done?

:The 4% bulkhead reflection can be reduced significantly by connecting a pigtail and dumping the light by using index matching gel on the end.

:Multiple reflections from the various connectors can be reduced by using index matching gel as well.

The above precautions will reduce, but not eliminate multiple reflections and ghosts. The equipment multiple reflections result in a multitude of ghosts close to the bulkhead. These cannot be eliminated but can be circumvented by inserting a piece of fiber between the bulkhead and the test fiber. The length required may be 10 to 100 meters and it is necessary to make the connections with very low return loss to eliminate a source of more ghosts.

The seriousness of the ghosts and the ease of reducing the effects depends on many things. Each operator must determine what he can "live with"

****

17. FRESNEL AND RAYLEIGH BACKSCATTER

A Fresnel reflection or backscatter is caused by a discontinuity in the index of refraction. This occurs quite strongly at an glass/air interface and less strongly at a glass/glass interface. The discontinuity is a well defined point in space and in general a strong backscatterer. The reflected signal will normally vary from 10 to 60 dB down from the input signal.

Rayleigh backscatter on the other hand is caused by index of refraction variations in volumes with dimensions smaller in size than the wavelength of light being transmitted. These are very weak scattering points but there are many and they are fairly uniformly distributed along the length of the fiber. Rayleigh backscatter is measured from 60 to 70 dB down per meter of fiber. Thus to see Rayleigh backscatter from a 1 millimeter length of fiber one would expect a return signal some 90 to 100 dB down. This is in the neighborhood of single photon return from a 100 ps wide pulse.

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18. OBSERVE RAYLEIGH BACKSCATTER

** Set up as in Figure 15-A with a fiber length of 100 to 1000 meters then do the following;

:Set the REF to zero and find the fiber length in ns, (L say).
:Subtract 750 ns from this, (L-750 = REF).
:Set this as REF, DLY = 0, and T/DIV = 100.

Look for the "pulse" which will be a single dot. The display should look similar to Figure 18-A. Now review Section 14. SEARCH TECHNIQUE. Most of the explanations there, apply here as well. In particular the pulse can appear and disappear in a similar manner and for the same reason. Spend some time adjusting the various settings, then reset as above and continue.

The bulkhead reflection is so strong and provides so many counts relative to the Rayleigh backscatter that the latter appears to be zero. To see the Rayleigh backscatter this strong reflection must be reduced.

** Tie a knot near the fiber end (½ m in) and slowly tighten while watching the Fresnel reflection from the end. When the Fresnel reflection has been reduced to the noise level, take 512 averages. Now the display should appear similar to Figure 18-B. Play with this loop, trying different averages and loop tightness.

There is a sloped line, (Rayleigh backscatter), a sharp peak, (Fresnel reflection from the fiber end), and a zero return baseline, (beyond the fiber end).

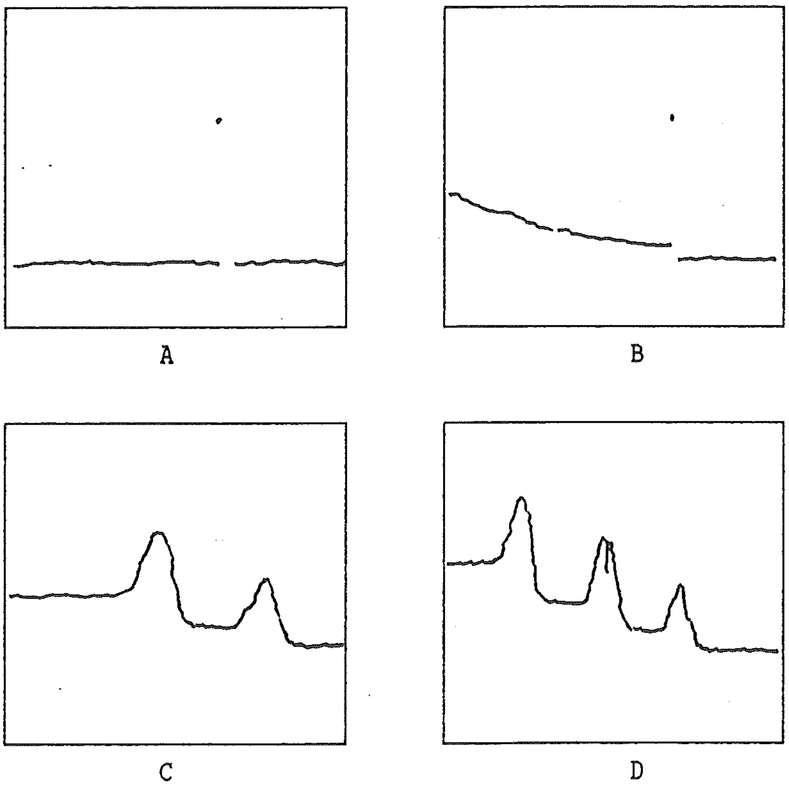

Figure 18

** Adjust the window and delay so that;
:the fiber end appears in the right half of the display scope.
:T/DIV is 0.5 ns.

** Untie the previous knot and re-tie 0.3 m in from the end. Repeat the above measurements. The results should look like Figure 18-C. Tie a second knot 0.6 meters in from the end. These can be adjusted to look like Figure 18-D.

Here you see the Rayleigh backscatter expanded and you see the backscatter from the two macrobends as well as the loss from these two bends.

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19. <u>A RETURN LOSS MEASUREMENT</u>

** Measure return loss from the end of a long fiber.

For this measurement a calibrated attenuator must be inserted between the laser and splitter. The dynamic range of the photon counter is very low, as indeed, it must be if it counts single photons. The optical system will appear as in Figure 19-A. Note the changes:...

:The addition of the calibrated attenuator.
:Connectors are now all securely mated.

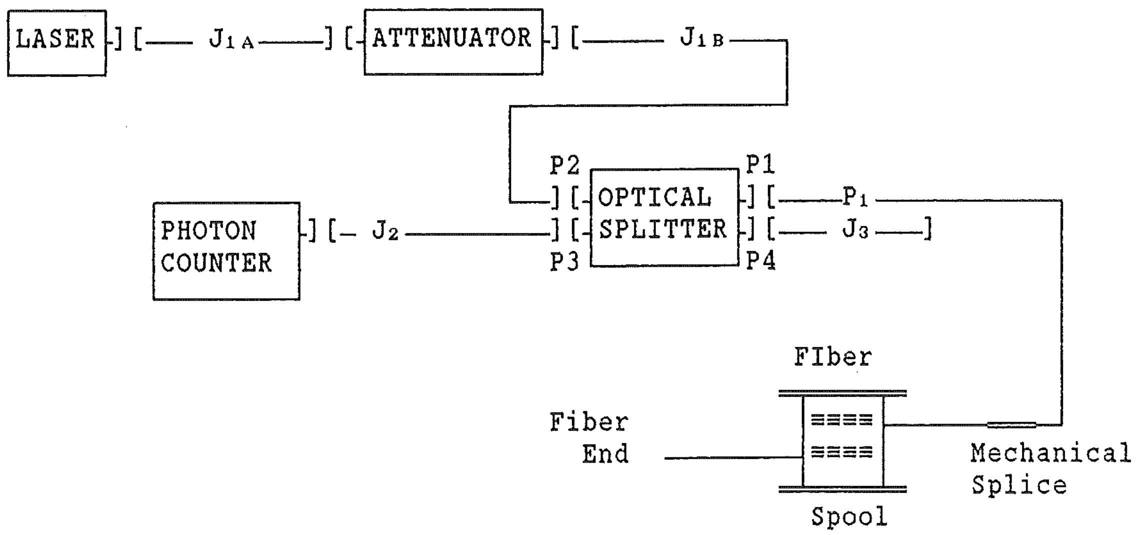

Figure 19-A

** Locate the polished end of Jumper J_3. This should be carefully cleaned as it will provide the reference pulse calculated to be a 14 dB down signal. As before, center the signal, insure there are only a few four counts by adjusting the attenuator, set 2048 averages and take a REFERENCE. Set REF RETAIN on the TDR30 and note the attenuator reading.

** Locate the test fiber end. It may be necessary to open up the attenuator. Adjust the pulse as above. Take a measurement. The return loss is the sum of the following:

a:REFERENCE PULSE	14	dB
b:ATTENUATOR	___	dB
c:TDR30 dB LOSS Window (x 2) ..	±___	dB
	═══	
RETURN LOSS	____	dB

a:The reference pulse is a 4% reflection or 14 dB down signal.

b:The attenuator contribution is the difference between the attenuation readings for the reference and measured signals.

c:The TDR30 measurement is read from the dB LOSS window after the calculation has been completed. Note the x 2 factor.

The TDR30 does not know about the reference pulse and it does not know about the attenuator. It simply compares the area under the returned signal as seen on the display scope. Thus, it can happen that the measured signal is larger than the reference signal, in which case the + sign must be used above rather than the - sign. The operator must determine the correct usage here.

NOTE:- About the x 2 ... The Processor has been set up to measure insertion loss as outlined in Section 20 below. This implies that the optical pulse passes through the component twice so that the loss is twofold. The Processor adjusts for this in the loss read-out. In the case of return loss, the pulse is reflected straight back and does not pass through the component twice, hence the read-out must be adjusted (the factor of 2) by the operator. to see this effect directly:-

** Do the following;

:Set up the TRP.
:Take a REFERENCE.
:Adjust the jumper to get a signal one half of the REFERENCE amplitude.
:Take a MEASUREMENT.

Note the reading in the LOSS window. Although the signal was cut in half, (3 dB), the window will read 1.5 dB. Be sure to understand this when doing loss measurements.

** Insert the fiber end into some index matching gel and measure again. Repeat for water. Which is better? Try for other liquids and other gels if available. If the fiber end is not connectorized, try breaking it, try cleaving it. If connectorized, try adding a jumper, add index matching gel. Compare all the measurements.

Note that this procedure assumes no fiber loss. If the fiber is lossy as well, this must be taken into account either by actual measurement or by using known loss figures as supplied by the fiber manufacturer

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20. AN INSERTION LOSS MEASUREMENT

An insertion loss implies a throughput. Thus the technique used here is to measure the input, insert the component and measure a known reflection. The setup is shown in Figure 20-A below.

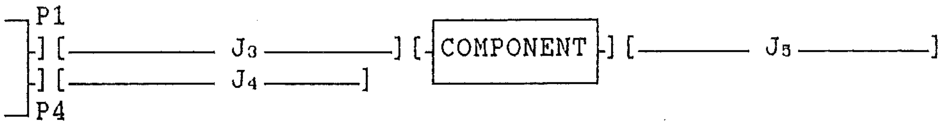

Figure 20-A

** As in section 19 above, take a REFERENCE from the end of the disconnected jumper J_3. Insert the component, add a Jumper J_5 as shown in Figure 20-A. Now locate an MEASURE the end of Jumper J_5. This is a known 4% reflection. As above the insertion loss can now be calculated.

a:ATTENUATION reading (÷ 2)... ____ dB
b:TDR30 dB LOSS WINDOW .... ±____ dB

INSERTION LOSS ____ dB

a:The attenuator contribution is half the difference between the attenuation readings for the reference and measured signals. The signal passes through the component twice so that the attenuator measures a two way loss.

b:This is the difference in the two signals as seen by the Processor. The value can be positive or negative; the sign must be determined by the operator.

The insertion loss is the total transmission loss due to the inserted component. Subtraction of the return loss from the insertion loss give the forward scattering loss plus the absorption loss. These two last losses cannot be separated with this instrument. Normally, absorption losses would be very small with forward scattering loss being dominant.

Note: The insertion loss as shown in Figure 20-A includes the component and the two connectors. If the component output connector were a 4% reflection or a least a known reflection, then the Jumper J_5 would be unnecessary and the MEASUREMENT could be made on the output connector. If this reflection is different from 4% it must be accounted for by the operator.

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21. MEASURE A SMALL INSERTION LOSS

The following can only be done with TDR30 Processors manufactured after September 1990 or unit which have been updated after this date.

** Set up as shown in Figure 15-A. Tie a knot in the fiber about ½ meter from the end. Adjust this to look like Figure 18-C. Fix the tie with tape or some other means.

** Adjust the window size to 1 meter. Now take a REFERENCE with the window positioned in front of but not including the pulse returned from the tie-off. Move the window just beyond the tie-off and take a MEASUREMENT.
The Processor SCALING/LOSS (dB) window will show a loss. The Processor takes the number of counts from the Rayleigh backscatter before the tie-off as reference and subtracts the measurement number found beyond the tie-off to determine the loss through the macrobend.

** Repeat the above procedure for different window sizes and number of averages.

** Use this same procedure to measure a connector loss. (i.e. let the component in Figure 20-A be a connector.)

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22. A CLEAVING TECHNIQUE CHECK

** Set up as shown in Figure 22-A.

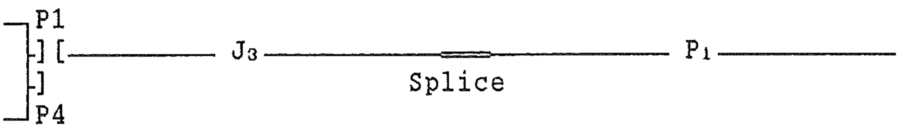

Figure 22-A

** Find the end of the pigtail P_1 and take a REFERENCE.

** Cleave a short piece from the end of the pigtail and then take a MEASUREMENT. What is the loss? If both cleaves were good, the loss will be zero. Repeatedly cleave, then take a MEASUREMENT and observe the results.

The loss could be positive or negative depending on how good the REFERENCE cleave was. This procedure can be used to check the repeatability of a cleaving technique.

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23. SOME FURTHER EXERCISES

To help the operator appreciate the true power of the system the following exercises are suggested.

** A. Connect the PPL30K source to the PFC coupler port P2 with jumper J_1. Connect one end of jumper J_2 to coupler port P4. Use the PDG20 settings suitable to find a short delay signal. Now point the free end of jumper J_2 in the general direction of the photon counter input. A strong signal should be obtained if the transmission and receiving fibers are both within their acceptance angle. A weaker signal will be obtained from oblique angles. A darkened room may be required to reduce the photon counter "dark count". The same exercise can be repeated with two singlemode jumpers pointed at each other.

** B. Take the cabled jumper J_2 and bend the free end into a small radius. Hold this radius near the photon counter input and see the light leak from the cable. If no signal is found, this implies that the protective sheath is also a good absorber.

** C. Hold your thumb over the photon counter input connector. Put the jumper cable connector against the thumb fingernail. Take 512 averages to see the light transmitted through the thumb.

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In summary, it should be noted that the OTDR system measures just two parameters;

1: TIME OF FLIGHT

2: PULSE ENERGY DIFFERENCES

All measurements of distance, temperature, pressure, strain, return loss, insertion loss, index of refraction measurements, liquid sensing and the myriad of other measurements must all be related to the above two parameters (time and measured energy differences) in a known way in order for valid measurements to be made. In spite of this apparent severe restriction a very large number of measurements can be made and information can be retrieved; information which is just not available from any other source.

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This completes the training session with the Opto-Electronics OTDR photon counting system. The operator should now be prepared to use the equipment for any of the large number of applications possible.
