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TIME DOMAIN REFLECTOMETRY FOR SLC BPM SYSTEM*

by

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MASTER

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SYNOPSIS

This document is intended for use as a maintenance manual for troubleshooting installed SLC Beam Position Monitor stripline assemblies and the associated cabling, using Time Domain Reflectometry.

1. WHAT TDR CAN DO FOR YOU

Time domain reflectometry allows the knowledgeable person to easily and non-destructively perform the following tasks:

- Find out how long an installed cable is.
- Discover whether the far end of a cable is open, shorted, or terminated in an impedance.
- See if an installed cable has an in-line connector or a bad kink, and accurately measure the distance to the discontinuity.
- "Look" inside a vacuum-tight installed BPM stripline.
- Compare present BPM stripline condition to the laboratory calibration condition. Photographs were made of each stripline before installation; J.-L. Pellegrin has the original photographs.
- Accurately cut cables to identical lengths.

2. TDR CONCEPTS--HOW IT WORKS

A TDR system can be compared to "wire radar". A fast-rising step voltage at least twice as long as the cable under test is injected into a cable. The echo is plotted on a CRT with respect to time. Time is plotted on the x-axis (left-to-right), and the voltage reflection coefficient (ρ) is plotted on the y-axis (vertical).

The amplitude of the voltage reflection coefficient is related to the impedance of a cable or electrical system at any given point. However, ρ versus impedance is not a linear relationship. Please see reference 6 for more information.

The length of time displayed horizontally on the CRT is a precise indication of electrical length, and therefore also an accurate indication of physical length.

An open circuit termination drives the right-hand side of the CRT display upwards by an amount equal to the input pulse step.
($\rho = +1$.)

A short circuit termination shows up as a downward deflecting CRT trace, by an amount equal to the input pulse step.
($\rho = -1$.)

If the cable is terminated in its characteristic impedance, the right hand side of the trace will be level, beyond a small "bump" at the termination point.
($\rho = 0$.)

An in-line connector or a bad kink in a cable will show up as a "bump" in the display.

An inductance results in a positive bump; capacitance produces a negative bump.

3. QUICK DIRECTIONS FOR OPERATING THE TDR

(For a more detailed discussion of the controls and capabilities, please see reference 1.)

3.1. PRECAUTIONS

3.1.1. Discharge Cable:

Discharge cable before connecting it to the TDR. (Momentarily apply a short to the cable connector.)

3.1.2. Limit Input to 1 volt or less:

Be CERTAIN any input voltages to the TDR set are less than 1 volt peak-to-peak. This is necessary to protect the tunnel diode of the sampler.

3.1.3. Be Careful With the Sampler:

Treat the 1817 sampler unit with care--the tunnel diode assembly is delicate and quite expensive.

3.2. MAKE THE CONNECTIONS

(See figure 24)

3.2.1. Gray Cable:

Connect the gray multi-conductor cable from the scope front panel to the 1817A sampler

3.2.2. Diode Mount Plug:

Connect the tunnel diode mount plug to the tunnel diode mount

3.2.3. Diode Mount Assembly:

Connect the tunnel diode mount assembly to the plug marked "Input"

3.2.4. External Cable:

Connect the external cable to be TDR'd to the plug on the 1817A marked "Output"

3.3. SET UP THE CONTROLS

(See figure 25)

3.3.1. Set "rho" per div. to 0.5 (fully CCH):

3.3.2. Set MARKER POSITION to 000:

3.3.3. Set FT/DIV to 10.

3.3.4. Set EXPAND knob to 1:

3.3.5. Set FUNCTION to POLY:

3.3.6. Set MARKER zero fully counter-clockwise:

3.3.7. Set SCAN to NORMAL:

3.3.8. Set NORM/SIGNAL AVG. switch to NORM:

3.3.9. Look at a Cable:

Connect a short (about 4 feet) section of cable to the input of the 1817 sampler. (See figure 24, § 3.24)

3.4. ADJUST THE TUNNEL DIODE BIAS

Use a jeweler's screwdriver to adjust the tunnel diode bias to produce the display shown in figure 5.

Please note the displays obtained with improper tunnel diode biasing. (figures 1 thru 4)

3.5. LOOK AT SHORT

Place a dead short on the end of your 4 foot section of cable, and you should see a display similar to figure 6.¹

3.6. SET CONTROLS FOR SPECIFIC APPLICATION

3.6.1. Bpm Stripline Viewing:

"rho" per div. = 0.05

foot per div. = 1

expand = 0.05

Be very gentle with the BPM stripline connections. They are quite delicate, and breaking vacuum is a disaster. It is much better to work slowly and carefully than to work quickly and possibly damage the BPM stripline feed-thru.

If the stripline you wish to TDR has pigtails attached between the stripline feedthru's and the long cable up to the gallery, make the TDR through the pigtail. Do not remove the pigtails: they are installed there to save you the trouble of working inside the magnets.

¹ "A diode that's bought the farm does not like a dead short. Instead of the display looking like figure 6, it looks like figure 4. Readjusting the tunnel diode bias may help."

-Verne S. I. n

Disconnect the cable going upstairs at the pigtail junction, and connect the TDR input to the pigtail.

Set up the controls as in 3.3 above. Using a 4 foot long cable, make the connection from the TDR input to the BPM stripline feed-thru. You should now have a display similar to figure #13.

Next, then turn 'rho'/div knob to 0.05 (one step at a time, keeping the display on the CRT with the vertical position knob).

Be SURE the portion of the trace representing the 50 ohm cable is positioned precisely on the center line: this provides the reference for the impedance of the stripline portion of the trace.

Next, set ft/div (outer knob) to 1, keeping display centered with marker position knob. Now turn the expand (inner knob) control to 0.05, again one step at a time, while centering display.

You should now have a CRT display that resembles one of the four displays in figure 19. If not, check the set-up and cabling. (For Damping Ring striplines, see figure 21.)

Be aware that the TDR picture of each BPM stripline is slightly different in much the same way different individuals have different signatures.

The laboratory photographs were made at 200 picoseconds per division, with FUNCTION set to TIME. "Rho" was the same; 0.05 per division.

Setting the controls as in Section 3.6.1 expands the feedthru and stripline display horizontally for more resolution, but preserves the vital impedance information.

The TDR's resolution is such that a 1% variation in impedance is visible (1/2 ohm.)

If it becomes necessary to produce a CRT photograph with the TDR set up in precisely the same way as for the lab calibration photographs, it will be necessary to set the tunnel diode's bias to the same operating point. Verne Smith has a "lab standard" BPM stripline assembly for precisely adjusting this bias.

Tweaking the bias through its operating range changes the apparent slope of the stripline's horizontal display.

Always put each cable back on the BPM feed-thru it came from (observe color convention-- See the color coding illustration, figure 26.) Re-torque the SMA connector to 8 ounce-inches.

It is unfortunately not possible to view the stripline from "upstairs" and get meaningful results. The long cable "smears out" the stripline reflections too much; see fig. 11.

However, it is possible to tell if a LINAC, LTR, or RTL cable is connected to its shorted stripline. A downward-deflecting trace like figure 11 tells the operator that the cable is connected, and that the stripline is terminated.

By comparing the displayed length of a "good" cable to a "bad" one, it is possible to locate a discontinuity to either the cable itself or to the stripline assembly.

The TDR set can be used to look at installed BPM cables even with beam in the machine--stripline pulses arriving at the upstairs end of the cables are too small to exceed the 1 volt maximum input level of the sampling head.

3.6.2. Cable Length Measurement:

(For more details, see reference 4 or 5.)

"rho" per div. = 0.5

Feet per div. = 100

Expand = 1

First set up the controls as in step 3.3 above. Connect the cable to be measured.

Next, set ft/div outer knob to 100, expand knob (inner) also to 100. You should get a CRT display as in figure 9. (Here each horizontal centimeter division represents 100 feet.)

Rotate marker zero knob back and forth to find the bright marker pip on the CRT. Place it on the rise of the reflection that corresponds to the start of the cable under test.

Now turn the expand knob to 1 foot. Re-zero the marker zero knob (figure 10).

Rotate the marker position knob (it has three digits inside knob) until the knee of the cable's far end reflection is lined up with the marker; see figure 11.

Read off cable length directly in feet from the three digits inside the marker position knob.

For cable fabrication, see references 4 and 5.

Appendix A

REFERENCES

(Sources are in parentheses.)

1. *Operating and Service Manual, Models 1815A/1815B/1817A TDR/Sampler Group*, Hewlett-Packard Company, Colorado Springs Division, 1979.
(Technical Library)
2. *Cable Testing With Time Domain Reflectometry*, Hewlett-Packard Application Note 67, 1965.
(Technical Library)
3. *Time Domain Reflectometry*, Hewlett-Packard Application Note 62, March 1964.
(Technical Library)
4. *Timing Requirements and Proposed Tests for the Position Monitors' Cables*, J.-L. Pellegrin, Single Pass Collider Memo CN-119, October 24, 1981.
(SLC Secretary)
5. *Cable Fabrication Procedures for the BPM System*, William B. Smith, SLAC-TN-84-3.
(SLAC Publications)
6. *Time Domain Reflectometry Measurements*, James A. Strickland, Tektronix Publication 062-1244-00
(Tektronix, Inc.)

Appendix B
ILLUSTRATIONS

All Photos Taken at 'Rho' = .5, Ft/Div = 1
(unless otherwise noted)

<u>FIGURE</u>	<u>NOTES</u>
1	Tunnel Diode Bias, Improper Adjustment; Bias set too high
2	Tunnel Diode Bias, Improper Adjustment; Bias set too high
3	Tunnel Diode Bias, Improper Adjustment; Bias set too low
4	Tunnel Diode Bias, Improper Adjustment; Bias set too low
5	Tunnel Diode Bias, Proper Adjustment; 4 foot cable, open
6	4 foot cable, shorted
7	4 foot cable, 1 foot pigtail
8	Expanded view of connector in Figure 7
9	148 foot cable, Far end shorted
10	148 foot cable, 1 ft/div, Marker zero'ed
11	148 foot cable, Marker at far end of cable
12	148 foot cable, Stripline at far end
13	4 foot cable, Grounded stripline at far end
14	4 foot cable, with grounded stripline, 'Rho' = .05, ft/div = .05
15	Expanded view of in-line SMA connector
16	Expanded view of SMA connector and bad kink in cable

- 17 4 foot cable with 50 ohm termination
- 18 121 foot cable with open (bad condition)
Linac stripline, Sector 2 # 51 Blue (#2)
"Rho" = 0.05/div, 1 ft/div 12-07-1983
- 19 Grounded striplines, good condition.
RTL QD-38, SN R22, 12-08-1983
"Rho" = 0.05/div, 0.05 ft/div
- 20 Grounded striplines, #4 in bad condition.
RTL QF-38, SN R20, 12-08-1983
"Rho" = 0.05/div, 0.05 ft/div
- 21 Open striplines, good condition.
Damping Ring, QD-116, SN 009, 12-08-1983
"Rho" = 0.05, 0.05 ft/div
- 22 Open striplines, #3 in bad condition.
Damping Ring, QF100B, SN 202, 12-03-1983
"Rho" = 0.05, 0.05 ft/div
- 23 Grounded striplines, #2 in bad condition
(inner conductor shorted to feedthru body)
Linac Sector 1 # 92 Blue (#2) SN 61.
"Rho" = 0.05, 0.05 ft/div, 12-08-1983
- 24 TDR Sampler Connections
- 25 TDR Front Panel Controls
- 26 B&H Striplines Color Coding

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Fig. 2

Fig. 3

Fig. 4

Fig. 5

OBJECT 1, FAR END SHORTED
Fig. 9

Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

Fig. 17 $\rho = 0.5$ FT/DIV = 1

Fig. 18 $\rho = 0.05$ FT/DIV = 1

$p = 0.05$
FT/DIV =
0.05

12-08-83
QD38(RTL)
SN R22

GROUND STRIPLINES

Fig. 19

$\rho = 0.05$
 $FT/CLV =$
 0.05

12-08-83
 GF33(RTL)
 R20

$(\rho = 0.1)$ BENT STRIPLINE

Fig. 20

A-005
 12-09-83
 0005

12-09-83
 0016
 SN009

OPEN (Damping Ring) STRIPLINES

GOOD CONDITION

Fig. 21

$p = 0.05$
 FT/DIV =
 0.1

12-08-83
 OF 1008
 SN 202

OPEN (Damping Ring) STR PLINES

BENT STRIPLINE

Fig. 22

$p=0.05$
FT/Div:
0.05

12-08-83
LI01
SN61

LINAC STRIPLINES

(#2 Is Broken -- Shorted)

Fig. 23

412 410

Fig. 24

TDR FRONT PANEL CONTROLS

See Section 3.3

Fig. 25

LTR, DR, RTL

LINAC