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NUMOD and NUTSA: Software for Interactive Acquisition and Analysis of Time Domain Reflectometry Measurements

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

With Factors for Conversion to Units of the International System of Units (SI)

Abbreviation	Unit of measure	To convert to—	Multiply by—
ft	foot	meters	0.3048
in	inch	centimeters	2.54
millirho[1]			

[1]The term "rho" refers to the ratio of reflected voltage to transmitted voltage.

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NUMOD AND NUTSA: SOFTWARE FOR INTERACTIVE ACQUISITION AND ANALYSIS OF TIME DOMAIN REFLECTOMETRY MEASUREMENTS

By Fei-Chiu Huang,[1] Kevin M. O'Connor,[2] David M. Yurchak,[3] and Charles H. Dowding[4]

ABSTRACT

The principle of time domain reflectometry (TDR) is being used by the U.S. Bureau of Mines to monitor strata displacements induced by mining. The Northwestern University TDR Signature Analysis (NUTSA) Program was developed under contract with the Bureau to allow for visual comparison of three TDR waveforms quickly and easily. This program is interactive, and on-line help is available. The Northwestern University Remote Control TDR Data Acquisition System and Modification of Tektronix SP232 Host Application Program (NUMOD) was then developed to allow acquisition of TDR waveforms from a remote cable tester via modem. The NUMOD system utilizes commercially available software while the NUTSA program is available from the Bureau. This report begins with a discussion of TDR principles followed by a description of the NUMOD system. An interactive example of signature analysis is then used to demonstrate features of the NUTSA program.

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INTRODUCTION

TDR was initially developed in the 1960's as a method to locate discontinuities in coaxial transmission cables (*12*).[5] The concept has been extended to measurement of properties of materials in which probes are embedded, such as water content of soil (*22*) and evaluation of dielectric behavior of coaxial cables (*5*). This technique was adapted by the U.S. Bureau of Mines in 1978 for use in monitoring the movement of rock during underground mining (*14, 17, 23*). Coaxial cables are grouted into a rock mass that is expected to cave, and progressive rock movement deforms the cable. Consequently, there is a progressive change in cable electrical properties, which produces changes in TDR pulse reflection signatures. TDR technology has been advanced by Northwestern University to the point where it is now possible to locate, characterize, and quantify rock mass displacements by analyzing these changes in TDR signatures (*8-9*).

The ability to quantify rock mass displacements has been enhanced by the availability of cable testers with serial communication modules that allow users to acquire signatures in digital form (*19, 21*). A natural progression was the development of NUTSA to view and compare waveforms and to analyze signature changes. With this capability in place, NUMOD was developed to interrogate long cables at remote sites several times daily to accurately assess the rock movements responsible for cable damage. As part of the Bureau's program to characterize subsidence, this combination of software and hardware has been used to remotely monitor overburden response to longwall mining at a site in Illinois (*15*).

TIME DOMAIN REFLECTOMETRY OPERATING PRINCIPLE

An installation for monitoring rock deformation consists of a TDR cable tester and a cable grouted into the rock mass, as shown in figure 1. Ultrafast rise-time voltage pulses are sent down along the cable from the tester. Cable defects, such as crimps, short circuits, or breaks, cause reflected pulses, which are detected by the tester. Pulse reflections from all changes in geometry along the cable are superimposed on the input pulse to form a reflected TDR signature. TDR reflection signature characteristics are determined not only by the type of cable defect (*19*) but also by the magnitude of cable deformation caused by rock displacement.

[5]Italic numbers in parentheses refer to items in the list of references preceding the appendixes.

The TDR waveform observed on a cable tester screen consists of many individual reflections associated with localized deformations along the cable. Assuming that the propagation velocity of a voltage step pulse is constant, the distance to each defect is proportional to the elapsed time between initiation of the voltage step pulse and the arrival of the returned voltage. The cable tester converts this time to units of distance so that it is possible to determine the location and the type of each defect by inspection of the recorded TDR waveform.

The capability of distinguishing crimps from breaks, shears, abrasions, etc. provides a convenient means for improving the accuracy with which each defect can be located. Without reference crimps along a cable, accuracy is on the order of 2% of the distance from the tester, so that a defect at a distance of 100 ft can only be located to within ±2 ft of its actual position. If a cable is crimped at selected intervals, however, a set of reference reflections is recorded each time the cable is interrogated. Defects created by rock mass movement can then be located relative to these references. If reference crimps were made

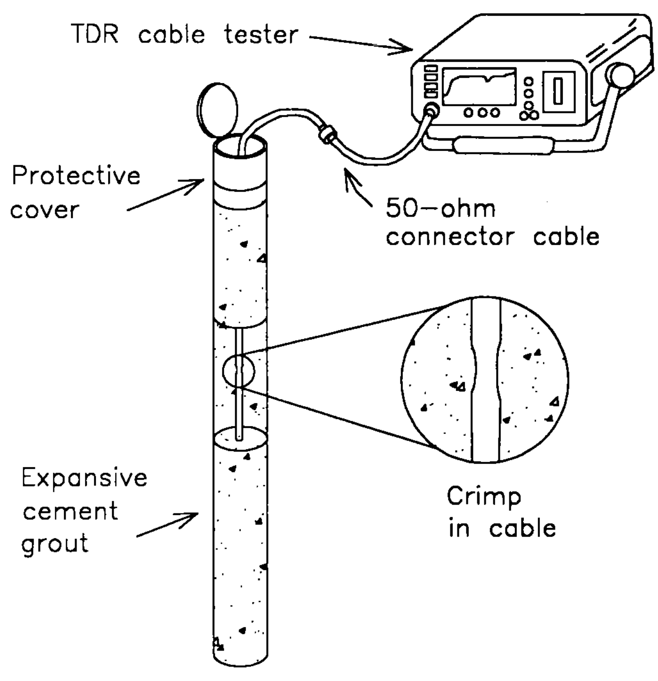

Figure 1.—Schematic of installation for monitoring rock deformation.

every 20 ft, defects could be located with an accuracy of ±0.4 ft.

Prior to installation, the cable is crimped at desired intervals to optimize resolution and an appropriate connector (e.g., ultrahigh frequency) is attached to the top-of-the-hole end. The cable is connected to a TDR cable tester via a special 50-ohm connector cable, and a reading is made to ensure that all crimps will be recorded. Crimps must be deep enough to ensure a strong reflection (e.g., 20 mrho), but not so deep as to cause a short circuit. The cable is then lowered downhole and bonded to the surrounding rock with an expansive cement grout that is tremied into the hole.

TIME DOMAIN REFLECTOMETRY SIGNATURE CHANGES

Characteristics of TDR signature changes depend on a number of factors, such as cable length, upstream cable deformation, and mode of cable deformation (shear, tension, bending, etc.). Laboratory tests (*18*) have shown that shearing of a cable encapsulated in cement grout produces a voltage reflection spike, whose amplitude increases in direct proportion to the amount of deformation, as shown in figure 2. On the other hand, extension causes only a subtle, trough-like voltage reflection that increases in length as the cable is extended, as shown in figure 3*A*.

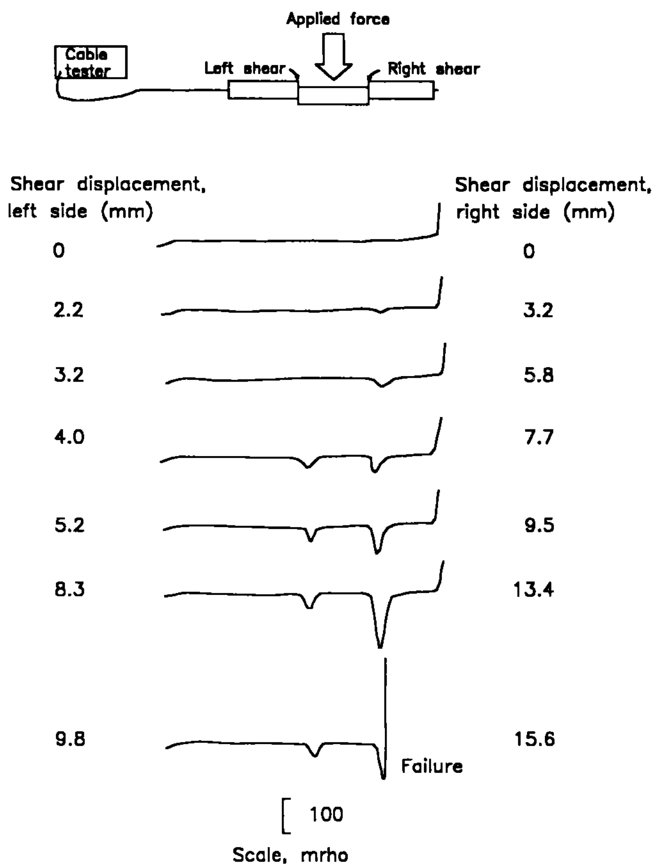

Figure 2.—TDR signature changes during direct shear test of coaxial cable encapsulated in cement grout. [From Su (*18*)]

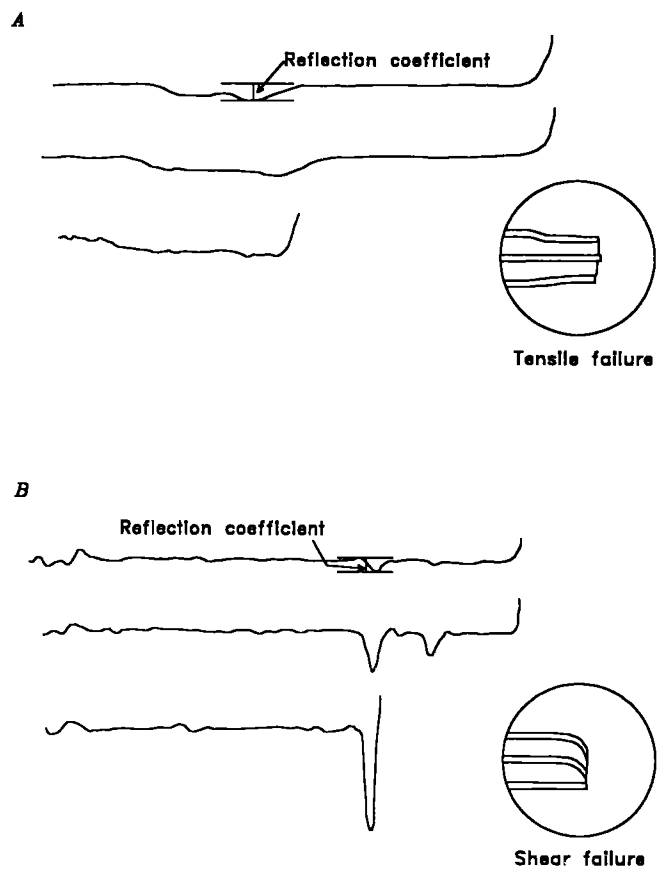

Figure 3.—Comparison of termination signatures. [From Su (*18*)] *A*, Cable failed in tension; *B*, cable failed by shearing.

Particularly significant is the difference in end-of-cable reflection signature for tensile failure versus shear failure. Extension necking produces a negative voltage reflection trough just before the large positive open-circuit reflection. On the other hand, shearing produces a distinctive negative voltage reflection spike before the large positive open-circuit reflection (fig. 3*B*).

Several researchers have developed correlations with the objective of quantified interpretation of TDR signature changes. Su (*18*) conducted a series of direct shear tests on grouted cables of different diameters; some of the results are shown in figure 4. The initial displacement that occurs before cable deformation begins and the rate of change in signature magnitude is a function of the cable diameter. Kim (*10*) performed a series of direct shear tests on cables up to 500 ft long and found that the relationship between reflection magnitude and deformation was nonlinear and a function of distance. O'Connor (*13*) describes a series of direct shear tests on grouted cable assemblies in which the range of reflection magnitudes for a given value of shear displacement made it statistically invalid to infer a linear relationship. Logan (*11*) performed a series of direct shear tests on cables embedded in crushed gravel and found that the mode of cable deformation could be identified by considering the change in both width and magnitude of TDR reflections. Aimone-Martin, Oravecz, and Dussell (*1*) are currently performing a series of tensile tests on cables grouted into salt cores to develop a correlation for use with ground control instrumentation.

Definitive correlations between elementary TDR signature characteristics (magnitude and width) and cable deformation (magnitude and mode) have not yet been developed. It is conceivable that a more sophisticated analysis of signature characteristics will produce the desired correlation. A data base of TDR signatures and cable deformation modes is being assembled by the Bureau. However, an initial methodology has been developed by Northwestern University based on visual analysis of signatures combined with quantification of magnitude and width only. This methodology is demonstrated in the NUTSA tutorial example.

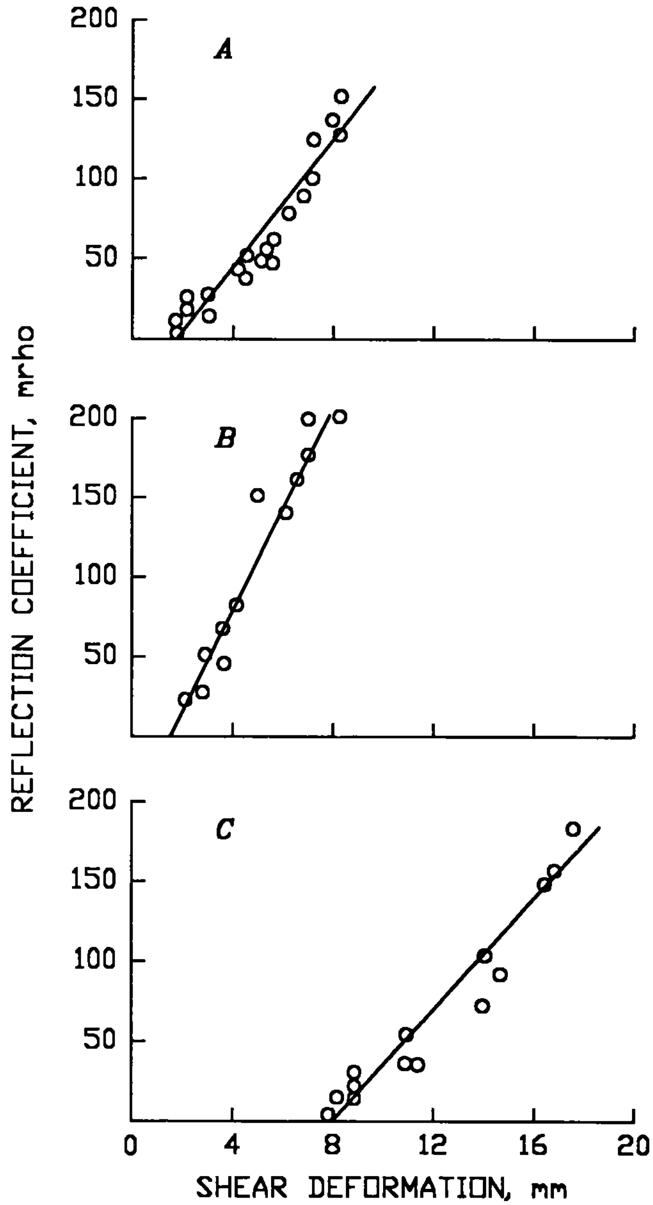

Figure 4.—Correlation between reflection coefficient amplitude and shear deformation for different sizes of cable. [From Su (*18*)] *A*, 10-mm diameter; *B*, 13-mm diameter; *C*, 22-mm diameter.

NUMOD—INTERACTIVE REMOTE DATA ACQUISITION SOFTWARE

TDR has been used successfully for monitoring rock mass displacements over active and abandoned coal mines in Illinois as well as other locations (*2-3, 16-17, 23*). While these installations have proven the viability of this technology, there have been some limitations. The lack of a remote monitoring capability restricted the frequency with which cables could be interrogated. Cable failures have occurred between readings, and the rock mass displacement responsible for cable deformation could not be determined with certainty. TDR cable testers are now avaialable with serial communication modules (*21*). It is now feasible to monitor cables from a remote location via modem and interrogate cables as frequently as desired (*15*). Interrogation of cables on an hourly basis (or even more frequently) makes a valid assessment of the rock mass movements more likely.

NUMOD is an acronym for "Northwestern University Remote Control TDR Data Acquisition System and Modification of Tektronix[6] SP232 Host Application Program." The system allows a user to acquire TDR waveforms from a cable tester via modem. Data are acquired interactively and analyzed using the NUTSA program, which permits real-time monitoring of changes in TDR waveforms.

INSTALLATION

Hardware Requirements

The hardware components required for remote monitoring measurements are illustrated in figure 5. Hardware at the remote site includes (1) Tektronix model 1502B or 1502C TDR cable tester with SP232 serial extended function module, (2) external 1,200-baud Hayes-compatible "smart" modem (low baud rate used to minimize data transmission errors), (3) cable for connection between modem and telephone wall jack (RJ-11), (4) null modem serial cable with DB-25 connector pins 2 and 3 and 6 and 20 crossed for communication between TDR unit and modem (see appendix E), and (5) test cable connected to cable tester via 50-ohm connector cable. Hardware at the control site includes (1) computer (IBM-compatible with EGA-VGA monitor), (2) external 1,200-baud Hayes-compatible "smart" modem, (3) cable for connection between modem and telephone wall jack (RJ-11), and (4) cable for serial connection between computer and modem. It is recommended that the same type of modem be used at both the remote site and the control site to minimize problems with communication protocol.

Software Requirements

Communication software, as well as data acquisition software, is required for the NUMOD system. Any communication software that permits asynchronous communication is adequate. A commercially available product (*6*) was used during system development and testing. The data acquisition program (*20*) provided by Tektronix with the SP232 extended function module does not permit modification of baud rates. The SP232 Host Application Program must be purchased separately and modified (see appendix A) to allow for data acquisition via modem.

DATA ACQUISITION

When communicating interactively with a 1500 series cable tester, the user must set several parameters (*19*). Default settings can be used, but it is recommended that these settings be modified to obtain TDR measurements that are meaningful to the user. The settings can be modified each time a measurement is made, or stored in a file for future use. A complete discussion of adjustable cable tester settings is presented in the SP232 manual (*21*), but a brief summary with suggested settings and an example file (RUN.SET) is included as appendix B.

Settings File for Remote Data Acquisition

The settings file is basically a set of commands sent to the remote cable tester from the control computer (table 1). The tester interrogates a cable based on these settings, and a TDR waveform (251 data points) is displayed on both the computer and the tester screens. This waveform can then be downloaded to a specified output file. Units are dictated by the settings used for data acquisition (table 1). Either metric or U.S. customary units can be used, but U.S. customary units have been predominately used. When communicating with a remote cable tester, the user should not interactively modify settings since errors can be created during transmission. It is best to create a settings file and download it to the tester.

Table 1.—Cable tester settings for remote data acquisition

Setting	*Description and typical units*
Instr_id	Model of cable tester (1502).
Averages	Number of records that should be sampled and averaged.
Vertical	Vertical location in window.
Gain	Vertical sensitivity (millirhos per vertical division).
Ddiv	Distance per horizontal division (ft per division).
Vp	Propagation velocity (percentage of speed of signal in free space).
Cpos	Cursor position in window (feet).
Cdist	Distance at which sampling should begin (feet).
Maxhold[1]	Turn on or off capture of waveform.
Pulse[1]	Turn on or off detector mode.
Swingsweep[1]	Turn on or off single sweep function.
Dspohms[1]	Turn on or off display of ohms at cursor.
Buttons[1]	Turn on or off display of input.

[1]Default settings established by SP232 Host Application Program.

The length of cable interrogated depends on the distance per division (Ddiv). A screen consists of 10 divisions, and by using a Ddiv of 2 ft per division, for example, it will only be possible to interrogate 20 ft of cable. Sequential interrogation of a cable is accomplished by

[6]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

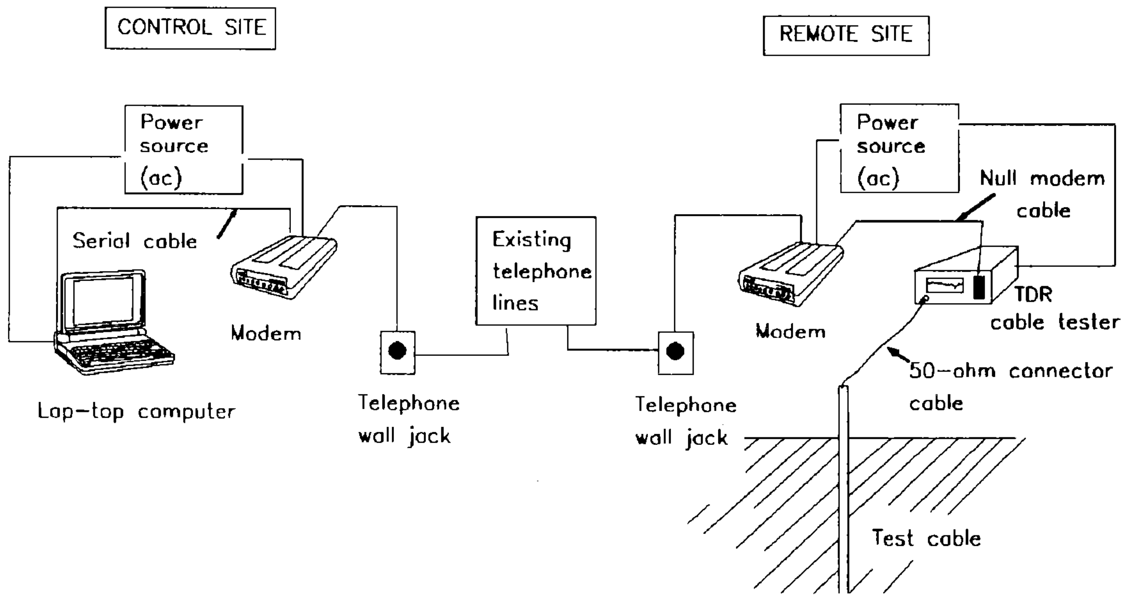

Figure 5.—Remote data acquisition system.

by appending commands in the acquisition settings file. The file in appendix B instructs the tester to acquire four screens of data. The only parameter that changes from one screen to the next is the distance at which measurement should begin (Cdist). The relationship between Ddiv and Cdist is

$$\mathrm{Cdist}_{n+1} = \mathrm{Cdist}_n + [\mathrm{Ddiv} \times 10 \text{ div/screen}], \quad (1)$$

where n = previous screen number, as illustrated in table 2, and div = division. Values of Cdist from -2 to 0 ft correspond with internal locations of the cable tester. The examples in table 2 only consider four screens, but a settings file can request as many screens as required to interrogate the entire length of cable (up to a maximum of 2,000 ft) (*19*).

Table 2.—Dependence of Cdist on Ddiv

Ddiv, ft per division	Cdist, ft			
	Screen 1	Screen 2	Screen 3	Screen 4
0.1	-2	-1	0	1
0.2	-2	0	2	4
0.5	-2	3	8	13
1.0	-2	8	18	28
2.0	-2	18	38	58
5.0	-2	48	98	148

As the waveform is being acquired and displayed on the computer screen, the user should check that the waveform amplitude has not exceeded the screen limits. This will require adjustment of the vertical sensitivity and/or vertical position (gain and vertical in table 1), then repeated interrogation with the new settings. It is recommended that the user create a suite of files with a variety of settings.

Procedure for Remote Data Acquisition

Once an acquisition settings file is created, waveforms can be remotely acquired.

Establish Telecommunications Link

Using the communication software (*6*), dial up the remote site. Use a baud rate of 1,200 with no parity, eight data bits, and one stop bit. When communication is established, exit to DOS. Invoke the SP232 Host Application Program (modified for modem communication) by typing **SP12**[7] and <Enter>.[8] If there is no communication error message, the main menu is displayed: *Get, Set, Read, Write, Info, Alt, Diff, Erase, Quit, More.*[9] Press <G> and the program will indicate that the *remote link is being established.*

Specify File Names for Acquisition and Storage

In response to the prompt *Settings filename?*, type the name of an existing acquisition settings file (e.g., **RUN.SET**) and then press <Enter>. In response to the

[7]Boldface characters are typed by the user in either lowercase or uppercase.

[8]Function keys, indicated by < >, are pressed by the user.

[9]Prompts displayed on the screen by the program are italicized.

prompt *Output filename?*, type the desired name for an output file (e.g., **TEST1.OUT**) and press <Enter>. Alternatively, just press <Enter> to view the current waveform without storing it. In response to the prompt *All, Misc, Settings, Waveform, Nothing?*, press <A> and then <Enter> to save acquisition settings as well as the waveform. The output file will consist of three parts for each screen (see example in appendix C): (1) miscellaneous notes, (2) settings, and (3) waveform data points.

Exit From Program and Disconnect Telecommunications Link

After data collection is completed, the main menu is displayed: *Get, Set, Read, Write, Info, Alt, Diff, Erase, Quit, More*. Press <Q> to exit from the program. Exit to the communications program (refer to the software user's manual) and hang up the telecommunications link.

NUTSA—INTERACTIVE TIME DOMAIN REFLECTOMETRY SIGNATURE ANALYSIS

The Northwestern University TDR Signature Analysis (NUTSA) program is designed to allow for visual comparison of three TDR waveforms quickly and easily. Development was motivated by the need to analyze and interpret the large number of TDR records obtained when monitoring long coaxial cables on a daily basis. The program is interactive, and on-line help is available to assist a user in becoming proficient with this tool.[10]

This initial version of NUTSA is primarily intended to facilitate visual identification of signature changes using function keys and cursor movements. The location, magnitude, and width of changes are quantified, but no attempt has been made to develop an expert system or artificial intelligence for analyzing changes in TDR signatures. It is anticipated that future versions of the NUTSA program will incorporate this capability.

The NUTSA program uses output files created with the SP232 Host Application Program (appendix C). Once input files have been opened, the program allows the user to view the waveform for an entire cable or change the horizontal scale (Hscale) and vertical scale (Vscale) to view a particular location along the waveform. Following a discussion of installation requirements and main program features, a tutorial example is used to familiarize the user with program details.

INSTALLATION

Hardware Requirements

The NUTSA program was written using MicroSoft QuickBasic version 4.5. It requires an IBM-compatible computer using MS-DOS 3.3 or higher with a minimum 520K memory and an EGA or VGA display monitor. A hard drive is recommended to allow for analysis of large files since scratch files must be created.

This version of NUTSA cannot be used with an IBM-compatible computer with a CGA graphics card. Earlier versions were developed for use with CGA graphics, but these versions do not allow for highlighting commands and menu options.[11]

Software Requirements

The program is available on either a 3.5- or 5.25-in floppy disk (see footnote 10). The following files are provided: (1) READ.ME (updated information about the program), (2) NUTSA.EXE (the program itself), (3) NUTSA.HLP [American Standard Code for Information Interchange (ASCII) text for Help screens], (4) AAA, BBB, CCC (example data files), and (5) RUN.SET (example acquisition settings file). To install the program on a hard disk drive, type (1) **mkdir NUTSA** (to create a new NUTSA directory), (2) **cd NUTSA** (to access the NUTSA directory), and (3) **copy A:*.*** (to copy files from the disk, which is assumed to be in drive A, to the NUTSA directory). It is important that NUTSA.EXE and NUTSA.HLP are placed in the same directory to ensure proper operation of the on-line help capability.

MAIN PROGRAM FEATURES

Type **NUTSA** and then press <Enter> to invoke the program. The program will display a disclaimer and prompt *press any key to continue*. The next screen is the main menu (fig. 6). The cursor is located at the Help command and the prompt *How to Get Help About Menu Choices* appears above the main menu. Whenever a command is highlighted with the cursor, the program will display a brief description above this window. Help is available on line. Simply press <F1> at any time to receive help with the current option. Help screens appear with headings cross referenced to the user's manual.

[10]The program is available on a 3.5-in or 5.25-in floppy disk. To obtain a copy, send requests to the Twin Cities Research Center, U.S. Bureau of Mines, 5629 Minnehaha Ave. South, Minneapolis, MN 55417. Please reference this report.

[11]A copy of this NUTSA version for use with CGA graphics can be obtained from the Twin Cities Reseach Center.

The general sequence of operation is to (1) set graphics card configuration, (2) open files, and (3) view waveforms. To verify that the input files are correct, or to check the units used during data acquisition, highlight "View Input" for a listing of acquisition notes and settings. To exit the program, move the cursor to highlight "Quit to DOS" and press <Enter>.

Set Graphics Card Configuration

When the user moves the cursor to highlight "Configure," the default setting for an EGA graphics card is indicated above the main menu. Press <Enter> and the screen shown in figure 7 will be displayed. If EGA graphics are used, simply press <Enter>. If a VGA graphics card is used, move the cursor to highlight this option and press <Enter> to return to the main menu.

Open Files

When the user highlights "Open Files" and presses <Enter>, the screen shown in figure 8 will be displayed. The user can either find files, input file names, or exit to the main menu by highlighting the desired option and pressing <Enter>. The default file format for one screen of data is shown in appendix C. The file contains three parts for each screen: (1) title, (2) acquisition settings, and (3) waveform data. NUTSA reads all information for the first screen, then only waveform data for subsequent screens. The waveform data are reformatted and the scratch files created (see appendix D).

```
How To Get Help About Menu Choices

MAIN MENU                NUTSA

Configure                Northwestern University TDR Signature Analysis Program
Open Files
View Input               BOM Version 1.01, 1992
View Waves
Quit to DOS
►Help◄

                         Developed for

                         U.S. Bureau of Mines
                         Twin Cities Research Center
                         Minneapolis, Minnesota
```

Figure 6.—NUTSA main menu.

```
MAIN MENU

Configure                Indicate Graphics Capability
Open Files
View Input               Graphics Card---EGA
View Waves               Graphics Card---VGA
Quit to DOS
Help
```

Figure 7.—Graphics configuration menu.

Find Files

This option can be used to list files and to change the current path for all user files. When the user highlights "Find Files" and presses <Enter>, the screen shown in figure 9 is displayed. In response to the prompt *Path (Example: A:\File):?*, type the desired drive and/or directory to change the current path and press <Enter>. The prompt, *What File (Example: *.*):?* will appear on the screen. Type ***.*** (or press <Enter>) to list all files, or type ***.<extension>** to list files with a specific extension. Type a file name to determine if this file is located in the current path.

After the desired file name is entered and <Enter> is pressed, a list of files corresponding to the user's specification will be displayed, as shown in figure 10. This step can be repeated until the desired files have been found. The drive and directory specified for the current path become the default location for all user (input, output, and scratch) files.

Specify Input Files

When the user highlights "Input File Names" and presses <Enter>, the screen shown in figure 11 is displayed. Up to three files may be input and viewed simultaneously:

1. T-File waveform will be displayed in the top window.
2. M-File waveform will be displayed in the middle window.
3. B-File waveform will be displayed in the bottom window.

In response to the T-File (top), M-File (middle), and B-File (bottom) prompts, enter the desired file names (these must be in the current path). If the user only wants to open one file, type its name in response to the *T-File* = = > prompt and press <Enter>, then press <Enter> in response to the *M-File* = = > and *B-File* = = > prompts. If the specified file(s) cannot be found, the message *File not found* is displayed and the prompt

```
MAIN MENU

Configure
Open Files
View Input
View Waves
Quit to DOS
Help
```

```
OPEN FILES MENU

Input File Names
Find Files
Exit To Main Menu

Highlight using arrow keys and press <ENTER>
```

Figure 8.—Open Files menu.

```
FIND FILES   Current Path: C:\NUTSA
Path (Example: A:\File):? █
```

```
MAIN MENU

Configure
Open Files
View Input
View Waves
Quit to DOS
Help
```

Figure 9.—Find Files prompt.

```
            FIND FILES   Current Path: C:\NUTSA
 MAIN MENU  Path (Example: A:\File):
            What File (Example: *.*):
            --------------------------------------------------
Configure   Directory of   C:\NUTSA
Open Files  --------------------------------------------------
View Input  .                  ..              AAA        BBB
View Waves  CCC                NUTSA     BAS   NUTSA  EXE READ    ME
Quit to DOS NUTSATP   TMP      NUTSA_2   BAS
Help

            File list completed.  Press <ENTER> to return to menu.
```

Figure 10.—Listing of files.

```
 MAIN MENU

Configure          OPEN FILES MENU
Open Files
View Input         Input File Names
View Waves         Find Files
Quit to DOS        Exit To Main Menu
Help
               Highlight using arrow keys and press <ENTER>

             PATH: C:\NUTSA
             Enter the name of the file you want to input.
             (Include the base name and the extension name
             along with the drive designation if necessary)
             T-File ==>aaa
             M-File ==>bbb
             B-File ==>
```

Figure 11.—Input Files prompt.

press any key to continue will appear. Try reentering the file name(s) in case a typographical error was made.

If <Esc> is pressed during entry of any of the three file names, the message *Do you want to cancel file entry (Y/N)?* is displayed. By typing Y and then pressing <Enter>, the user will return to the Open Files menu. By typing N and then pressing <Enter>, the user is allowed to continue entry of file names. Pressing any other key will cause a beep without changing the screen. Either <↓> (down) or <Enter> can be used to terminate entry of a file name. Either <←> (left) or <Backspace> can be used during entry of file names to delete characters.

If the file name specified for T-File was not found in the current path, the program will display an error message and prompt with a beep. Press any key to return to the Open Files menu. If the file name specified for M-File was not found, but the T-File was found, an error message is displayed, indicating that only the T-File is opened. In response to the beep, press any key to return to the main menu. The same is true if the file name specified for B-File was not found. Highlight "Exit to Main Menu" and press <Enter> to invoke this option.

View Input File Acquisition Settings

When the user highlights "View Input" and presses <Enter>, a screen similar to figure 12 will be displayed. If no files have been opened, the program displays *No data to view*. The title and acquisition settings portion of T-File is displayed and the user is prompted to *press any*

```
MAIN MENU

Configure
Open Files
View Input
View Waves
Quit to DOS
Help
```

```
T-File settings.....

Thu May 10 13:37:24 1990
*
instr_id: 1502
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: -2.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1


Press any key to continue.................
```

Figure 12.—Listing of acquisition settings.

key to continue. Once a key is pressed, the program displays M-File information and prompts to press any key to continue. After a key is pressed, the program displays B-File information and prompts to press any key to continue. If there is no file, the program displays *No information available.*

View Waveforms

When the user highlights "View Waves" and presses <Enter>, the message *Loading, please wait......* appears. If no files have been opened, the program displays *No data to view.* After the program reads in the data, the waveforms are drawn and displayed, as shown in figure 13. The screen has been divided into five windows. The top window displays explanations for the function keys (<F1>, <F7>, <F8>, <F10>, and <Esc>) and a brief explanation of the parameter highlighted in the left window (by default, "Vscale" is highlighted). T-File, M-File, and B-File waveforms are displayed in the three large windows. The menu window along the left side of the screen is used to change display parameter values and to invoke the <Diff> (difference between waveforms) and <Zoom> (change horizontal scale) options.

Units for each parameter are dictated by the settings used for data acquisition (table 3). Either metric or U.S. customary units can be used, but U.S. customary units have been used predominately. The value of Vscale, Bdist (beginning distance), and Edist (ending distance) in force when waveforms are initially viewed is dictated by the T-File settings. Notes for each file are displayed in its respective window.

Table 3.—Typical parameter units

Parameter	*Unit*
Vscale	Millirhos per division.
Hscale	Feet per division.
Vertical index:	
VindT	Graphical units.
VindM	Do.
VindB	Do.
Bdist	Feet.
Edist	Do.
PeakLoc	Do.
Amplitu	Millirhos.
PWidth	Feet.
Diff	Millirhos.

<F7>—Redraw

The user will be prompted to redraw waveforms after changing display parameters such as Vscale, Hscale, Bdist, etc. Press <F7> and the message *Screen redraw in progress. Please wait....* will appear.

<F8>—Restart

If the user has adjusted many parameter values and wants to reset to the original settings, press <F8> and the message *Loading, please wait...* will appear. The input files are reloaded and waveforms redrawn using the initial settings.

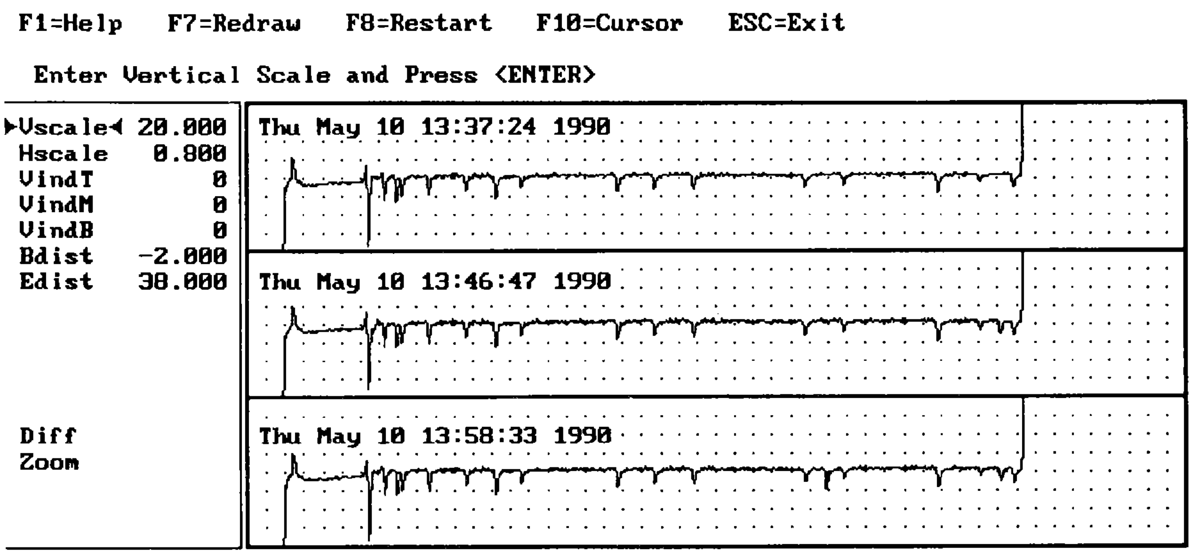

Figure 13.—Command, parameter, and waveform display windows.

Return to Main Menu and Exit Program

Press <Esc> to return to the main menu. In response to the prompt *Do you want to leave graphic screen (y/n)?*, type Y and then press <Enter> to return to the main menu. If N is typed and then <Enter> is pressed, the program will remain in graphics mode and nothing will change. In the main menu, highlight "Quit to DOS" and press <Enter> to exit the program.

TUTORIAL EXAMPLE

The following example illustrates basic sequences and features of NUTSA. It is recommended that a first-time user run the program and execute these sequences rather than simply reading the manual.

Start Program

Type **NUTSA** and press <Enter>. A disclaimer page will appear. Press any key and the main menu shown in figure 6 is displayed. By pressing <F1> at any time, the user will invoke on-line help and the program will display sections of this manual appropriate to the current command or parameter.

Set Configuration

Highlight "Configure." The default setting for an EGA graphics card is indicated above the main menu. Press <Enter> and the screen shown in figure 7 is displayed. If EGA graphics are used, simply press <Enter>. If a VGA graphics card is used, highlight this option and press <Enter> to return to the main menu. This version of NUTSA cannot be used with a CGA graphics card. Earlier versions are available,[12] which were developed for use with CGA graphics.

Input Files

Highlight "Open Files" and press <Enter>. The screen shown in figure 8 is displayed. To find files, input file names, and exit to the main menu, highlight the desired option and press <Enter>. Three example input files were stored in the same directory as NUTSA.EXE when the software was installed. Highlight "Find Files" and press <Enter> twice to list files in the current path. The three waveform data files AAA, BBB, and CCC will be listed, as shown in figure 10. Exit to the Open Files menu by pressing <Enter>.

Highlight "Input File Names" and press <Enter>. In response to the *T-File* ==>, *M-File* ==>, and *B-File* ==> prompts, enter the file names **AAA**, **BBB**, and **CCC**, respectively (fig. 11). The program may issue an error message and prompt *press any key to continue* if any specified file(s) cannot be found in the current path. Try reentering the file name(s) in case a typographical error was made. The program will indicate *Reading data, please wait.....* as it reads all information from the input files and creates scratch files (see appendix D). These scratch files decrease the time required to redraw waveforms. After inputting the file name(s), return to the main menu.

---

[12]See footnote 11.

View Waveforms

It is now possible to view waveforms. Highlight "View Waves" and press <Enter>. The message *Loading, please wait......* appears as scratch files are read into memory. The waveforms are displayed, as shown in figure 13. The example files have the same cable length (35 ft of 50-ohm cable (7) plus the 3-ft connector cable). Bdist is -2 ft and Edist is 38 ft. The Vscale of these three files are the same (20 mrho per division).

<F10>—Cursor Movement in Waveform Display Windows

By using arrow keys, the user can move a cursor (vertical line) to any location in any of the display windows. Press <F10> and the command window appears, as shown in figure 14. <↓> (down) moves the cursor down one window. <↑> (up) will move the cursor up one window. <→> (right) and <←> (left) move the cursor within a window.

Hold down <→> and observe the cursor moving across the top window. The location of a peak, "PeakLoc," and its amplitude, "Amplitu," can be determined. The values of PeakLoc (cursor location) and Amplitu (waveform amplitude) change as the cursor moves along. In figure 15, the cursor position is 1.6 ft from the cable tester and has an amplitude of 73.75 mrho (see appendix D).

By default, the cursor moves from one data point to the next data point each time <→> or <←> is pressed. The cursor speed is displayed in the command window. If the cable is long, cursor movement will be very slow. <PgUp> and <PgDn> change the cursor movement speed. Press <PgUp> to increase the value to 10 or 100 data point increments, as shown in figure 16. Press <PgDn> to decrease the increment size. Press <Esc> to return to the command menu.

Change Horizontal Scale

If a cable is long, small spikes cannot be seen along the waveforms when the entire data file is displayed. Even if VGA graphics are used, there is a limitation due to screen resolution. The alternative is to zoom or magnify an area of interest. NUTSA provides two approaches: (1) Highlight "Bdist" and "Edist" and enter the desired values, or (2) in the "Zoom" feature, use a cursor to select desired beginning and end locations.

Bdist and Edist.—Bdist is the location of the first point displayed. The default waveform display begins at Cdist of the first screen acquired (see table 2 and appendix B). When the user highlights "Bdist," the program prompts *Enter beginning distance (ft) and press <Enter>*. The value should be less than the cable length (i.e., the value should be less than Edist). After typing a value and pressing <Enter>, <F7> must be pressed to redraw waveforms using the new setting.

Edist is the location of the last point displayed. The default value is the last point of the last screen acquired. When the user highlights "Edist," the program prompts *Enter ending distance (ft) and press <Enter>*. The value of Edist should always be greater than Bdist. After typing a value and pressing <Enter>, <F7> must be pressed to redraw waveforms using the new settings. If the distance between Bdist and Edist is greater than 2,501 data points,

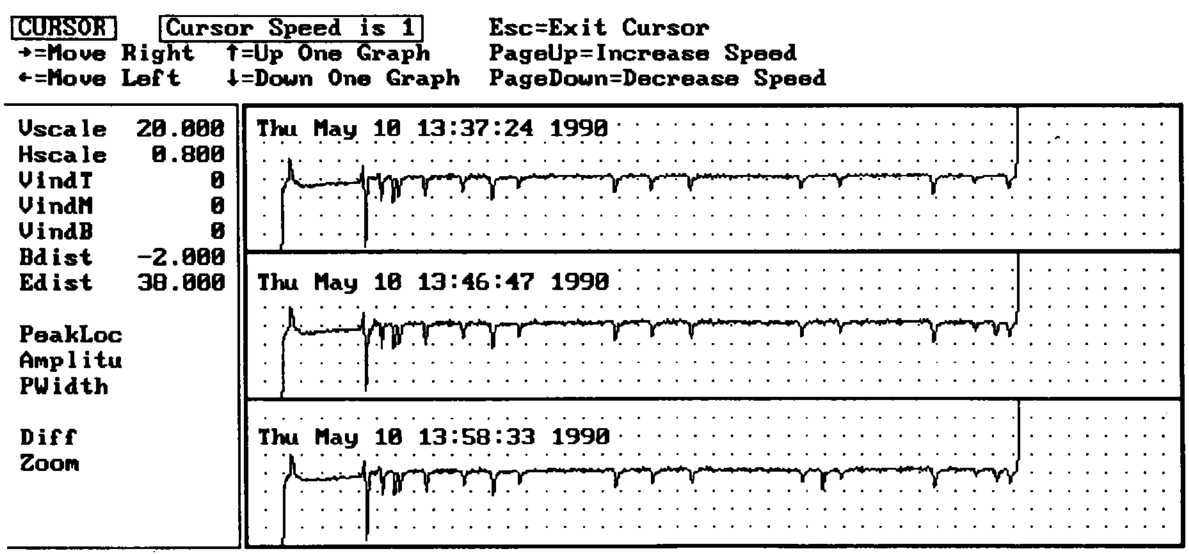

Figure 14.—Cursor movement command window.

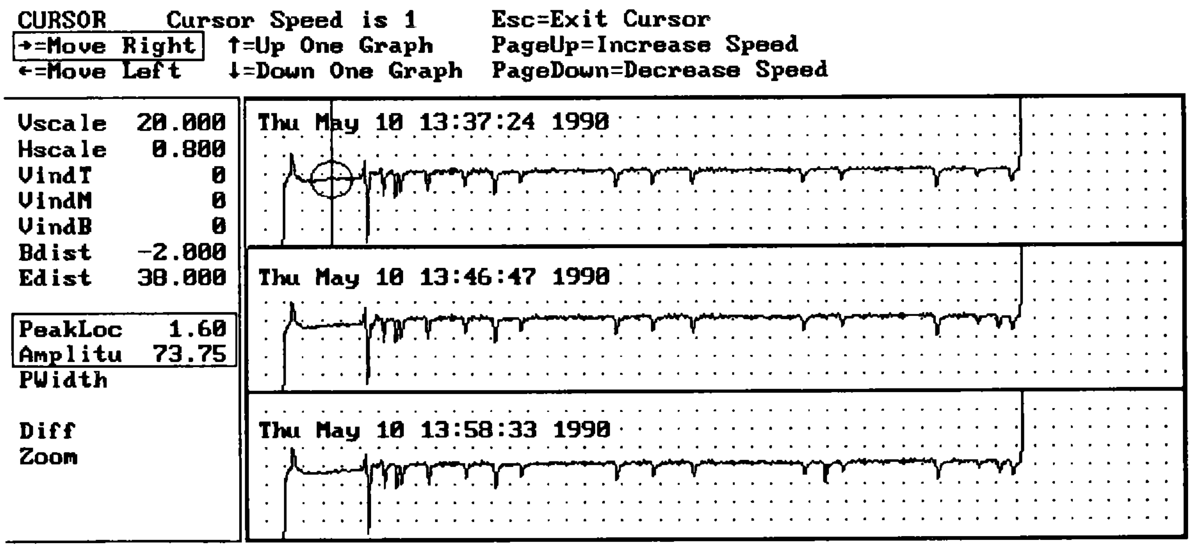

Figure 15.—Reflection coefficient magnitude at cursor location.

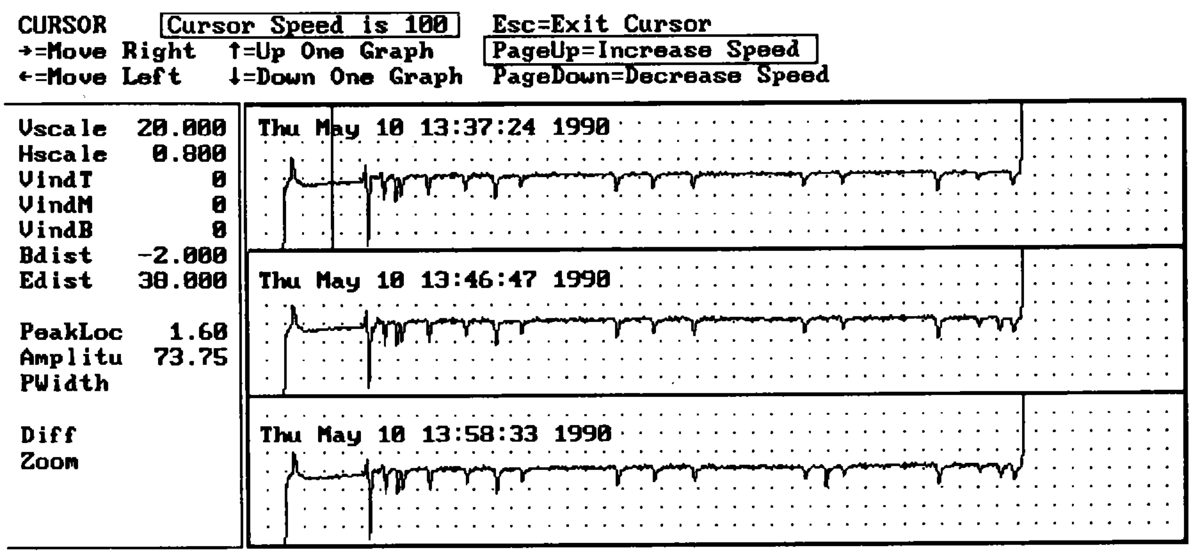

Figure 16.—Cursor movement speed increased using PgUp.

an error message will be displayed and the program will prompt to change those values.

If the user attempts to enter illegal characters for Bdist or Edist, the program will prompt with a beep and the current value will not be changed. If an attempt is made to change Bdist to a value that is smaller than allowed, Bdist will be set to the smallest possible value. If an attempt is made to change Bdist to a value that is equal to or larger than Edist, the program will prompt with a beep and the value will not be changed. If an attempt is made to change Edist to a value that is larger than allowed, Edist will be set to the largest possible value. If an attempt is made to change Edist to a value that is equal to or smaller than Bdist, the program will prompt with a beep and the current value will not be changed.

For the example shown in figure 17, "Bdist" has been highlighted and a value of 20 entered. After pressing <Enter> and <F7>, the message *Screen redraw in progress. Please wait.........* is displayed in the command area as the waveforms are redrawn (fig. 18). Using the Bdist value as an entry point, the program searches the scratch files (see appendix D), reads waveform data from Bdist up to Edist, and replots these data. The redrawn waveforms are displayed, as shown in figure 19.

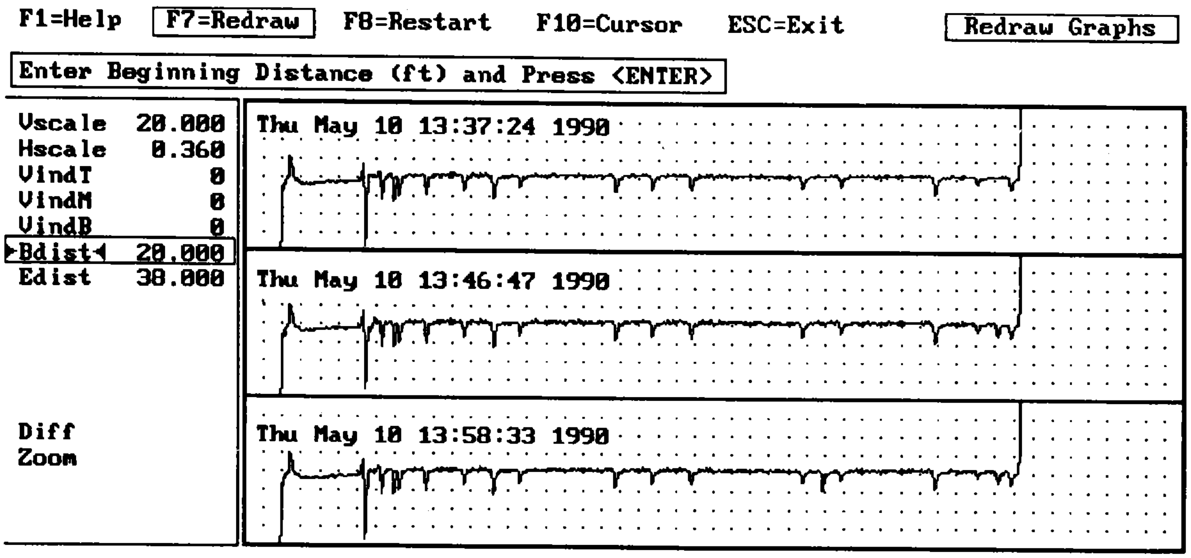

Figure 17.—Bdist prompt in command window.

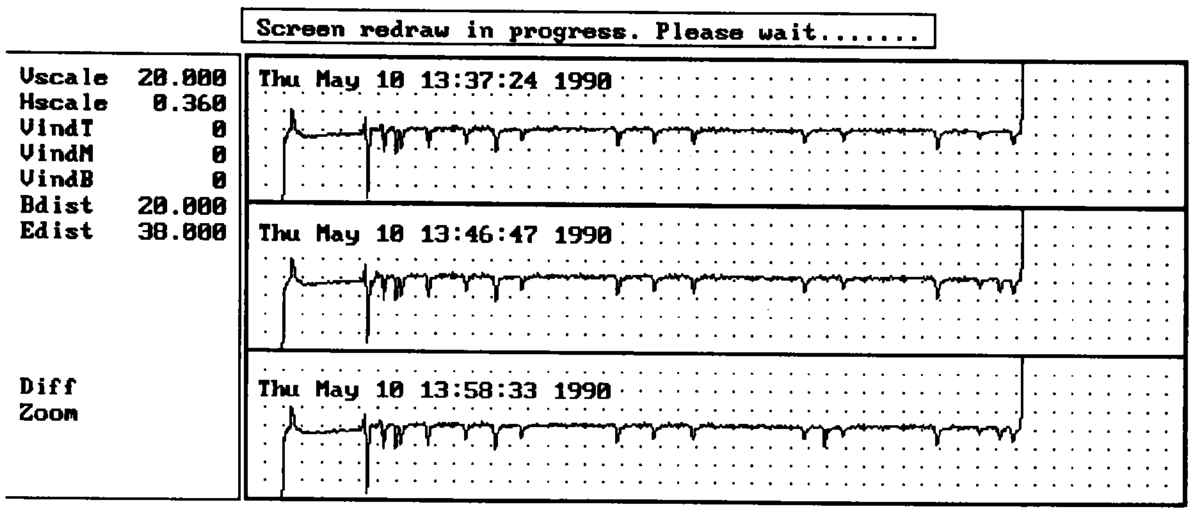

Figure 18.—Message indicating that waveforms are being redrawn.

There are 50 horizontal divisions in each waveform display window. For the example in figure 19, Bdist equals 20 ft and Edist equals 38 ft, so that the horizontal scale is

$$\text{Hscale} = \frac{(\text{Edist} - \text{Bdist})}{50 \text{ div}} = 0.36 \text{ ft/div}, \qquad (2)$$

as indicated in the parameter menu. Press <F8> to return to the original settings.

Zoom Feature.—An alternative procedure for changing Hscale is to zoom a window. Highlight "Zoom," as shown in figure 20, and press <Enter>. The cursor movement commands appear, as shown in figure 21, and the program will prompt *Set first edge* (i.e., Bdist). Using <↓> or <↑>, move the cursor to the waveform display window of interest. Using <→> or <←>, move the cursor to the beginning of the area of interest, then press <Enter>. The program will now prompt *Set second edge* (i.e., Edist), as shown in figure 22. Using <→>, move the cursor to the end of the area of interest and press <Enter>. The screen will be redrawn, as shown in figure 23. The new values of Bdist (2.040 ft), Edist (8.000 ft), and Hscale (0.119 ft per division) are indicated. If the second edge coincides with the first edge (i.e., attempt to set Bdist equal to Edist), the program will prompt with a beep and the current window will not change. Press <Esc> to exit the Zoom option. Reset Bdist to 20 ft and Edist to 38 ft, and press <F7>.

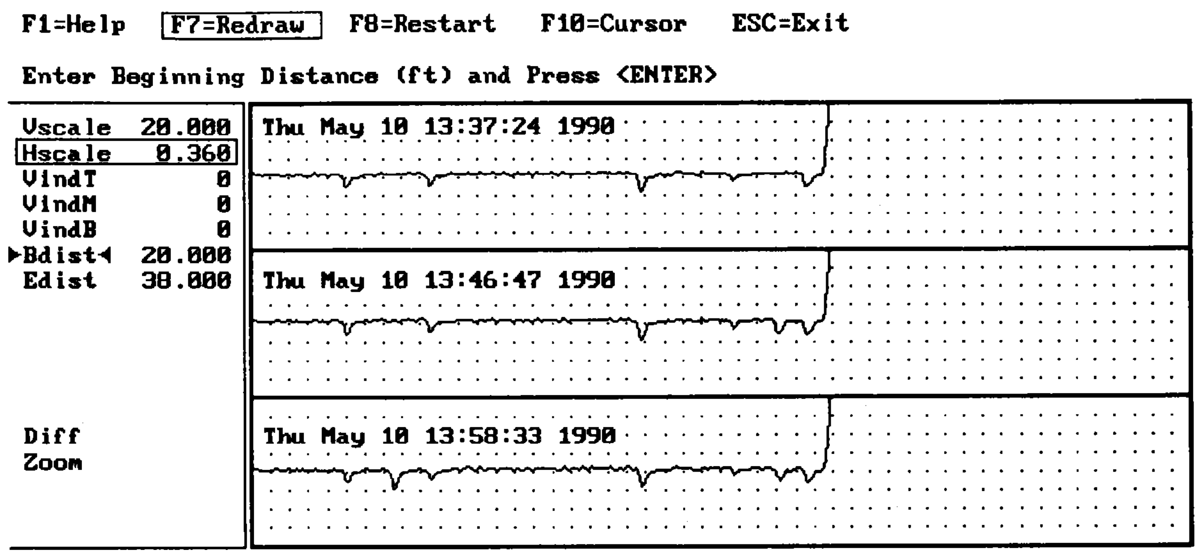

Figure 19.—Waveforms redrawn at new horizontal scale.

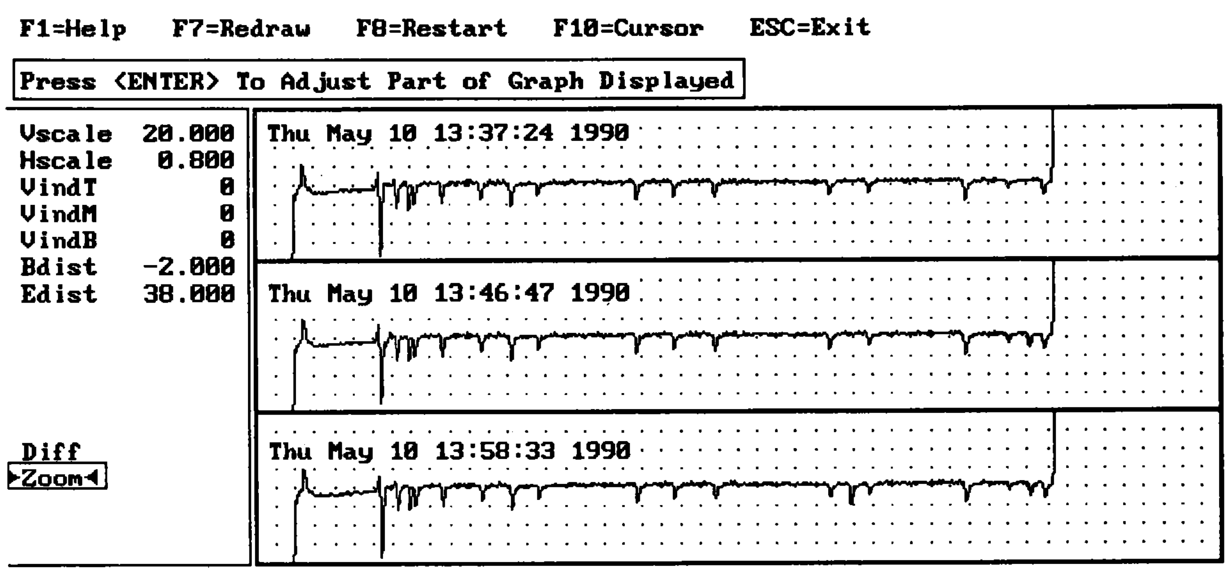

Figure 20.—Invoke Zoom feature.

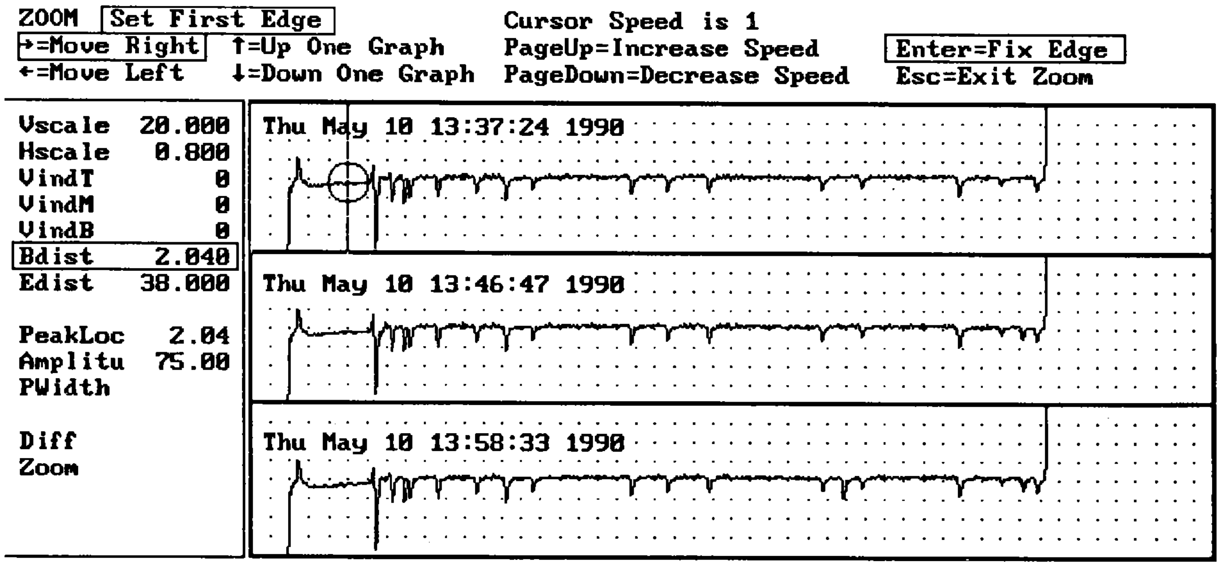

Figure 21.—Select left side of Zoom window.

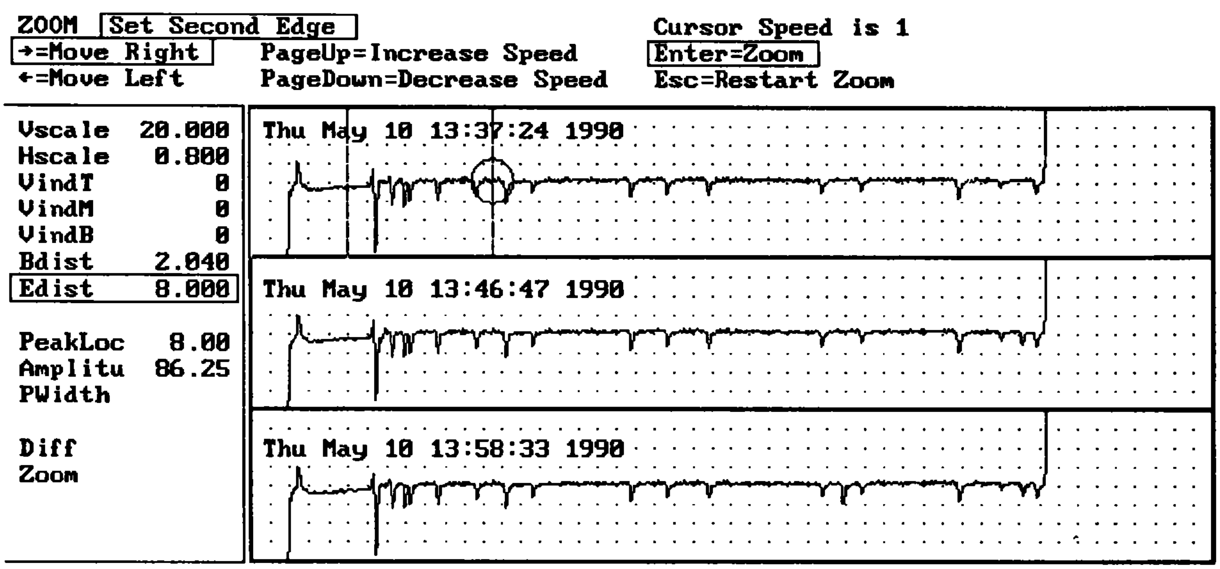

Figure 22.—Select right side of Zoom window.

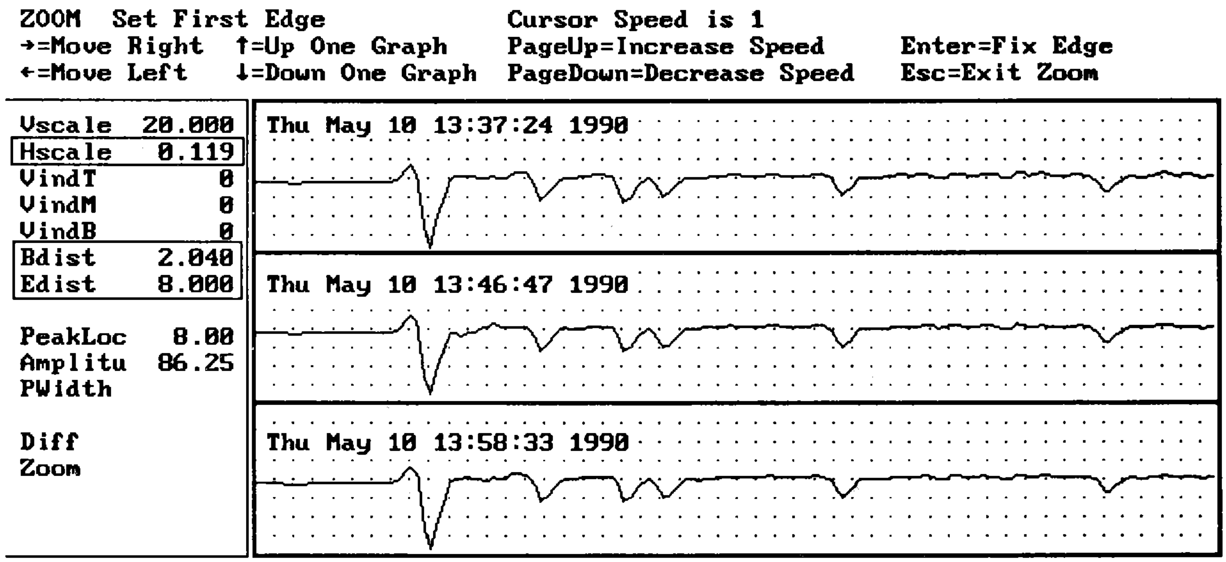

Figure 23.—Waveforms in Zoom window redrawn.

Investigate Signature Change

Compared with the T-File waveform in figure 19, M-File and B-File have additional spikes, which indicate that a change of cable geometry occurred at those locations. NUTSA was developed to allow visual investigation of such signature changes. By using the "Diff" and <Zoom> capabilities, the user can easily identify, view, and quantify such changes between waveforms.

Select Files To Be Compared

Move the cursor to highlight "Diff," and the command menu appears, as shown in figure 24. The program will prompt the user to *Enter waveform difference desired (T/M, T/B, or M/B) and press <Enter>*. For example, type **T/M** and then press <Enter>. The program indicates *Screen redraw in progress. Please wait....* and then displays the difference waveform in the B-File display window, as shown in figure 25. The program computes the arithmetic difference waveform by subtracting the first waveform from the second waveform (see appendix D). The difference waveform is displayed in the window that is not used. For example, if **T/B** is typed, the difference waveform is displayed in the M-File window. If the user attempts to enter characters other than **T/M**, **T/B**, or **M/B**, the program will prompt with a beep and the current windows will not be changed.

Select Specific Change

Move the cursor to the difference waveform spike, as shown in figure 26. The spike has an amplitude of -15.00 mrho at 30.12 ft (see appendix D).

Vertical Scale

The default vertical scale of the displayed waveforms is the gain used when the T-File waveform was acquired. It is often desirable to expand Vscale when visually analyzing characteristics of TDR waveforms. To demonstrate this capability, press <Esc> to exit the Zoom option and highlight "Vscale" (fig. 27). Enter a value of 10, as shown in figure 28. If the user attempts to enter illegal characters or a value less than or equal to zero, the program will prompt with a beep and the current value will not be changed. After pressing <F7>, the program indicates *Screen redraw in progress. Please wait..........* The T-File, M-File, and difference waveforms are redrawn, as shown in figure 28. Adjust Bdist to 27 ft and Edist to 32 ft, and press <F7>; the waveforms will be displayed, as shown in figure 29.

Quantify Change

In addition to displaying the difference between two waveforms, the width of spikes can be computed. The current version of NUTSA uses a very simple algorithm to compute width.

<Ctrl> <D>—View Peak Width.—To demonstrate quantification of a signature change, invoke the cursor by pressing <F10>. Move it to the location of the difference spike apex (amplitude of -15.00 mrho at a location of 30.12 ft), as shown in figure 30. Press <Ctrl><D>, as shown in figure 31, and the program displays a peak width (PWidth) of 0.52 ft. This width is calculated (see appendix D) as

$$\text{PWidth} = \text{number of increments} \times \text{distance/increment}. \qquad (3)$$

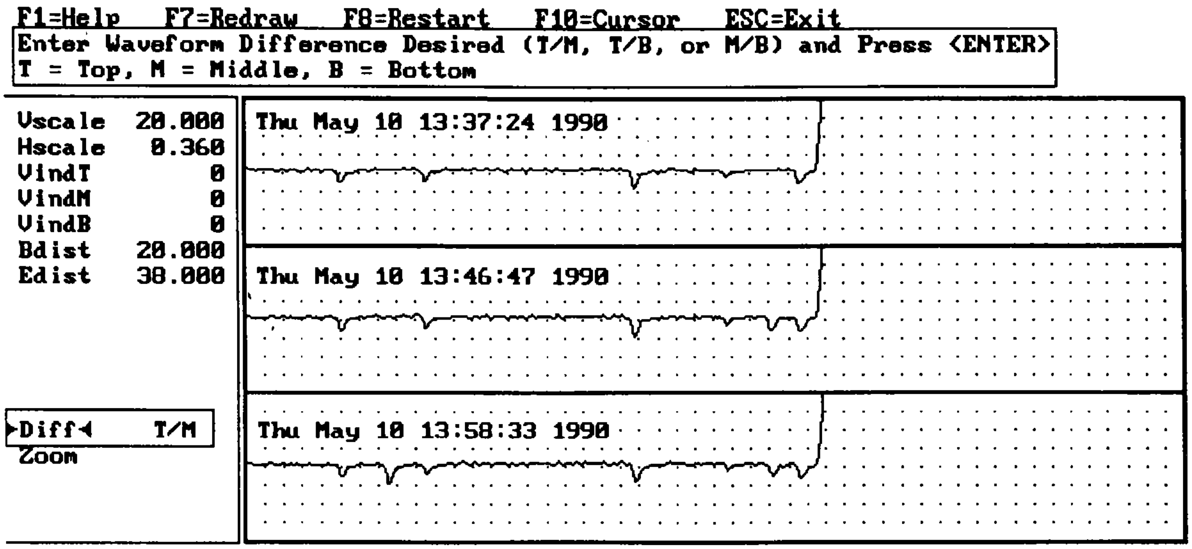

Figure 24.—Diff prompt in command window.

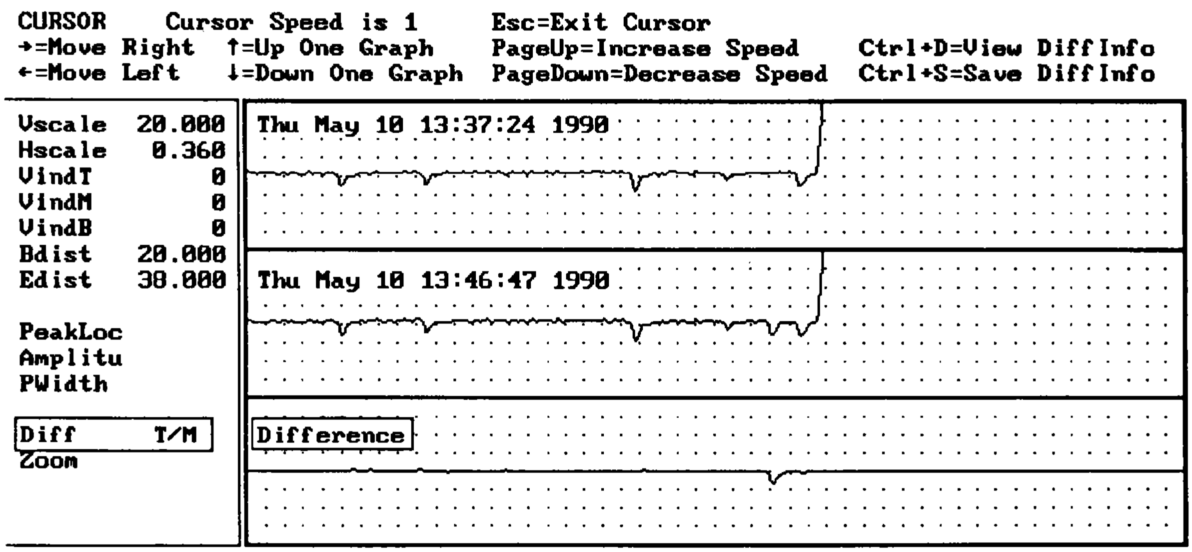

Figure 25.—T-File, M-File, and difference waveforms.

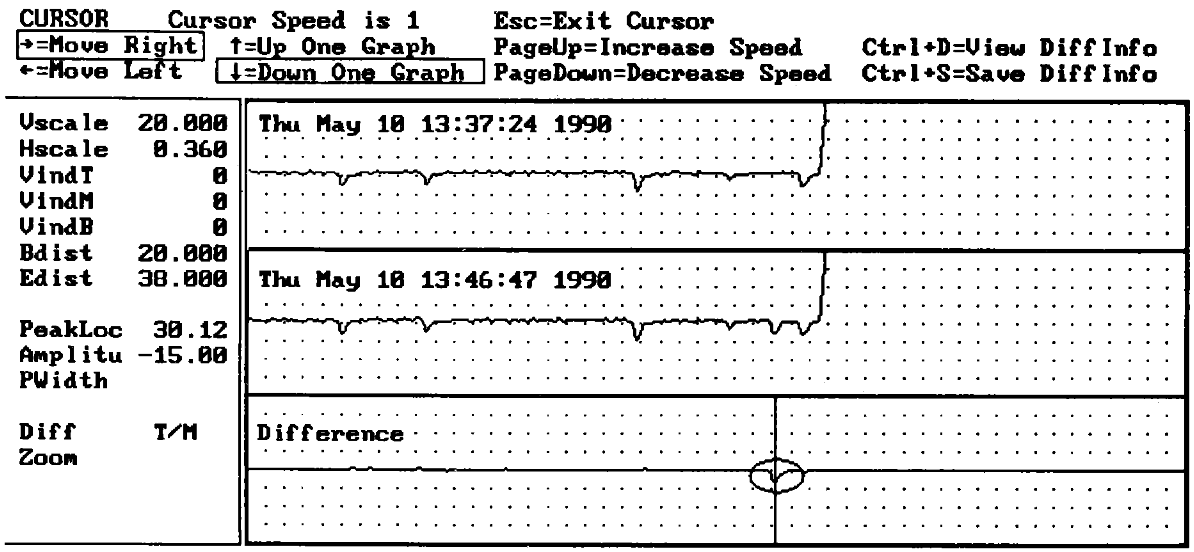

Figure 26.—Cursor positioned at spike in difference waveform.

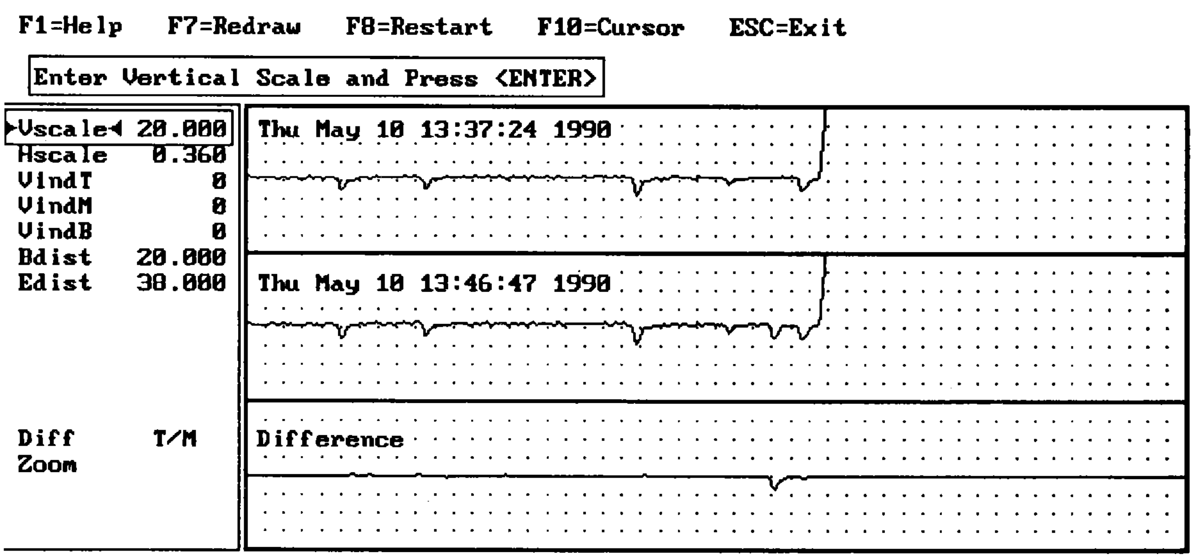

Figure 27.—Vscale prompt in command window.

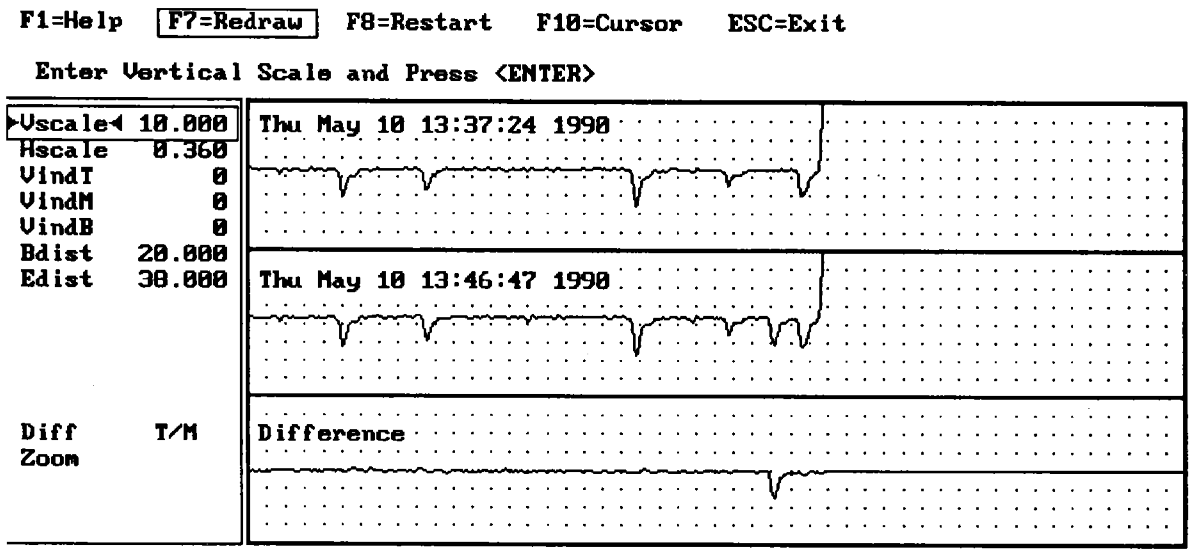

Figure 28.—Waveforms redrawn at new vertical scale.

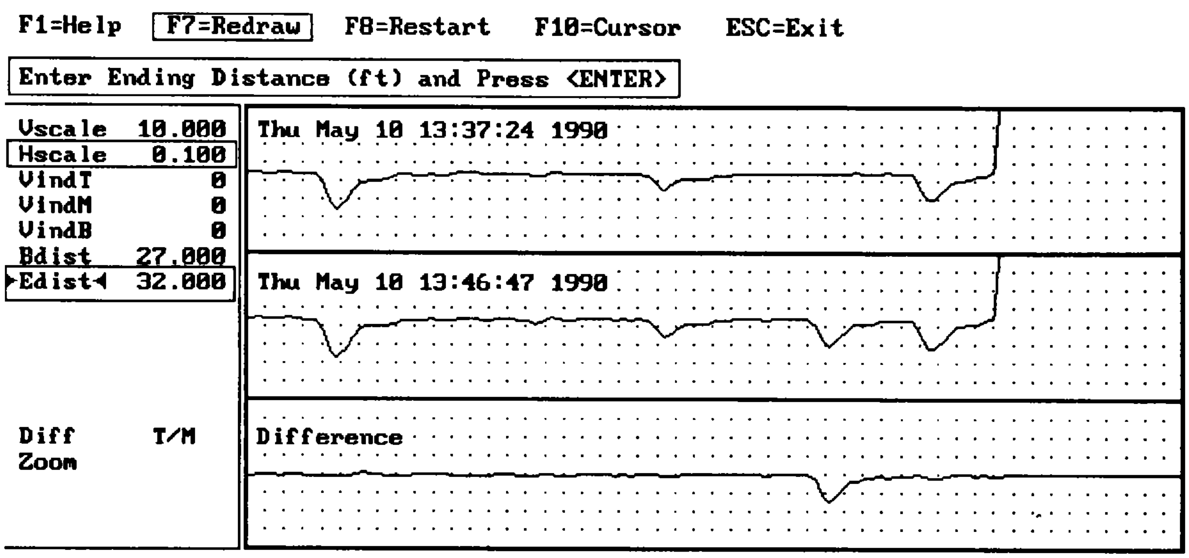

Figure 29.—Waveforms redrawn after Bdist and Edist were changed.

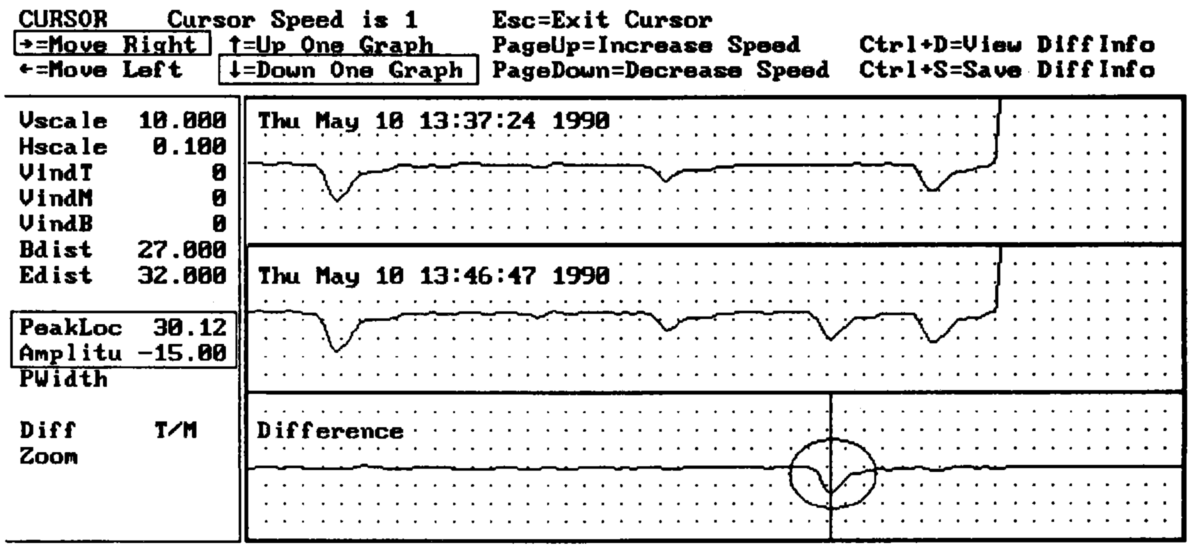

Figure 30.—Cursor positioned at spike in difference waveform.

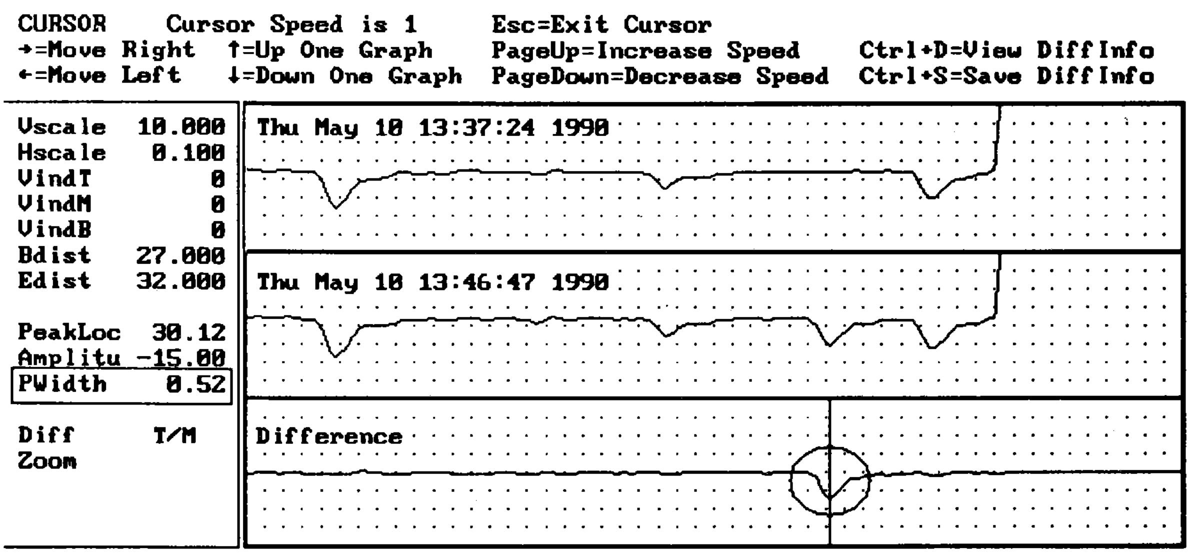

Figure 31.—Using <Ctrl> <D> to compute spike width.

The waveforms in figure 31 from 29.52 to 30.76 ft are reproduced in figure 32 (see table D-1). The program searches from the cursor position (30.12 ft) to the left until a difference amplitude of zero is reached (point A). It then searches from the cursor position to the right where a difference amplitude of zero is not reached after incrementing over 10 data points. NUTSA then considers point B as the right end point. If the cursor is moved to the right a few increments and <Ctrl> <D> is pressed, a larger width will be calculated because of the tail on the right side of the spike and the arbitrary criterion of 10 data point increments from the cursor location. A more sophisticated algorithm for computing PWidth is presented in reference 20, and it is anticipated that such an algorithm will be incorporated into future versions of NUTSA.

<Ctrl> <S>—Save Peak Information.—The location, amplitude, and width of difference spikes can be written to a file. Press <Ctrl> <S> and the program will prompt *Output file name:?* For example, type **peak.out**, as shown in figure 33. Press <Enter> and the program will prompt for any desired notes. These can be up to 40 characters long, as shown in figure 34. Press <Enter> and the notes will be included in the output file, as shown in figure 35, and displayed in the difference waveform window, as shown in figure 36.

The cursor can be moved to other signature changes. Press <Ctrl> <D> to calculate the width of the spike, and press <Ctrl> <S> to save the information. If <Enter> is pressed when the program prompts for an output file name, the information will be appended to the file opened previously. The user can modify settings and repeat this step as many times as desired. Press <Esc> to return to the command menu.

Changing Vertical Index

VindT is the vertical index of the T-File waveform (i.e., the vertical position of the waveform relative to the window origin); VindM is the vertical index of the M-File waveform; and VindB is the vertical index of the B-File waveform. When a portion of a waveform is outside its display window, it can be translated vertically by increasing or decreasing the index value.

To demonstrate this feature, change Bdist to 20 ft, Edist to 38 ft, Vscale to 5 mrho per division, and press <F7>, as shown in figure 36. The top two waveforms are now outside the range of their windows. Highlight "VindT," type **-140**, and press <Enter>. Do the same for "VindM." Press <F7> and the display is redrawn, as shown in figure 37. The waveforms have now been shifted down so that they are within the limits of the windows.

One vertical division of a display window is equal to 32 graphical units. A positive value means the waveform is moved up. A negative value means the waveform is moved down. A value of zero means the waveform is at

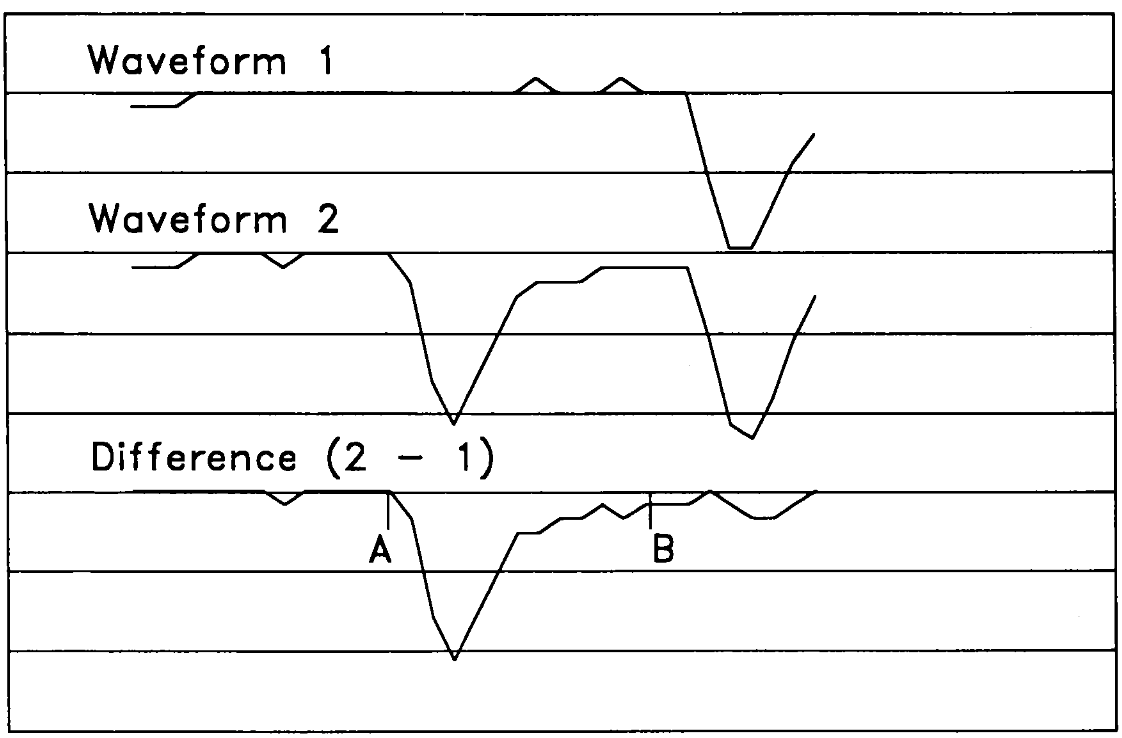

Figure 32.—Definition of difference spike width. (A and B = points.)

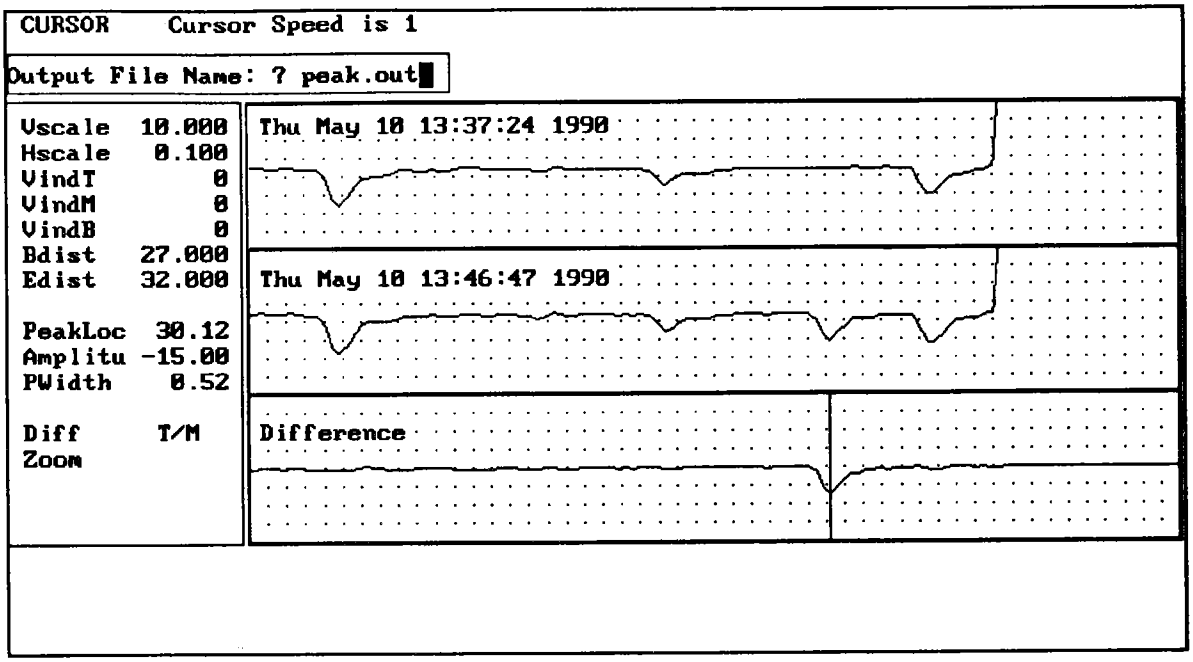

Figure 33.—Using <Ctrl><S> to save difference spike information.

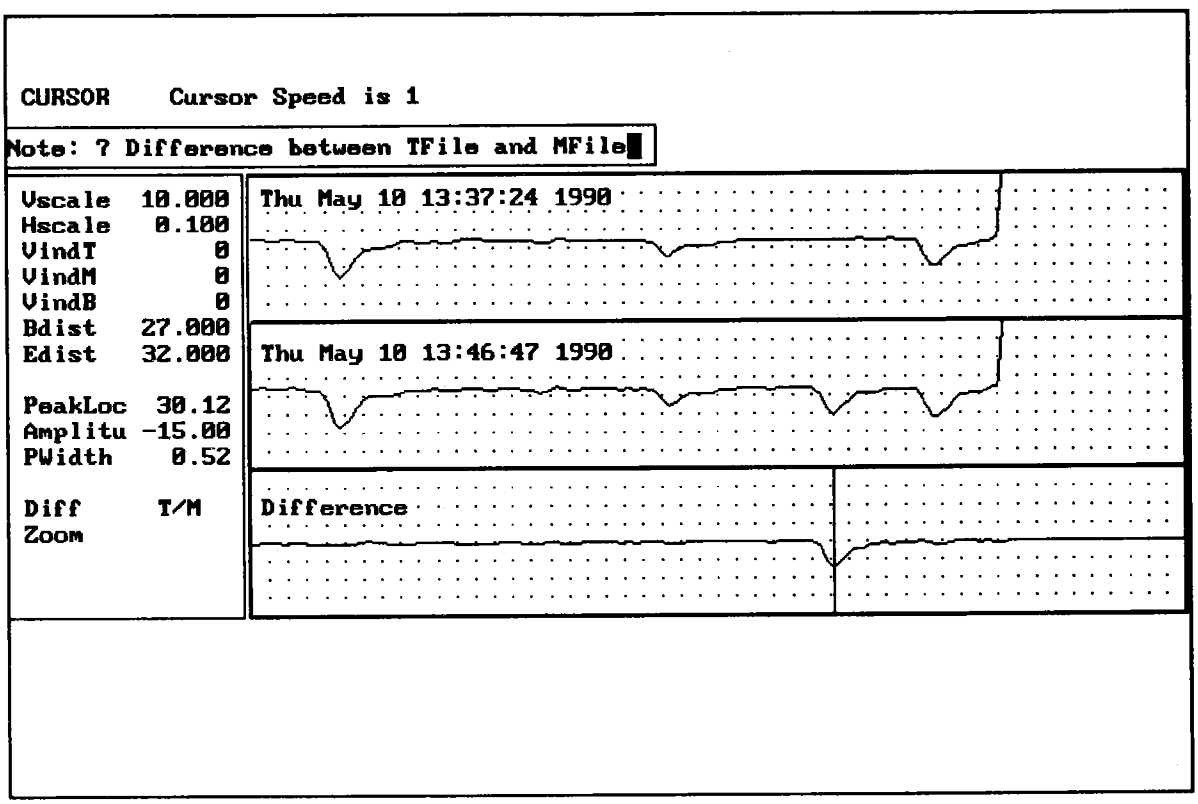

Figure 34.—Appending notes to difference output file.

```
NUTSA
Northwestern University/U.S. Bureau of Mines
TDR Signature Analysis Program, V.1.01, 1992

Difference between TFile and MFile

Peak Location      Peak Value      Peak Width
  30.12            -15.00            0.52
```

Figure 35.—Listing of difference output file.

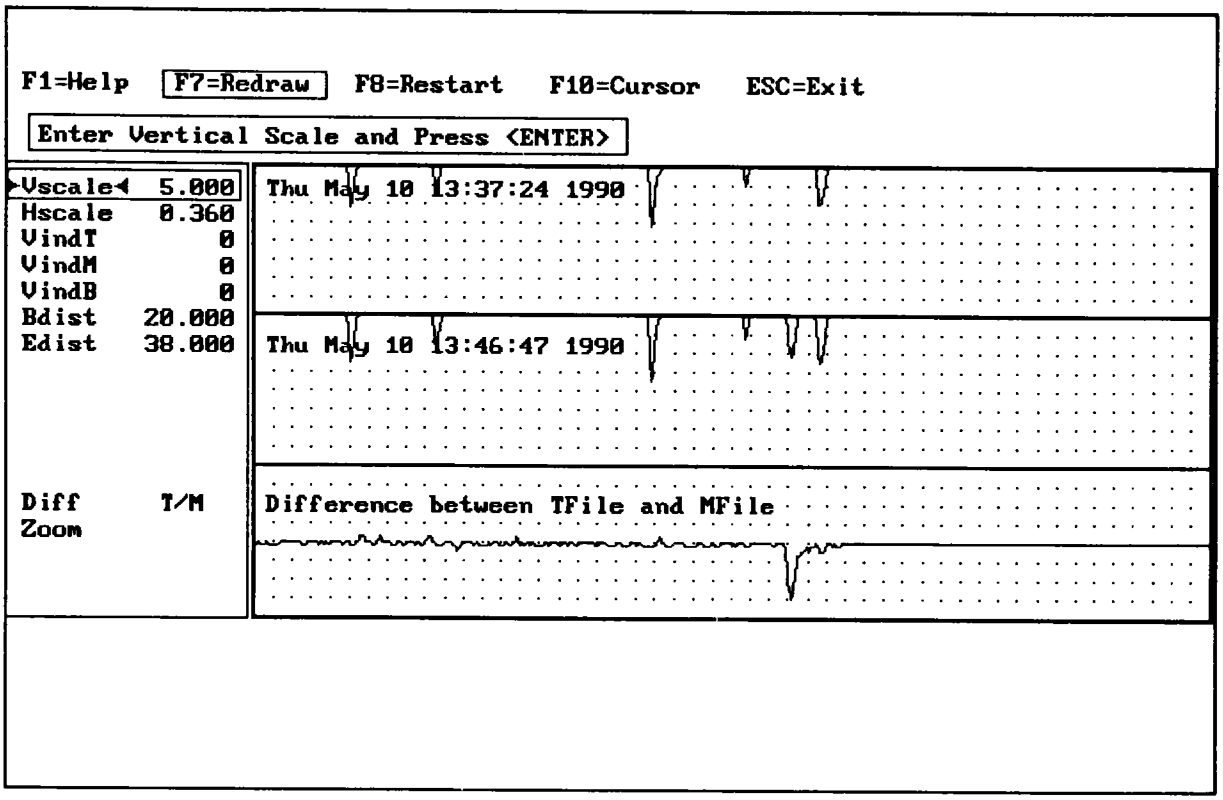

Figure 36.—Waveforms exceed window limits when Vscale is changed.

the original position. If the user attempts to enter illegal characters, the program will prompt with a beep and the current value will not be changed.

Return to Main Menu

To return to the main menu, simply press <Esc> and the prompt *Do you want to leave graphic screen (Y/N)?* will be displayed, as shown in figure 38. If Y is typed and <Enter> pressed, the program will return to the main menu. If N is typed and <Enter> pressed, the program will remain in the graphics mode and nothing will change.

INTERPRETATION OF SIGNATURE CHANGES

The "Diff," "Zoom," and <Ctrl><D> features of NUTSA were motivated by techniques currently being used to interpret TDR signature changes. Su (*18*) has shown that waveform shape is characteristic of the mode of deformation (fig. 3) and the reflection magnitude is proportional to the magnitude of deformation (fig. 4). Logan (*11*) found that quantifying changes in width as well as magnitude provided a simple technique for quantifying waveform shape. These quantities can be tabulated, as shown in figure 35.

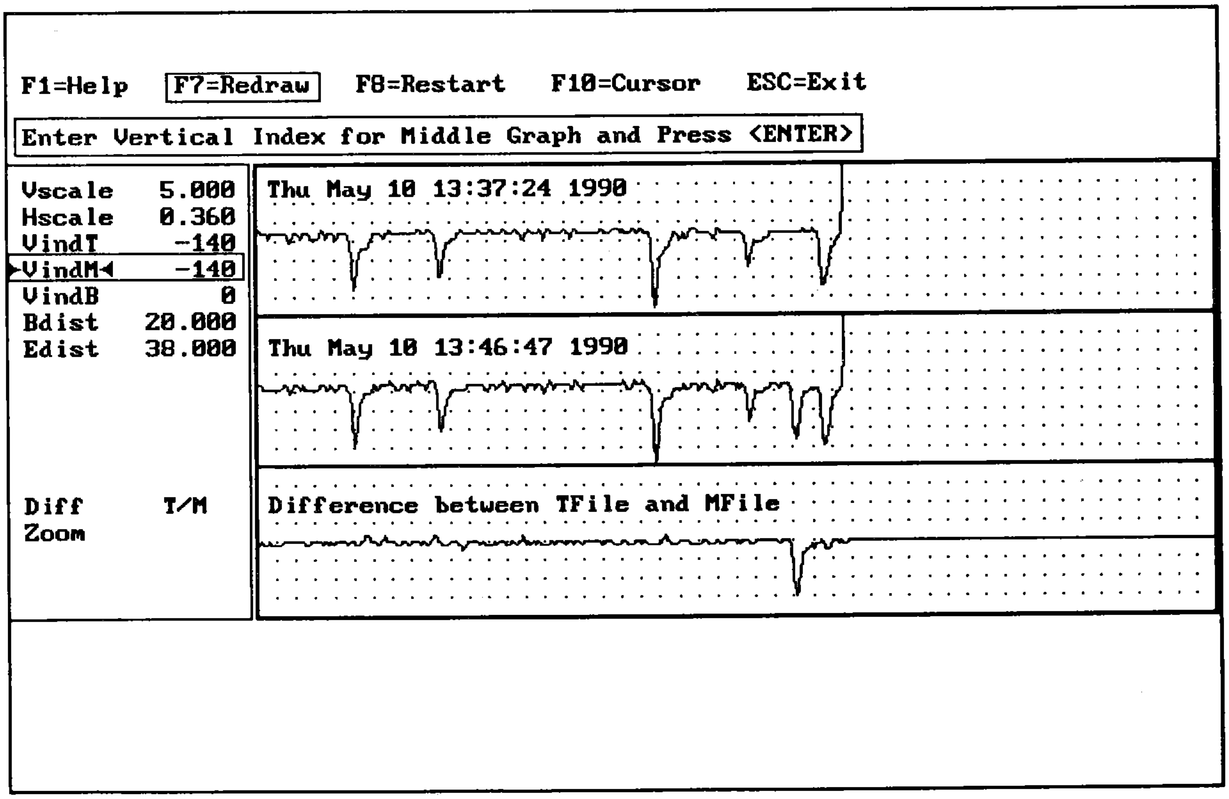

Figure 37.—Waveforms redrawn after VindT and VindM were changed.

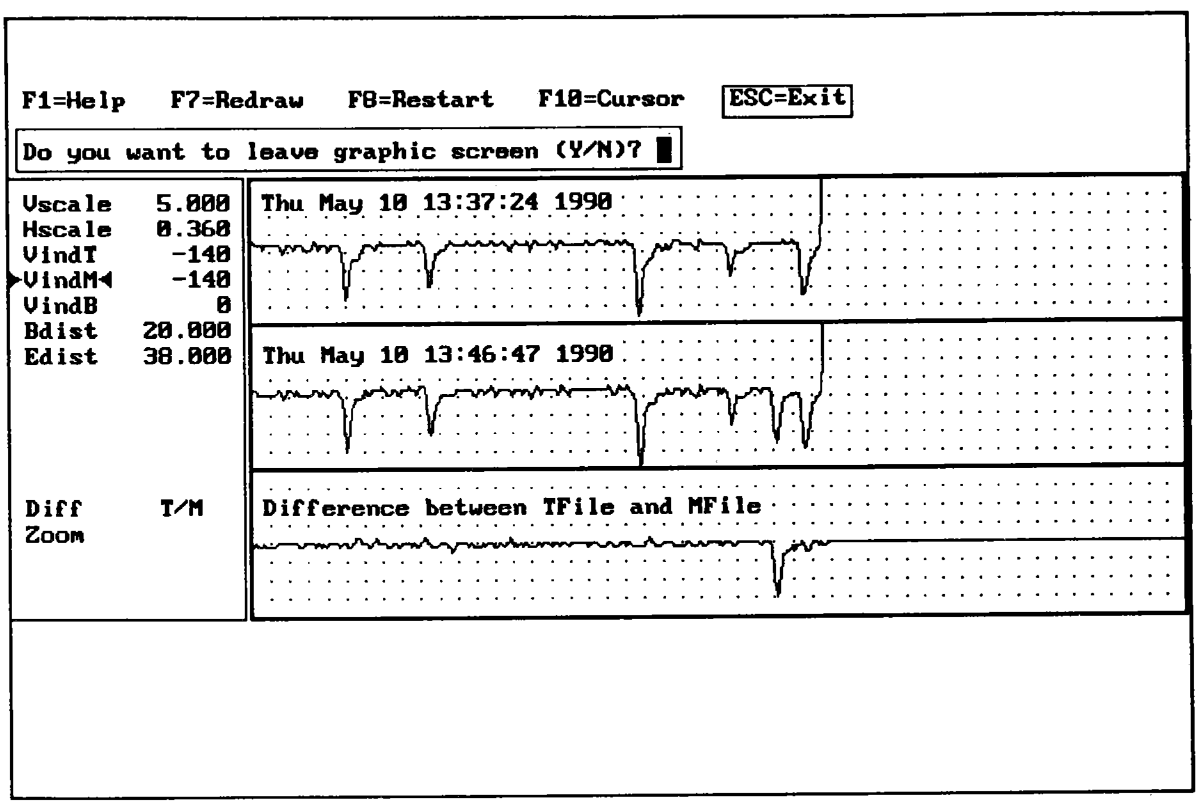

Figure 38.—Prompt to exit graphics before returning to main menu.

TDR signature changes in figure 13 were identified using "Diff," "Zoom," and <Ctrl><D>. The times, locations, and amplitudes are summarized in table 4. The spikes are consistent with localized deformation caused by crimping the cable with pliers. These spikes would also occur if the cable had been grouted into a borehole and subjected to shear due to rock mass deformation. For purposes of this example, assume that this is the case. The calibration shown in figure 4 for 1/2-in cable (*7*) can be used to convert signature change magnitudes to displacement. There is an inconsistent use of units (U.S. customary for location and metric for displacement) since an acquisition setting of feet per division was used rather than meters per division.

Table 4.—Summary of TDR signature changes for tutorial example

Time	Location, ft	Amplitude, mrho	Displacement, mm
13:37 . .	22.72	0.00	0.00
	30.12	.00	.00
13:46 . .	22.72	.00	.00
	30.12	-15.00	1.60
13:52 . .	22.72	-22.50	1.90
	30.12	-13.75	1.55

The negative spike at a location of 30.12 ft would be interpreted as a rock mass shear displacement that increased from 0.00 mm at a time of 13:37 to 1.6 mm at 13:46. The negative spike at a location of 22.72 ft would be interpreted as shear displacement, which increased from 0.00 mm at a time of 13:46 to 1.9 mm at 13:52.

The negative spike at a location of 30.12 ft decreased in amplitude from 15.00 mrho at 13:46 to 13.75 mrho at 13:52. This decrease should not be interpreted as a decrease in shear. It is actually because of the upstream deformation, which occurred at 22.72 ft. In fact, no further deformation had occurred at 30.12 ft. A decrease in amplitude can also occur when a cable is subjected to shear and then tension (*16*).

This example demonstrates limitations that exist in the current state-of-the-art interpretation and the need for visual as well as quantitative analysis. However, it does illustrate the importance of the NUTSA program in facilitating quantification of TDR signature characteristics. Subsequent versions of the program will incorporate more sophisticated capabilities for quantification and interpretation of signature changes.

CURRENT LIMITATIONS AND PLANNED DEVELOPMENTS

DATA ACQUISITION

The NUMOD system is limited to interactive remote polling of a single TDR monitoring cable. Remote polling of several cables will require multiplexing capabilities. Also, modification of software provided by Tektronix has been limited to simply changing baud rates to permit remote communication with a 1502 cable tester via modem. Future modification is necessary to run the program in batch mode, which would allow automated data acquisition.

Many of these limitations do not exist with a second system that the Bureau is using. This system, available from Campbell Scientific (*4*), allows for unattended data acquisition and multiplexing. The cable tester is controlled by a data logger, which stores data in modules. The entire system, including cable tester, is solar powered, and data files are downloaded using telemetry. This system does permit automated data acquisition, but it is not suitable for real-time interactive polling of a remote cable tester.

DATA FILE FORMAT

The NUTSA program was developed for visual analysis of data acquired using a Tektronix 1502B (or 1502C) TDR cable tester with an SP232 serial communications module. Data file format (appendix C) is dictated by the SP232 Host Application Program (*20*) developed for this module. The Campbell Scientific system (*4*) uses a data logger and proprietary software in conjunction with a Tektronix 1502B cable tester, but the data file format differs from that in appendix C. Algorithms are being developed for NUTSA to allow use with data from either of these systems.

DATA FILE LENGTH

When a cable is interrogated using a Tektronix 1502B cable tester, the waveform displayed on the tester screen is stored as 251 data points. The number of screens required to store all of the waveforms for an entire cable will depend on the Ddiv used when the waveforms are acquired. As shown in table 5, if a Ddiv of 2 ft per division was used, then 5 screens of data for a 100-ft cable and 50 screens for a 1,000-ft cable would be required.

Table 5.—Effect of Ddiv on input file size

Ddiv ft per division	Screen size, ft	Number of screens			
		100-ft cable	500-ft cable	1,000-ft cable	2,000-ft cable
2	20	5	25	50	100
5	50	2	10	20	40
10	100	1	5	10	20
20	200	1	3	5	10

The maximum number of data points that can be read into the NUTSA program is 2,501. Therefore, the maximum number of screens that can be read in is

$$(2{,}501 + 9 \text{ points}) \div (251 \text{ points/screen}) = 10 \text{ screens}, \quad (4)$$

where nine points are ignored because of overlap between screens (table 6). If the data file is larger than 10 screens, it will not be possible to view the entire waveform at one time. However, the entire waveform can be viewed in portions by specifying Bdist and Edist. NUTSA will read the input files again and create new scratch files (appendix D).

Table 6.—Number of data points in scratch files

Screen	Number of points	
	Stored	Ignored
1	251	0
2	250	1
3	250	1
4	250	1
5	250	1
6	250	1
7	250	1
8	250	1
9	250	1
10	250	1
Total ..	2,501	9

HARD COPY OF SIGNATURES

The current version of NUTSA does not create plot files, but hard copy of the screen can be obtained using various techniques. For example, by pressing <Shift> <Print Screen>, the user can print the screen at CGA resolution. Also, many commercially available utilities (e.g., the GRAB utility available with WordPerfect 5.1) can be used to capture graphics screens. The WordPerfect GRAB utility was used to produce the figures in this manual. Future versions of NUTSA will allow output files to be stored in various formats, such as ASCII and Autodesk Document Interchange Format (DXF) for use with commercially available spreadsheet and graphics programs.

QUANTIFYING SIGNATURE CHANGES

NUTSA was developed primarily for visual analysis of signature changes. It is intended that the <Diff>, <Zoom>, and <F10> (cursor movement) features will be used to locate and characterize changes. A very simple algorithm for quantifying the width of difference waveform spikes was incorporated to allow for a gross quantification of changes in width. The example in figure 32 and appendix D demonstrates limitations of this algorithm. A more sophisticated version is presented in reference 20. It is not currently feasible to integrate an expert system or artificial intelligence for analyzing changes in TDR signatures. A large data base of TDR records does exist, but there is a large variation in waveform characteristics. The factors responsible for these variations must be identified, and the laboratory calibrations currently available are too limited in scope. Research is continuing and the number of field applications is increasing; therefore, the need for batch processing of TDR records will become more critical. More sophisticated capabilities for quantifying signature changes will be incorporated in future versions of NUTSA.

CONCLUSIONS

Development of the NUMOD system was motivated by the desire to remotely poll a cable tester equipped with a serial communication module. The tester can be polled as frequently as desired via modem. Development of the program NUTSA was motivated by the desire to visually compare digitized TDR waveforms and rapidly identify signature changes. It is interactive and user friendly with a limited algorithm for quantification of signature changes. The interactive examples used in this report involved interrogation of coaxial cables less than 2 m in length, but actual field installations involve cables that are hundreds of meters long. The large number of TDR records obtained when monitoring such long coaxial cables on a daily basis is motivating continuing work on filtering out redundant data and increasing the number of data points displayed from 2,500 to 25,000. Algorithms are being developed for use with data acquired using other systems, such as the one available from Campbell Scientific. Future versions will allow output files to be stored in various formats to improve the graphical presentation of TDR signatures.

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APPENDIX A.—MODIFICATION OF HOST APPLICATION PROGRAM

To acquire TDR waveforms via modem, the Host Application Program, developed by Tektronix for use with the SP232 serial extended function module, requires modification. The default baud rate is 9,600. The following changes were made so that a baud rate of 1,200 could be used:

1. In the file COMM.H, change "#define FAST_SETUP OXE3 /* baud rate was 9600 */" to "#define FAST_SETUP OX83 /* change baud rate to 1200 */."
2. In the file SP232.C, find the function sp_connect and change "send_baudrate_chg (BR_9600)" to "send_baudrate_chg (BR_1200)."

The user should request that Tektronix make these changes or request a copy of the original source code. A TURBO C version 2.0 or TURBO C++ compiler will be needed to recompile the modified source code. When compiling, make sure that (1) the default library and graphic library are ON, and (2) the memory model is LARGE. Also, when using a Turbo C++ compiler, two files must be added to the file SPGRAPH.C: (1) **#include <stdarg.h>**, and (2) **#include <alloc.h>**.

APPENDIX B.—EXAMPLE ACQUISITION SETTINGS FILE

Waveforms are acquired as a sequence of screens with settings required for each screen. When long cables are interrogated, as many as 100 screens may have to be acquired. The acquisition settings file can be created and modified interactively using the Tektronix SP232 Host Application Program (SP12.EXE), but it is often more expedient to create and store the settings file using an editor (e.g., Norton Editor) or word processor (e.g., WordPerfect). An example settings file (RUN.SET) is included with the NUTSA diskette so that a user can edit it to create a variety of settings files.

INTERACTIVE CREATION OF SETTINGS FILE

To show components of a settings file, a step-by-step example will be used to interactively create one. The SP232 Host Application Program will prompt a user with a range of values to select for some parameters. The values that have been proven to be desirable initial settings are given in parentheses.

1. Connect the computer and cable tester:

   a. Use the serial cable.
   b. Turn the computer and cable tester on.

2. Invoke the Host Application Program:

   a. Type **sp12**.
   b. Press <Enter>.
   c. The main menu is displayed: *Get, Set, Read, Write, Info, Alt, Diff, Erase, Quit, More.*[1]

3. Establish communication between computer and cable tester *[Set]*:[2]

   a. Press <S>.
   b. Program indicates *remote link being established.*
   c. If there is no communication error message, the following command line is displayed: *Avg, Gain, Ddiv, Vp, Cdist, vert, Hor, dspOhms, Send, End*?

4. Change acquisition settings:

   a. Number of measurements to be acquired and averaged before storing *[Avg]*.

      (1) Press <A>.
      (2) *1,2,4,8,16,32,64,128?*
      (3) Type one of the values (example: **8**).
      (4) Press <Enter>.

   b. Vertical sensitivity *[Gain]*.

      (1) Press <G>.
      (2) *d|m|<cr>?*
      (3) Press <M> (for mrhos per vertical division).
      (4) *Gain?*
      (5) Type the desired value of millirho per division (example: **20**).
      (6) Press <Enter>.

   c. Horizontal sensitivity *[Ddiv]*.

      (1) Press <D>.
      (2) *Dist units [m|f|<cr>]?*
      (3) Press <F> (for feet per horizontal division).
      (4) *.1, .2, .5, 1, 2, 5, 10, 50, 100, 200?*
      (5) Type the desired value of feet per division (example: **1**).
      (6) Press <Enter>.

   d. Propagation velocity (*19*)[3] of coaxial cable being monitored *[Vp]*.

      (1) Press <V>.
      (2) *Vp[.30 - .99]?*
      (3) Type the appropriate velocity (example: **.66**).
      (4) Press <Enter>.

   e. Distance at which measurement should begin *[Cdist]*.

      (1) Press <C>.
      (2) *Dist units [m|f|<cr>]?*
      (3) Press <F> (for feet).
      (4) Press <Enter>.
      (5) *Cursor dist?*
      (6) Type the desired distance (example: **-2**) (see table 2).
      (7) Press <Enter>.

   f. Vertical position of waveform *[veRt]*.

      (1) Press <R>.
      (2) *Vertical offset?*
      (3) Type the appropriate value (example: **6078**).
      (4) Press <Enter>.

---

[1]Prompts displayed on the screen by the program are italicized.
[2]Italicized, bracketed terms indicate commands being activated.
[3]Italic numbers in parentheses refer to the items in the list of references preceding appendix A.

Note: The user (1) will have to change this setting frequently and (2) can exit to the main menu and press <I> for information on current settings.

g. Move cursor on screen *[Hor]*.

(1) Press <H>.
(2) Use left-right arrows.
(3) Press <Enter> (to terminate).

5. Send new settings to TDR cable tester *[Send]*: Press <S>.

6. Exit to main menu *[End]*:

a. Press <E>.
b. *Resume?*
c. Press <Enter>.
d. *Get, Set, Read, Write, Info, Alt, Diff, Erase, Quit, More*.

7. Save settings *[Write]*:

a. Press <W>.
b. *Filename?*
c. Type the desired file name (example: **RUN.SET**).
d. Press <Enter>.
e. *All, Misc, Settings, Waveform, Nothing?*
f. Press <S> (i.e., this file contains settings only).
g. Press <Enter>.

Note: If file name is an existing file, the following prompt will be displayed: *New info will be appended to "filename."*

8. Acquire waveform using current settings *[Get]*:

a. Press <G>.
b. *Settings filename?*
c. Press <Enter> (to get current waveform).

9. Exit from program *[Quit]*: Press <Q>.

EXAMPLE SETTINGS FILE

The following settings file (RUN.SET) will acquire four screens of data. The Ddiv is set at 1 ft per division so that each screen represents 10 ft. The first screen acquires data from -2 to 8 ft. The second screen acquires data from 8 to 18 ft. The third screen acquires data from 18 to 28 ft. The fourth screen acquires data from 28 to 38 ft.

```
instr_id: 1502   < = = = begin commands for first screen
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: -2.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
instr_id: 1502 < = = = begin commands for second screen
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 8.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
instr_id: 1502   < = = = begin commands for third screen
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 18.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
instr_id: 1502 < = = = begin commands for fourth screen
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 28.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
```

APPENDIX C.—EXAMPLE ACQUISITION OUTPUT FILE

This output file (AAA provided with NUTSA diskette) was obtained using the settings file in appendix B. It represents four screens of data with each screen composed of three parts: (1) title and notes, (2) acquisition settings, and (3) waveform data. Each screen contains 251 data points stored as 2-byte integers. The physical setup consisted of a 35-ft-long, 50-ohm coaxial cable (*7*)[1] connected to a 3-ft-long precision, 50-ohm cable connected to a 1502B cable tester.

[1]Italic numbers in parentheses refer to the items in the list of references preceding appendix A.

date: Thu May 10 13:37:24 1990 *
notes: *
instr_id: 1502
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: -2.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
waveform: acquired seq: 1

0	0	0	251	5														
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	32	55	52	58	58	60	63	62	66	81	78	73	69	64	62
	61	61	62	60	59	58	58	58	59	58	59	59	58	58	58	59	58	58
	58	59	59	59	59	59	59	59	59	59	59	59	59	59	60	60	60	60
	59	60	60	60	60	60	59	59	59	60	60	60	60	60	60	60	60	59
	59	60	60	61	61	60	60	60	61	61	60	60	60	60	61	62	69	75
	65	21	4	28	46	61	65	65	66	65	64	64	65	63	64	67	68	68
	58	45	49	56	61	64	63	63	65	66	67	67	66	56	43	47	56	61
	64	59	48	51	57	61	64	64	63	64	65	65	65	67	67	66	66	66
	66	67	67	66	66	66	66	66	67	67	65	55	49	54	61	64	64	64
	64	65	66	67	67	66	67	67	66	64	64	67	67	67	66	66	67	67
	67	64	63	68	68	66	67	68	67	66	65	66	67	67	66	62	54	53
	58	60	64	65	64	64	65	67	68	67	66	67	67	66	64	66	69	

date: Thu May 10 13:37:31 1990 *
notes: *
instr_id: 1502
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 8.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
waveform: acquired seq: 2

0 0 0 251 5

70	67	66	65	66	67	68	67	65	65	66	66	62	49	46	53	58	62
62	63	64	64	64	66	66	64	66	65	65	65	66	65	65	67	66	65
65	66	66	66	66	60	55	58	61	63	65	64	63	65	66	66	66	66
66	67	66	66	65	67	68	66	66	66	66	67	66	66	66	67	66	66
66	67	67	66	67	68	68	67	66	67	66	66	67	67	67	67	67	67
67	67	66	67	67	67	67	67	67	67	67	66	66	65	67	68	67	67
67	67	67	66	67	67	66	65	66	67	67	66	66	66	67	67	66	67
67	67	67	67	67	66	66	67	67	67	67	67	68	67	68	67	66	61
52	53	58	62	64	64	64	64	66	67	67	67	67	67	66	66	67	67
68	68	67	66	67	67	67	67	67	67	67	67	68	67	67	68	67	67
67	67	66	60	54	57	61	64	65	65	65	66	67	67	67	67	67	67
66	66	67	68	67	67	67	67	67	68	68	67	67	67	67	67	68	67
67	67	67	68	68	67	67	67	66	58	54	57	60	64	65	65	64	64
67	68	67	66	67	67	66	66	67	68	67	66	67	68	68	67	66	

date: Thu May 10 13:37:38 1990 *
notes: *
instr_id: 1502
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 18.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
waveform: acquired seq: 3

0 0 0 251 5

66	67	67	66	67	68	68	67	66	67	67	68	67	66	67	67	67	67
67	66	67	67	67	66	66	67	66	67	67	67	67	66	67	67	67	67
67	67	67	68	67	67	67	67	67	66	67	67	67	66	67	68	67	67
67	66	67	67	67	67	67	67	67	67	66	65	66	67	67	67	66	67
67	67	67	66	66	66	66	67	68	67	66	67	67	67	66	66	67	67
67	67	67	65	58	55	57	61	63	64	64	64	65	66	67	67	67	67
67	66	67	67	68	67	67	67	67	67	67	67	67	67	67	67	67	68
68	67	67	67	68	68	67	66	63	58	58	61	63	65	65	66	66	66
67	67	68	67	67	67	67	67	67	67	68	67	67	67	67	68	68	67
67	67	67	68	68	67	67	67	67	68	67	67	66	66	67	67	68	67
67	67	67	68	67	66	68	68	67	67	67	67	67	67	68	67	67	66
67	68	68	67	67	67	67	67	67	67	67	67	67	68	68	67	67	67
67	68	68	68	68	67	68	67	67	67	68	68	67	67	68	68	67	67
67	63	54	51	54	59	62	63	64	64	65	66	67	67	66	66	67	

date: Thu May 10 13:37:45 1990 *
notes: *
instr_id: 1502
averages: 1
vertical: 6039
gain: 20.0000 mrho
ddiv: 1.0000 feet
vp: 0.66
cpos: 0
cdist: 28.0000
maxhold: off
pulse: off
singsweep: off
dspohms: off
buttons: 1
waveform: acquired seq: 4

0	0	0	251	5														
	67	66	66	67	68	68	68	67	67	67	67	67	67	67	66	66	68	68
	67	67	67	67	67	67	67	67	67	67	67	66	62	60	62	64	65	65
	65	65	66	66	66	67	67	67	67	67	67	67	67	67	67	67	67	67
	67	67	67	68	67	67	67	68	67	67	67	61	56	56	59	62	64	64
	65	66	66	68	02	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128
	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	128	

APPENDIX D.—QUANTIFICATION OF SIGNATURE CHANGES

CREATION OF SCRATCH FILES

During sequential interrogation of a cable, data for each screen are appended to the specified output file. NUTSA reads all information for the first screen, but only waveform data for subsequent screens. The program then creates scratch files (TFILE.TMP, MFILE.TMP, and BFILE.TMP) to decrease the time required to redraw waveforms.

Using a settings file such as the one in appendix B, the first data point of each screen will overlap with the last data point of the preceding screen. To account for this overlap when creating scratch files, NUTSA stores 251 data points for the first screen, but ignores the first data point of each subsequent screen (table 6). Occasionally, discrepancies result when there are differences in data point values. For example, the last point of screen 1 in appendix B has a value of 69, but the first point of screen 2 has a value of 70. Experience with the Tektronix SP232 Host Application Program has shown that these discrepancies are not significant, and a more sophisticated procedure for creating scratch files was not warranted. However, this is not the case with other acquisition systems, such as that developed by Campbell Scientific (*4*).[1]

CURSOR LOCATION AND WAVEFORM AMPLITUDE

When the cursor is invoked and moved along a waveform, the cursor location and waveform amplitude are displayed. The algorithm for computing these values is straightforward. Consider an example where Cdist is -2 ft, Ddiv is 1 ft per division, vertical gain is 20 mrho per division, and a data point within the window has a 2-byte integer value of 59 (e.g., point 91 of screen 1 in appendix C and the T-File waveform in figure 15).

[1]Italic numbers in parentheses refer to items in the list of references preceding appendix A.

$$\text{Number of increments} = \text{data point no.} - 1 = 91 - 1 = 90 \text{ incr}, \qquad \text{(D-1)}$$

where incr = increment.

$$\text{PeakLoc} = \text{Cdist} + \left[\text{No. incr} \times \text{Ddiv} \times \frac{10 \text{ div/screen}}{250 \text{ incr/screen}}\right] = -2 \text{ ft} + [(90 \text{ incr}) \times (1 \text{ ft/div}) \times (0.04 \text{ div/incr})] = 1.60 \text{ ft}. \qquad \text{(D-2)}$$

$$\text{Graphical amplitude} = \text{byte integer value} \times \frac{2 \text{ graphical units}}{\text{unit byte value}} = 59 \times 2 \text{ graphical units} = 118 \text{ graphical units}. \qquad \text{(D-3)}$$

$$\text{Reflection coefficient amplitude} = \frac{\text{graphical amplitude}}{32 \text{ graphical units/div}} \times \text{gain} = 118/32 \times 20 \text{ mrho/div} = 73.75 \text{ mrho}. \qquad \text{(D-4)}$$

CALCULATION OF DIFFERENCE SPIKE AMPLITUDE AND WIDTH

When the "Diff" command is invoked, NUTSA computes the arithmetic difference between data points of two waveforms. The algorithm for computing difference values can be shown using an example with 26 data points, Ddiv is 1 ft per division, and vertical gain is 20 mrho per division (e.g., point 39 through point 64 for screen 4 of file AAA in appendix C and file BBB included with the NUTSA diskette and in figure 32). Difference waveform data points listed in table D-1 were computed using the following three relations:

$$\text{Byte value difference} = (\text{byte value})_{BBB} - (\text{byte value})_{AAA}. \tag{D-5}$$

$$\text{Difference graphical amplitude} = \text{byte value difference} \times \frac{2 \text{ graphical units}}{\text{unit byte value}}. \tag{D-6}$$

$$\text{Reflection coefficient difference amplitude} = \frac{\text{difference graphical amplitude}}{32 \text{ graphical units/div}} \times \text{gain}. \tag{D-7}$$

Table D-1.—Calculation of difference waveform data points

Data point	Location, ft	Byte value			Difference amplitude	
		File AAA	File BBB	Difference	Graphical units	Reflection coefficient, mrho
39 ...	29.52	66	66	0	0	0.00
40 ...	29.56	66	66	0	0	0.00
41 ...	29.60	67	67	0	0	0.00
42 ...	29.64	66	66	0	0	0.00
43 ...	29.68	67	67	0	0	0.00
44 ...	29.72	67	67	0	0	0.00
45 ...	29.76	67	67	0	0	0.00
46 ...	29.80	67	66	-1	-2	-1.25
47 ...	29.84	67	67	0	0	0.00
48 ...	29.88	67	67	0	0	0.00
49 ...	29.92	67	67	0	0	0.00
50 ...	29.96	67	67	0	0	0.00
51 ...	30.04	67	67	0	0	0.00
52 ...	30.00	67	65	-2	-4	-2.50
53 ...	30.08	67	58	-9	-18	-11.25
54 ...	30.12	67	55	-12	-24	-15.00
55 ...	30.16	67	58	-9	-18	-11.25
56 ...	30.20	67	61	-6	-12	-7.50
57 ...	30.24	67	64	-3	-6	-3.75
58 ...	30.28	68	65	-3	-6	-3.75
59 ...	30.32	67	65	-2	-4	-2.50
60 ...	30.36	67	65	-2	-4	-2.50
61 ...	30.40	67	66	-1	-2	-1.25
62 ...	30.44	68	66	-2	-4	-2.50
63 ...	30.48	67	66	-1	-2	-1.25
64 ...	30.52	67	66	-1	-2	-1.25

The maximum reflection coefficient difference of -15.00 mrho occurs at point 54. On the left side of this maximum, the difference equals 0 mrho at 3 data point increments (point 51), and on the right side, search is terminated after 10 data point increments, so that

$$\text{Number of increments} = 3 + 10 = 13 \text{ incr.} \tag{D-8}$$

$$\text{Distance/increment} = \text{Ddiv} \times \frac{10 \text{ div/screen}}{250 \text{ incr/screen}} = 1 \text{ ft/div} \times 0.04 \text{ div/incr} = 0.04 \text{ ft/incr.} \tag{D-9}$$

$$\text{PWidth} = \text{Number of increments} \times \text{distance/incr} = 13 \text{ incr} \times 0.04 \text{ ft/incr} = 0.52 \text{ ft.} \tag{D-10}$$

A more sophisticated algorithm is presented in reference 20.

APPENDIX E.—NULL MODEM CABLE CONNECTION

The connector pin specifications shown in figure E-1 were used for the null modem cable connecting a Tektronix SP232 extended function module and a Ventel 2400 Plus II modem (fig. 5). The SP232 module is data communication equipment. The configuration used depends on the modem used. The user's manual should be consulted for specifications.

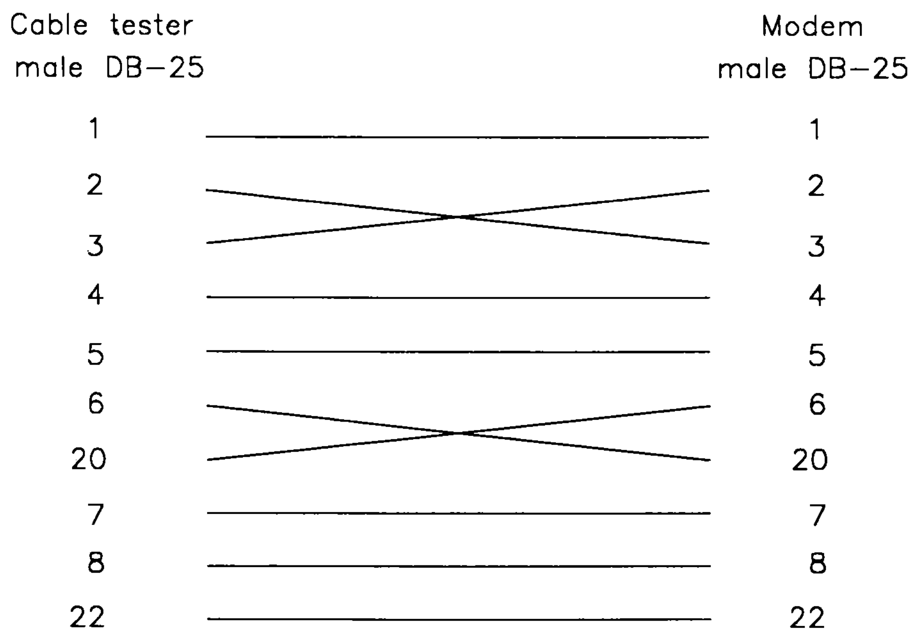

Figure E-1.—Connector pin specifications.

INDEX

—A—

—B—

—C—

—D—

—E—

—F—

—G—

—H—

—I—

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