NON-DESTRUCTIVE TESTING VIA STANDARD LABORATORY TEST EQUIPMENT

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ABSTRACT

Non-destructive testing research involving ultrasonics is being pursued at the United States Naval Academy under the sponsorship of the David Taylor Naval Ship Research and Development Center. Specifically, efforts to improve various aspects of testing, the equipment used and software developed, are addressed in this article. Particular emphasis is placed upon the software and the problems that were overcome in using a digitizing oscilloscope and computer made by different manufacturers.

SOMMAIRE

Des recherches portant sur des essais non-destructifs et utilisant des ultrasons sont menées à l'Académie Navale des Etats-Unis sous l'égide du Centre David Taylor de Recherche et Développement en Construction Navale. Les efforts poursuivis pour améliorer les divers aspects des tests, l'équipment utilisé et le logiciel développé sont traités de manière spécifique dans cet article. Un accent particulier est mis sur le logiciel et les problèmes qui furent résolus en utilisant un oscilloscope digital et un ordinateur fabriqués par deux companies différentes.

Numerous applications require that a pulse be detected in background noise. Radar and Sonar are common examples. Ongoing ultrasonic research uses the basic principles of sonar to detect flaws in materials where non-destructive testing is a necessity. Examples are qualifying the hulls of deep diving submersibles (nuclear submarines and research bells) and testing of nuclear reactor containment vessel walls. Another method of non-destructive testing is the use of X-Rays. This method is expensive due to both the initial capitol investment plus the additional cost of performing laborious measurements. The measurement costs are exacerbated by the removal of most workers from the local area while the X-Ray equipment is in operation. X-Ray testing is best suited to the detection of voids in solids. Detection of small cracks is best done with ultrasonic testing.

Continuous research is being performed at the Naval Academy in the use of ultrasonics to either supplement or replace the use of X-Rays as a measurement tool. This sonar type of hardware may typically consist of an ultrasonic transducer mounted on a pair of rails that are attached to the hull of a ship or some other test specimen. This assembly and the object to be tested are then immersed an ultrasonic conducting medium such as water. The transducer is then moved on the rails in close proximity to the test object's surface either in a steady lateral direction or in short lateral increments. Whether this controlled movement is continuous or in steps depends primarily on whether the returned ultrasonic pulse is discernible within the background noise. Background noise is added to the returned pulse either by the randomly oriented crystalline structure of the test specimen (a form of synchronous noise) or by local ambient noise source (asynchronous noise - amplifier thermal noise, welding, etc.) Asynchronous noise is more readily removed by statistical processing of the data. If the pulse is "buried" within the random noise, it may take many transmitted pulses at one test fixture location to "dig the pulse out-of the mud."

As better performance transducers evolve, the hardware design of the detection electronics, the computing hardware and software and the hardware used to display the collected data must also change accordingly.

In 1987, research efforts that included the mating together of some "off-the-shelf" hardware to perform a detection and display operation were implemented. The basic system consisted of a noise source, pulse generator and mixer supplying a signal to an oscilloscope. This signal was digitized by the scope and the data points were then sent over the IEEE-488 bus to a computer (see Figure 1). From the computer, the data were then sent over the IEEE-488 bus to a printer.

After the scope-computer-printer section was made operational, the noise source and pulse generator were replaced with a transducer. In this configuration, the transducer was mounted above a glass plate submerged in water and a reflection was detected at both plate surfaces. Two general approaches could have been used to detect the pulse in either test configuration.

First, the averaging capability of the Tektronix 2430 oscilloscope can be utilized. In this mode of operation, the scope is programmed to accept up to 256 samples of 1024 data points, average the data points that have been digitized by its flash converter, and send these data to the Hewlett-Packard 9000/300 computer. A sub-program then produces data that is plotted by the Hewlett-Packard 2932A printer.

A second approach is to use the scope to digitize the waveform but not average the values. In this mode of operation, each incoming pulse and its associated noise are immediately digitized and passed on to the computer. At the computer, a cross-correlation routine is used to extract the

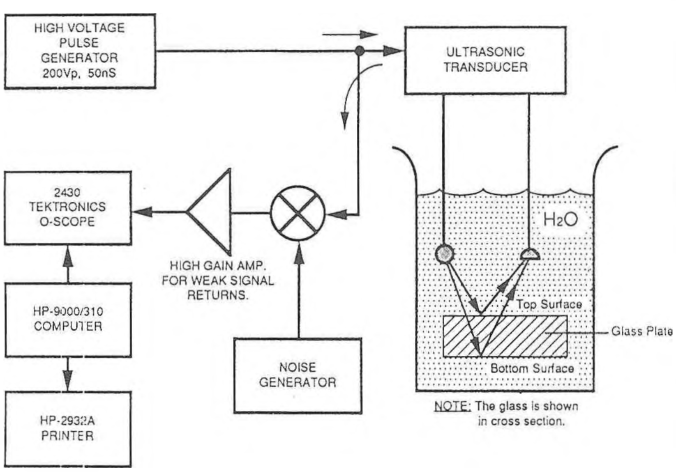

Figure 1. Equipment schematic.

pulse from the noise. Originally it was felt that this powerful computer could extract the pulse from the noise more rapidly than the scope could perform the averaging function. Both modes of operation were examined. Various software configurations were tested to examine the time required to complete the acquisition, transmission and display (or printout) task. Using the scope to perform the averaging function yielded the faster overall processing time. Data acquisition of a single plotting point consisting of 256 "pings" per location, the averaging of the data by the scope, transmitting the averaged data to the computer and finally the plotting of the point required an approximate time of 0.6 seconds.

This article provides some of the coding that was developed and describes the "pitfalls" that were encountered. For example, the computer-scope interface requires that the End Or Identify (EOI) status switch be set (manually) as opposed to use of a simple line feed (LF) recognition command.

Also the scope front panel switch settings and scale factors (volts per centimeter, seconds per centimeter) are transmitted from the scope to the computer in a single ASCII string. This string must be included in the plotting sub-program and accurately transmitted to the printer to enable correct scale factors to be printed.

Structured programming, wherein each major task, such as interrogating the scope or plotting the data points, is written as a sub-program. With a library of sub-programs, new research tasks can be solved more readily.

Before operation, the IEEE-488 bus address for each device must be established. Most Hewlett-Packard programmable test equipment contains rear panel mounted dip switches. One of the functions of these switches is to enable the user to set the address of the unit. The Tektronix 2430 oscilloscope address is set as a second level setting from a scope front panel switch. For each of the enclosed sub-programs, the scope address used was "30" or more completely "730".

For the waveforms shown in Figures 2 through 7, the following descriptors are used:

from Figure 3...

"1 Sep 1988, 12:14:52" => Date and time that the data was acquired.

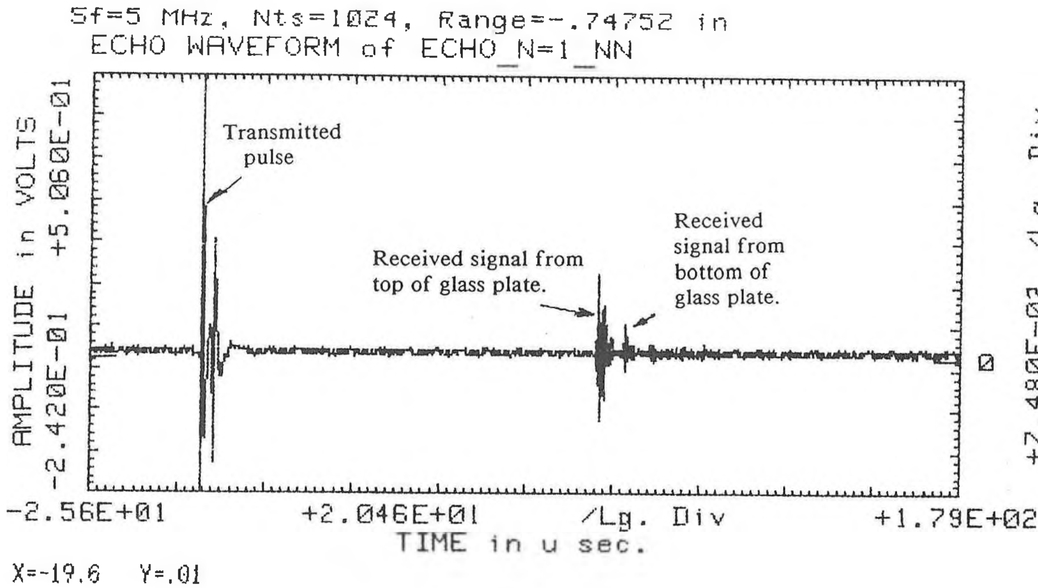

Figure 2. Signal With No Noise.

"sf = 5 MHz" => Rate at which the Tektronix 2430 Oscilloscope is sampling the incoming data.

"Nts = 1024" => Number of equally spaced (in time and spatially for the scope raster display) of eightbit sample points used by the Tektronix Scope.

"Range = -.74752 in" => With the outgoing energy pulse as a reference, the "range" represents the distance from the beginning of the trace to the left hand edge of the waveform portrayed on the screen.

"Echo waveform of ECHO-N=256-WN" => "Echo-N"is name of file where data representing the 256 individual points to be averaged at a specific location on the displayed waveform, is stored.

Figure 2 is a computer generated printout of a series of captured transmitted, reflected and received ultrasonic waveforms. The burst shown on the left of the waveform, is the outgoing "ping" from the transducer. The second burst (on the right) is the captured received waveform. It should be emphasized that although the waveforms shown appear to be singular, they are representative of the result of the scope's averaging of 256 bursts. Of course, when there is noise present, the more outgoing bursts that are employed, the more well defined the portrayed data will be. Figure 3 is an expanded view of the captured, received waveform of Figure 2 using the delayed trigger oscilloscope mode and an increased sampling rate of 100MHz.

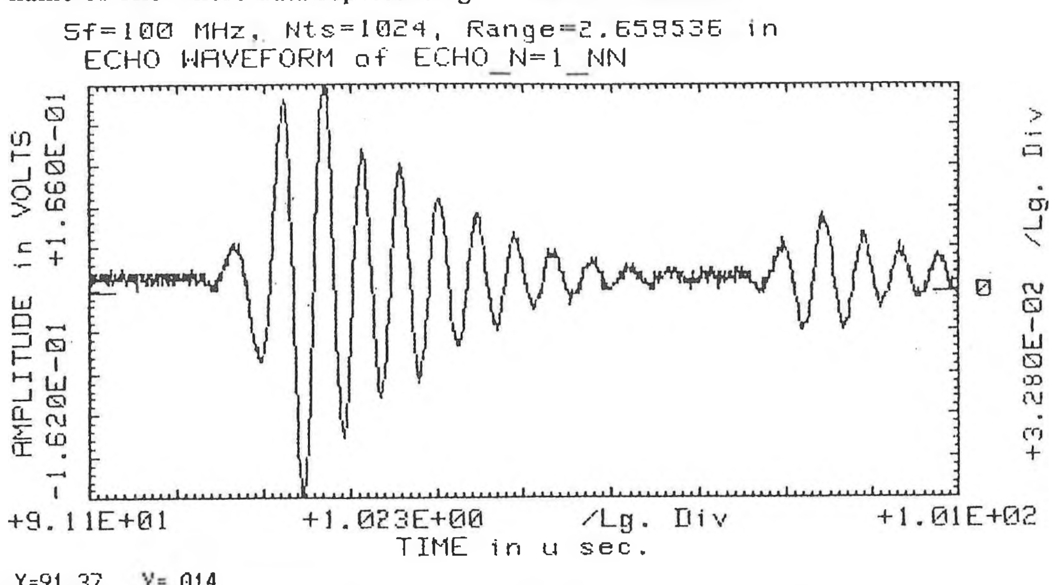

Figure 3. Expanded view of received pulse.

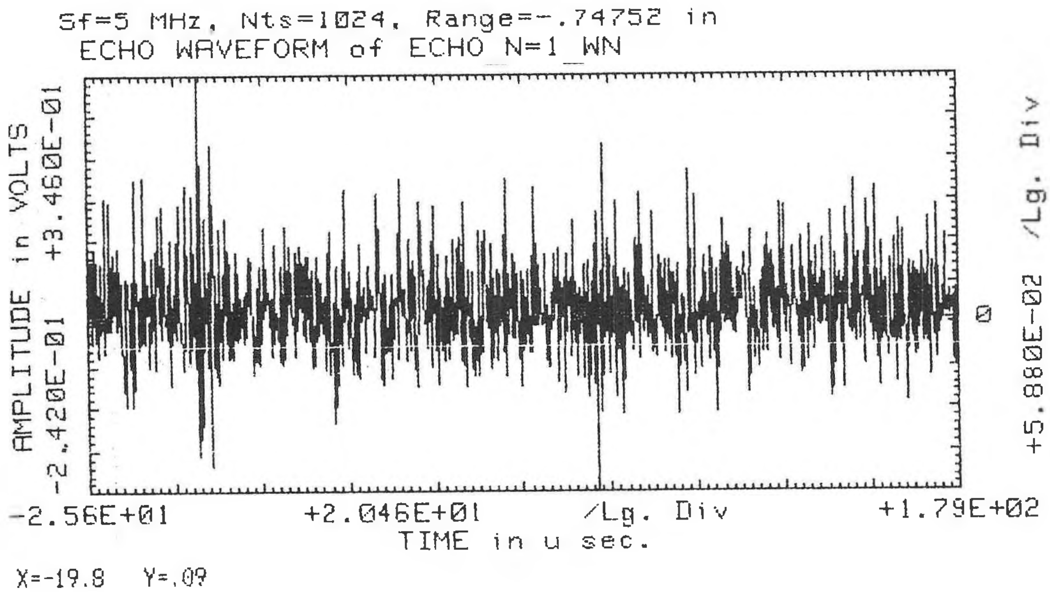

Figure 4. Outgoing and incoming pulses with noise.

Figure 4 is similar to Figure 2 with the exception that the computer printout is displaying both the captured, transmitted and received waveforms along with noise that has been deliberately introduced into the system. The purpose of the introduced noise is to stimulate the actual operating conditions under which a transducer may be employed. For the data displayed in Figure 4, the ratio of the peak transmitted "ping" signal (measured in volts-peak) to R.M.S. noise is approximately 0.3, i.e. Vsp/VN R.M.N. 0.3.

Figure 5 is a computer generated printout of the captured , received waveform. The time scale has been expanded considerably. We note that with the number of samples taken and the undesirable signal to noise ratio, the received signal is still discernable.

Figure 6 and 7 are the results of repeating the experimental procedures of Figures 4 and 5 with the excception that the sccope has been programmed to sample, store, and average the data from the 256 waveforms before forwarding these data to the somputer for curve plotting.

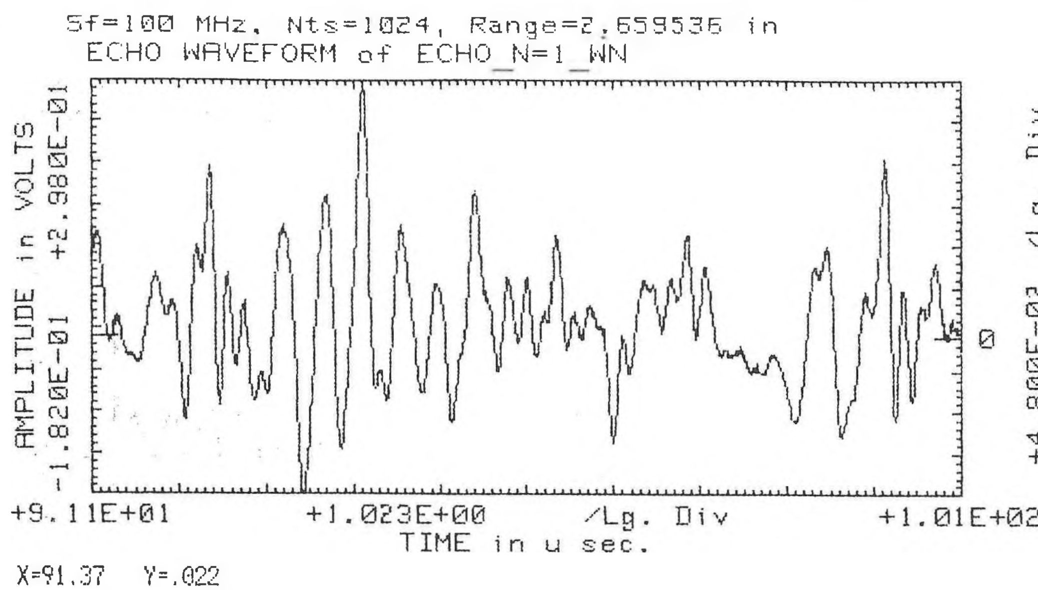

Figure 5. Expanded and received pulse with noise.

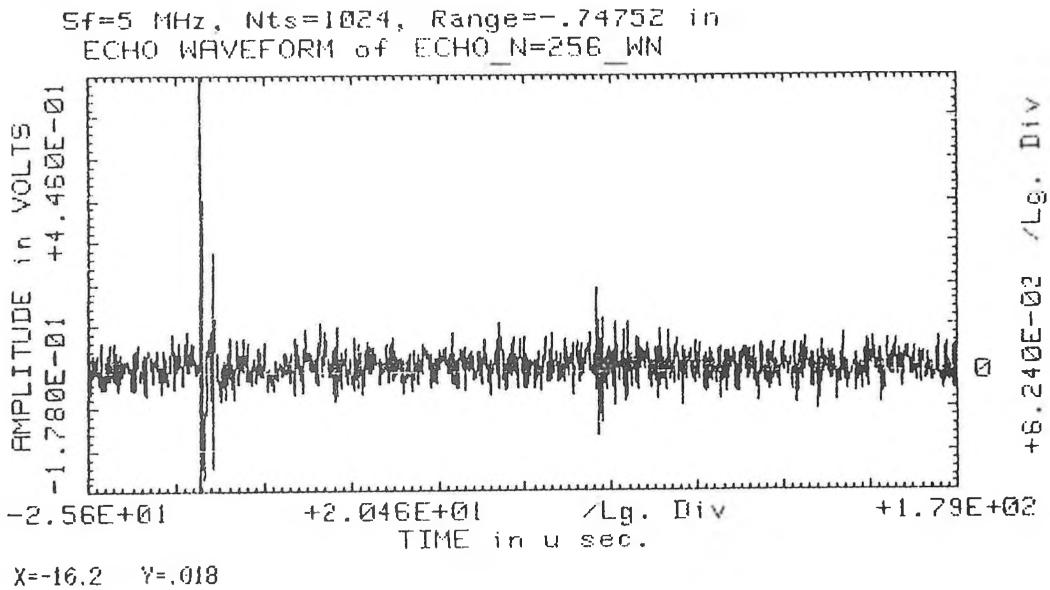

Figure 6. Averaged transmitted and received pulse.

We note that that the signal-to-noise ratio has improved by a factor of 256 as compared with data displayed in Figures 4 & 5. The reflected wavelets can now be distinguished within the residual noise.

To assist any reader who may be contemplating a similar interconnection of a Tektronix 2430 oscilloscope to a Hewlett-Packard 9000\300 computer, the following programming subroutines are provided. This code was written in Hewlett-Packard BASIC. The name given to the subroutine performing the transfer of the data from scope to computer is "Rb_scope1."

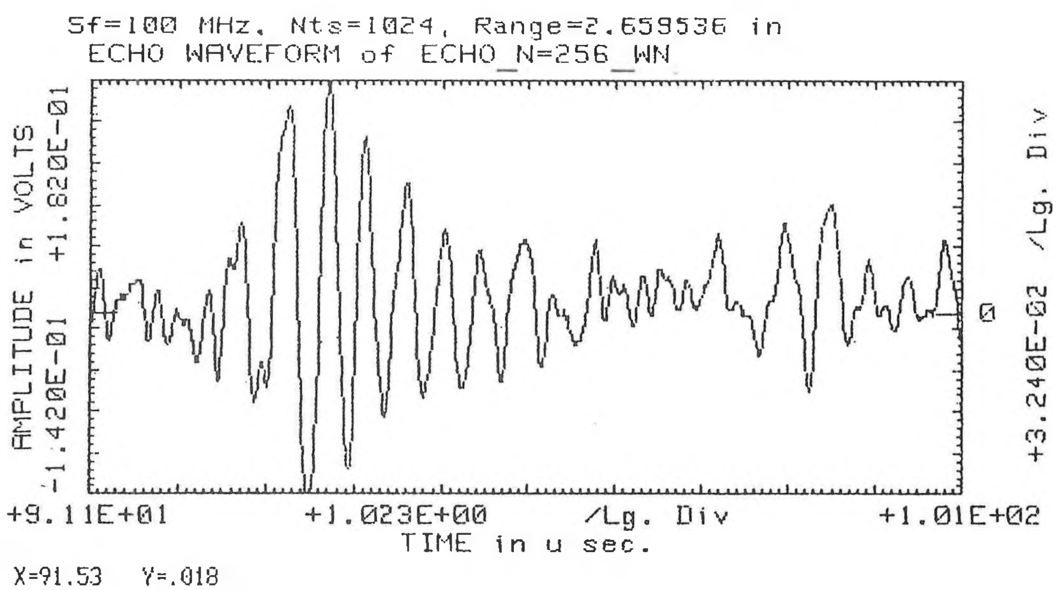

Figure 7. Expanded presentation of averaged, received pulse.

```
10     SUB Rb_scope1(Ydat(*),Np,Ton,Tinc)
20     !
30     ! Ydat(*)= CHAN. #1 VOLTAGE DATA ARRAY
40     ! Np=Number of sample points DATA FORMAT IS BINARY
50     ! Ton=ONSET TIME of the waveform in sec. MEASURE FROM the TRIGGER
60     ! Tinc=Time between sample points
70     !
80     !
90     ALLOCATE W$[160],H$[80],T$[80]
100    INTEGER I,J,K,Dlen
110    !
120 ASSIGN @Scope TO 730;FORMAT ON ! SYMBOLIC ADDRESS FOR TEK. 2430 SCOPE
130 !
140 ! INITIALIZE THE SCOPE
150 !
160 CLEAR @Scope
170 OUTPUT @Scope;"DEBUG ON"
180 OUTPUT @Scope;"DATA ENC:ASC"   ! GPIB FORMAT IS ASCII
190 OUTPUT @Scope;"DATA SOURCE:CH1"   ! SELECT CH. #1 FOR DATA SCURCE
200 !
210 !
220 OUTPUT @Scope;"DLYT DEL:OFF"
230 OUTPUT @Scope;"DLYE MOD:OFF"
240 !
250 OUTPUT @Scope;"PATH ON"
260 OUTPUT @Scope;"WFM?"   !Returns scope switch settings to computer
270 ENTER @Scope;W$
280 !
290 X=POS(W$,"XINCR:")
300 X=X+6
310 Xs=POS(W$,",YMULT:")
320 Xa$=W$[(X);(Xs-X)]
330 Tinc=VAL(Xa$)       ! TIME INTERVAL BETWEEN SAMPLE POINTS
340 !
350 Y=POS(W$,"YMULT:")
360 Ya$=W$[(Y+6);8]
370 Ymult=VAL(Ya$)   ! Y  SCALE FACTOR TO CONVERT SAMPLE VALUSE TO VOLTS
380 !
390 Yof=POS(W$,"YOFF:")
400 Yofe=POS(W$,",YUNIT:")
410 Yoff$=W$[(Yof+5);(Yofe-(Yof+5))]
420 Yoff=VAL(Yoff$)    !  VALUE Y OFFSET DUE TO POSITION KNOB
430 !
440 T=POS(W$,"PT.OFF:")
450 Tend=POS(W$,",PT.FMT:")
460 Tr$=W$[(T+7);(Tend-(T+7))]
470 Ntrig=INT(VAL(Tr$))   !  MARKING THE  LOCATION OF TRIGGER IN MEMORY
480 !
490 OUTPUT @Scope;"PATH OFF"
500 OUTPUT @Scope;"DLYT? DLY1"
510 ENTER @Scope;T$     ! DELAY VALUE IN SEC.
520 !
530 OUTPUT @Scope;"HOR? MOD"
540 ENTER @Scope;H$    !  SWEEP MODE
550 OUTPUT @Scope;"PATH ON"
560 !
570 Ton=-Ntrig*Tinc
```

```
580 IF H$="BSWEEP" THEN Ton=VAL(T$)-Ntrig*Tinc  ! IF IN DALAY SEEP ADD TH
590 !
600 Np=1024 ! # OF DATA POINTS
610 !
620 !  NOW BRING IN THE DATA
630 !
640 Nb=1036 ! NUMBER OF BYTESTS TO BE TRANSFERED
650 INTEGER Temp(520) BUFFER
660 ASSIGN @Buff TO BUFFER Temp(*);BYTE
670 RESET @Buff
680 !
690 OUTPUT @Scope;"DATA ENC:RIB"
700 OUTPUT @Scope;"CURV?"
710 ASSIGN @Scope TO 730;FORMAT OFF
720  T1=TIMEDATE
730 TRANSFER @Scope TO @Buff;COUNT Nb,WAIT
740 T2=TIMEDATE
750 ASSIGN @Scope TO 730;FORMAT ON
760 OUTPUT @Scope;"DATA ENC:ASC"
770 !
780 !PRINT "TIME=";T2-T1
790 !
800 T3=TIMEDATE
810 GOSUB Unpack
820 T4=TIMEDATE
830 !PRINT "TIME TO UNPACK=";T4-T3
840 !
850 DEALLOCATE W$,T$,H$
860 GOTO 1060
870 !
880 !
890 Unpack: !
900         X=Yoff*256
910         Y=Ymult/256
920         J=4
930         FOR I=0 TO 1022 STEP 2
940         Ydat(I)=Y*(SHIFT(Temp(J),-8)-X)
950         J=J+1
960         NEXT I
970         !
980         J=5
990         FOR I=1 TO 1023 STEP 2
1000        Temp(J)=ROTATE(Temp(J),8)
1010        Ydat(I)=Y*(SHIFT(Temp(J),-8)-X)
1020        J=J+1
1030        NEXT I
1040        !
1050        RETURN
1060 SUBEND
```

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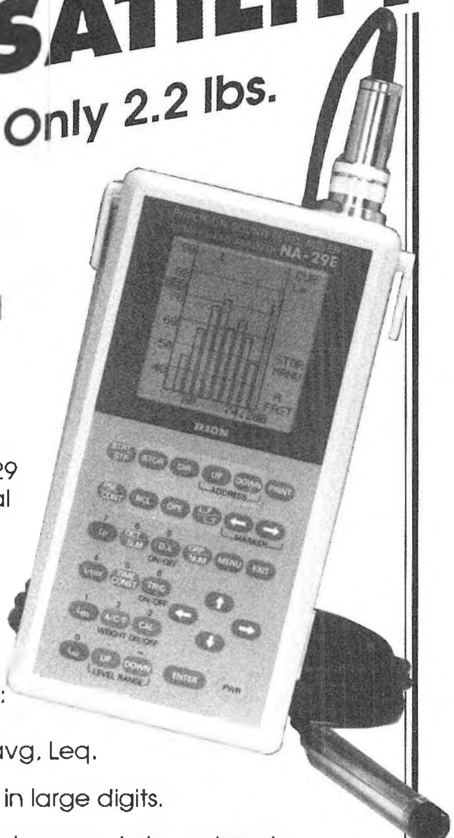

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