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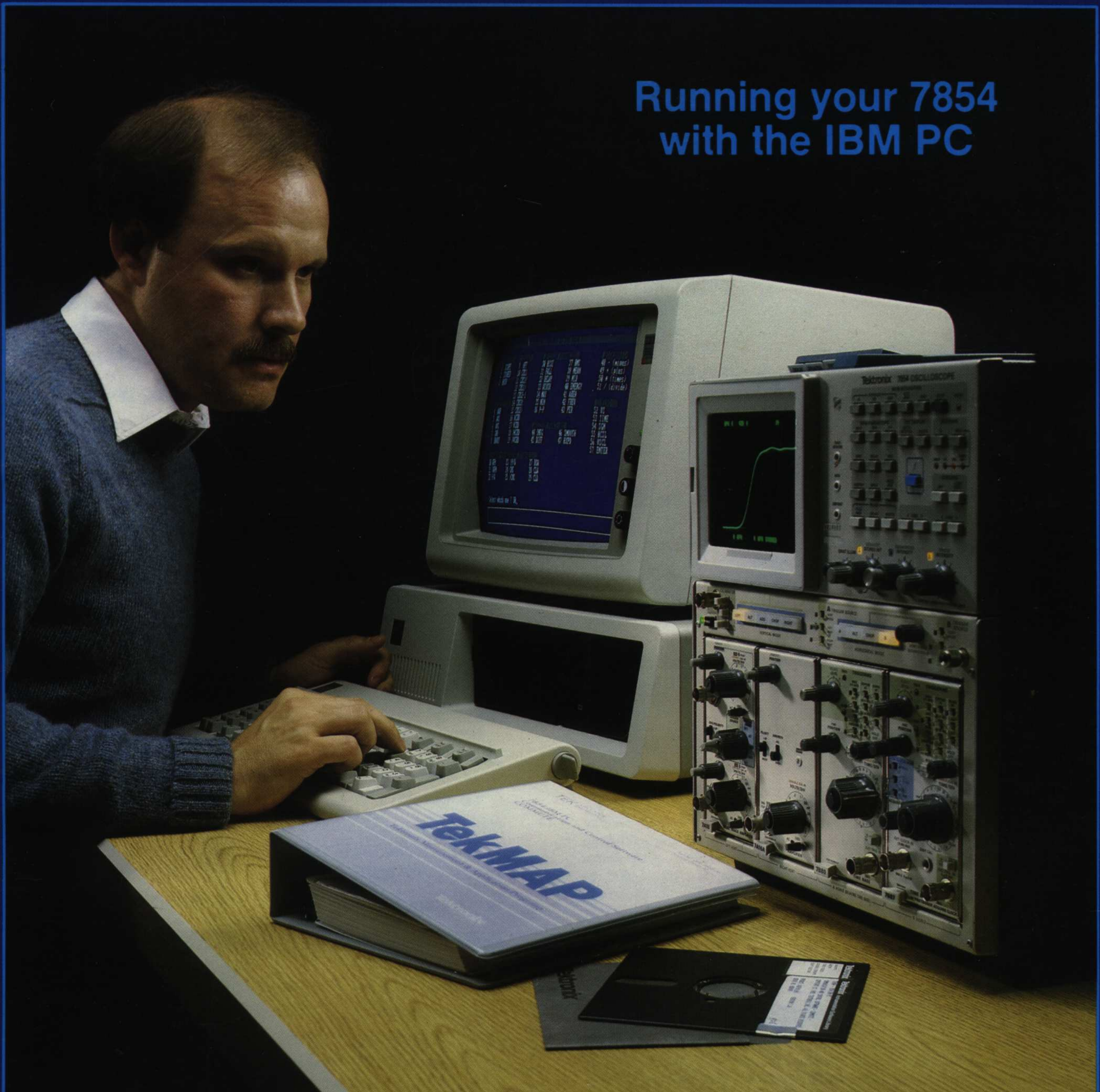
NEWSLETTER OF SIGNAL PROCESSING AND INSTRUMENT CONTROL



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Application Note details IBM PC/7854 operation

The 7854 Waveform Processing Oscilloscope has a lot of power and versatility built into it. Included in this is GPIB (IEEE 488 Standard) interfacing. This capability along with the prevalence of IBM PCs makes it natural to want to add off-line computing and storage power to the 7854.

If you have a 7854 and are wondering about using it with an IBM PC, you'll be interested in obtaining a copy of **BASIC Software Programs for Communicating Between the 7854 and IBM PC.** This Tektronix Application Note (42W-5802) covers interface and software installation in the IBM PC and then goes on to explore several BASIC programs for establishing communications between the PC and the 7854.

Programs listed in the application note include a Main Line Program with menu selections to—

- save 7854 programs on disk
- load 7854 programs from disk
- save 7854 waveforms on disk
- send waveforms from disk to 7854
- display saved waveform on PC monitor
- send text to the 7854 screen
- send command string to 7854
- get X register data from 7854
- send data to 7854 X register
- exit to BASIC

Routines to support all of these menu selections are also listed in the application note.

To obtain a copy of this application note, use the reply card in this issue of **HANDSHAKE** or contact your local Tektronix Field Office and request Application Note 42W-5802, **BASIC Software Programs for Communicating Between the 7854 and IBM PC.**

Using your 7854 Waveform Processing Oscilloscope with the IBM PC

Bob Ramirez
HANDSHAKE Staff

Although the 7854 Waveform Processing Oscilloscope has been available for several years, it is still one of the most advanced laboratory quality digital storage oscilloscopes (DSO) on the market. It has the flexibility to be operated either as a standard analog oscilloscope or as a DSO. And, as a DSO, it has a wide variety of built-in processing functions available at the touch of a button. It also has the distinction of being programmable from an attached keyboard (see Fig. 1). This allows individual 7854 operations to be combined into multiple line programs that can be stored and executed at will. In short, the 7854 is essentially a self-contained signal acquisition, storage, and processing system.

But, as with anything, there is always something more that can be done. In the case of the 7854, adding an external computer via the GPIB (IEEE 488 standard interface) is a powerful extension of 7854 capabilities. And, with IBM PCs and compatibles gracing more engineering and lab benches, PCs are becoming a popular choice as economical instrument controllers.

While a PC seems a natural choice, since they're so available and you don't have to cost justify a specialized controller, there are some tradeoffs to be aware of. First of all, the simplest systems to deal with are preconfigured systems. These are the systems of instruments, interfaces, instrument controllers, and instrument control and measurement processing software that have been completely integrated and configured by a single vendor. The system's component and compatibility bugs have already been resolved for you. Plus you get the benefits of full system warranty, system documentation, and system support. And, finally, specialized instrument controllers are, by and large, faster and more powerful than personal computers.

Nonetheless, PCs remain attractive alternatives for instrument controllers. They're a good low-cost preliminary controller for feasibility studies and prototyping. They also become more attractive as controllers for instruments that do their own specialized measurement processing internally, such as the 7854 Waveform Processing Oscilloscope. For such instruments, a PC makes good economic sense for simply uploading and downloading instrument programs, for permanent waveform storage, and for logging measurement data.

Extending 7854 features with the PC

As mentioned earlier, the 7854 Waveform Processing Oscilloscope contains substantial built-in waveform acquisition and processing features. Examining the Waveform Calculator keyboard shown in Fig. 1 provides an overview of some of these capabilities. After a brief look at how these capabilities operate, a look can be taken at some extensions available by interfacing an IBM PC to the 7854.

To summarize, the 7854 can acquire waveforms in several modes. These are indicated in Fig. 1 in the section labeled WFM ACQUISITION. The shifted function labeled AQS is for single-shot acquisition and storage. AQR is for repetitive waveform acquisition and storage. AVG selects the signal averaging mode, which allows you to average random noise off of repetitive signals.

As a simple example of Waveform Calculator use, consider digitizing and storing a noise-ridden signal. Signal averaging, using the AVG button, cleans the signal up

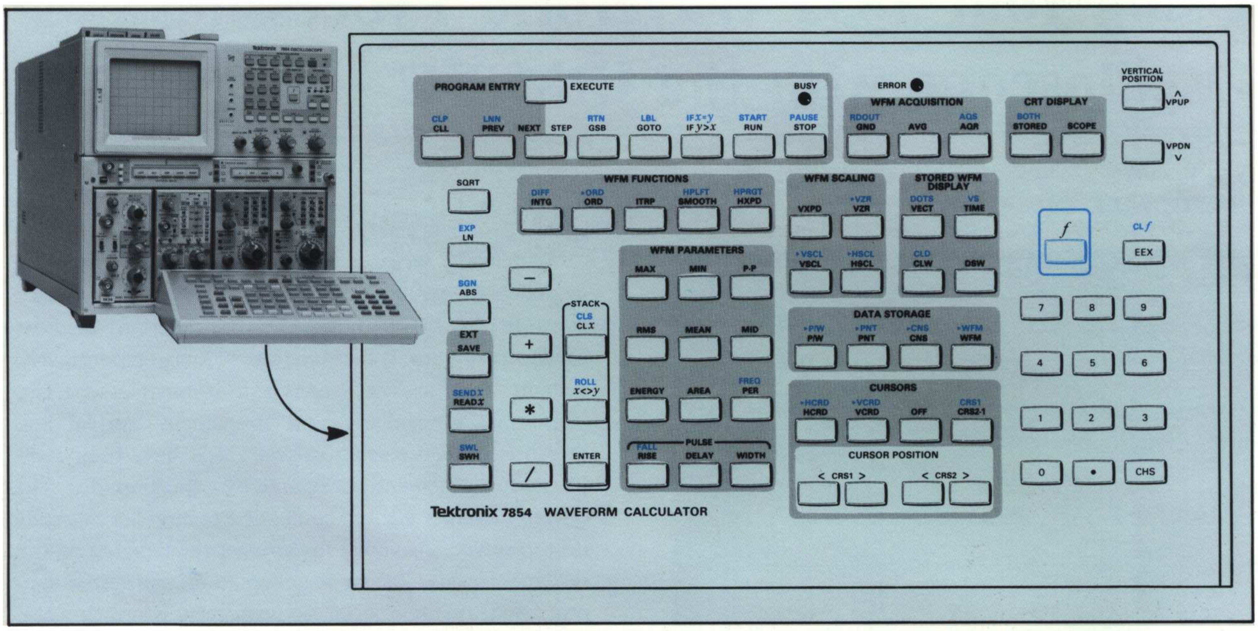

Fig. 1 *The 7854 Waveform Calculator keyboard provides access to a substantial amount of processing internal to the 7854.*

by acquiring multiple copies of the repetitive signal and computing an average waveform. The more averages done, the more noise reduction. For example, to store a waveform composed of 128 averages, simply use the numeric keypad to enter 128, and then press AVG. The signal will be average 128 times and stored in the operational waveform memory.

Once the signal is stored, further calculations on the signal can be done. For example, pressing the MAX key in the WFM parameters section causes the maximum value of the stored waveform to be found and displayed on screen. MEAN causes the mean value of the stored waveform to be found and displayed. Or you can integrate or differentiate the waveform by using the INTG or DIFF operations in the WFM FUNCTIONS section.

More complicated operations will, of course, require more keystrokes and can involve several waveform memory locations. Consider, for example, computing the delay between two pulses, one pulse being the input to a device and the other being the output. Each pulse is first acquired and stored into a different waveform memory location. Let's say the input pulse is placed into location 1 WFM and the output in 2 WFM. Then to compute the 50% level delay between the two pulses, you could enter the key sequence of:

2 WFM DELAY 1 WFM DELAY —

Basically, this sequence means: call up the waveform in 2 WFM, compute its delay or shift from the left edge of the screen (or the cursor 1 position if the cursors are on) and push the delay value onto the constant stack. Then call up 1 WFM, compute its delay value and put it onto the stack. And finally the minus sign causes the difference between the two delay values to be computed, giving the delay between the stored waveforms.

In the above example, notice the similarity of the 2 WFM DELAY 1 WFM DELAY — key sequence to a program line. Indeed, it can be stored in 7854 memory as a program line by using the keys in the PROGRAM ENTRY section of the 7854 Calculator Keyboard. Multiple key entries can be worked out and stored as multiple line programs in 7854 memory for repeated execution of complex measurement sequences. The EXECUTE section of the Calculator Keyboard even allows decision and branching operations to be included in 7854 programs.

Basically the Waveform Calculator keyboard also serves as a special waveform processing terminal. Commands can be executed one by one in an immediate mode, or they can be strung together in a program for batch execution.

There is still, however, another option. The calculator key commands can also be executed over the GPIB bus from an interfaced computer, an IBM PC or compatible for example. A key sequence like 100 AVG can be sent to the 7854 as a GPIB message for execution by the 7854.

But more important applications of the computer interface stem from the fact that the 7854's waveform and program storage memory is volatile. Turn the power off, and the stored waveforms and programs are lost. This is especially troublesome if your 7854 programs are very extensive because it means rekeying the entire program the next time you need it, an operation which we all know is rarely done without some keying errors. However, with an IBM PC interfaced to the 7854, you can upload and download 7854 programs and waveform data as needed.

You won't ever have to rekey important 7854 programs since they can be accessed from the PC's floppy or hard disk. The same is true for waveforms used as standards for comparison. They don't have to be regenerated and reacquired before each measurement session since they can be kept on floppy disk and reloaded into the 7854 whenever needed. You also have the further option of using PC software to generate idealized waveforms for display or use as standards of comparison in the 7854. Another useful feature is the ability to use word-processing editors for modifying 7854 programs in PC memory. Full screen editors, as long as they are used in an ASCII text mode instead of a formatting mode, are much more convenient than program or line editors for changing ASCII-coded programs.

Of course, you also have the option of writing your own PC-based signal processing routines and using them on waveform data transferred to the PC from the 7854. In general, it's better to perform waveform processing in the 7854 using the 7854 processing features. It's faster, for example, to compute the mean of a waveform with the 7854 MEAN function and transfer the single mean value to the PC than it is to transfer a 1024-point waveform over the bus and compute the mean in the PC with BASIC. However, there may be special purpose operations or statistics that you need which are not part of the 7854's general-purpose repertoire. In this latter case, an interfaced computer becomes a natural extension of the 7854's computational capabilities.

GURU links IBM PC with Tek instruments

The GPIB interface board conforms to IEEE Standard 488, and the GURU software consists of a set of programs and utilities designed to help you establish communication between your IBM PC and instruments connected to the GPIB.

For those not familiar with GPIB operation, the GURU manual contains an overview of the interface and a complete tutorial on setting up an instrument control system. Also, the major programs, such as IBCONF (Interface Bus CONfigure), are menu driven with prompts for your input to the system. The GURU manual and example programs span from a beginner's tutorial, through system program development with MICROSOFT BASIC, to advanced uses with a test procedure generator tool.

GURU is an acronym for GPIB User's Resource Utility. More than that, though, it's a complete package for establishing communication between measurement instruments and the IBM PC or compatibles. With GURU, you will be able to use your IBM PC as an instrument controller for programming measurement instruments and acquiring measurement data for further processing or analysis.

The GURU package comes complete with:

- GPIB interface board
- GPIB cable
- GURU software with manual

If you are just getting started in GPIB instrument control, GURU can save you endless hours of frustration and dead ends. Yet GURU is open-ended for those with GPIB experience. Its variety of utility routines and application examples allow you to progress quickly to more complex test and control operations.

For more information on GURU, contact your local Tektronix Sales Engineer or the Tektronix Sales Representative for your country. To obtain a data sheet on GURU, simply use the reply card in this issue of **HANDSHAKE.**

General interfacing considerations

Recognizing the potential benefits of interfacing a personal computer to the 7854 Waveform Processing Oscilloscope is one thing. Actually accomplishing the interfacing can be quite another.

Choosing a PC interface board is the first step. There are a number of GPIB (IEEE 488 Standard) interfaces for the IBM PC on the market. The methods and degrees of implementation vary from manufacturer to manufacturer. To be safe, it's best to start by looking at GPIB boards offering the fullest implementation of the IEEE 488 standard. As a guide of what to look for, a two-part **EDN** magazine article reprint on the IBM PC in ATE is available from Tektronix. Simply use the reply card in this issue of **HANDSHAKE** to request your free copy.

Advanced instrument controllers and software from Tektronix

Each system component is also individually covered by its own Tektronix warranty.

Tektronix measurement systems are based on two types of controllers.

For larger systems, there is the DEC MICRO/PDP-11 with 128K words of internal memory. Peripheral storage is provided by a built-in 10M-byte Winchester disk and a dual 5.25-inch flexible diskette drive. Depending on available slots in the MICRO/PDP, up to four GPIB interface boards can be supported. This means control of up to 56 GPIB instruments using the TEK SPS BASIC software supplied with the system. TEK SPS BASIC provides high-level instrument control and complete waveform processing, including FFT, convolution, correlation, and other advanced processing features. Full waveform graphics capability is also supplied.

Measurement packages can also be based on the Tektronix 4041 System Controller. This is a very compact controller that fits easily on a desk or bench top or that can easily be carried from site to site. It is a specialized instrument controller that operates on ROM based 4041 BASIC. Two GPIB interfaces can be supported by this high-level software, which includes many waveform processing routines. Advanced waveform processing and graphics routines are also supported by optional ROM packs.

Tektronix manufactures a variety of Digital Storage Oscilloscopes and Transient Waveform Digitizers. These instruments can be purchased stand alone or configured in packages with Tektronix supplied controllers and software. The factory-integrated measurement systems come with:

- On-site installation
- Training credit
- System check-out software
- 90-day, on-site system warranty

For complete information on available systems and controllers, contact your local Tektronix Sales Engineer and ask for the **Systems that Put You in Charge** brochure. Or request the brochure using the reply card in this issue of **HANDSHAKE**.

One word of caution, however. Since the article was printed, many IBM PC board manufacturers have enhanced the capabilities of their GPIB boards. Still the article reprint serves as a good guide of what to look for and what to be aware of.

Once you've purchased a GPIB board, there's the matter of installing it and establishing communication between the PC and the 7854. The documentation supplied with the board will help you with this, but the information will, of necessity, be quite general regarding instrument attributes. To help you over these initial installation quandries, Tektronix offers a package called GURU (see "GURU links IBM PC with Tek instruments") that includes a National Instruments interface card for the PC, a GPIB cable, configured software, and several levels of program generation and support software designed specifically for communicating with Tektronix instruments.

Perhaps you already have a National Instruments card or simply want to develop your own software as a learning experience or for proprietary reasons. To get you started, Tektronix has produced an application note entitled **BASIC Software Programs for Communication Between the 7854 and IBM PC,** which is available via the **HANDSHAKE** reply card. Complete installation details are provided in this application note as well as listings of BASIC routines for transferring 7854 programs to the IBM PC and storing them on disk, retrieving programs from disk and sending them to the 7854, sending and receiving waveforms, and graphing waveforms on the IBM PC monitor. Figure 2 lists one of the programs from the application note to give you an idea of the depth of coverage provided as well as the task facing you if you decide to undertake program development from scratch.

COMMUTE, a ready made approach

Rather than hand enter all of the IBM BASIC programs listed in the Application Note **BASIC Software Programs for Communication Between the 7854 and IBM PC,** you may prefer to obtain the programs on media. To serve this requirement as well as provide several enhancements, Tektronix has created a software program called **7854 to IBM-PC Utility Communication Software,** referred to as COMMUTE for Communication Utilities.

COMMUTE is a menu-driven package that performs the major 7854/IBM PC data transfer operations for you. Figure 3 shows COMMUTE's main menu which allows selection of operations such as waveform, data, and program transfer between the 7854 and the IBM PC. Additionally, there is a selection for graphing waveforms from disk onto the IBM PC screen. Each Main Menu selection takes you into a second menu which provides options for the selected operation. For example, the Display Waveform menu allows you to send the graphed

```
3000 REM ! ! Gets waveforms from 7854 and stores them on disk
3010 ' lines 3010 to 3100 prints title of routine, lists programs on disk, and
gives user an option of returning to main menu.
3020 CALL IBCLR(DSO%)
3030 CLS:LOCATE X+8,1:PRINT STRING$(80,205):LOCATE X-1,1:COLOR 0,7:PRINT
STRING$(240,32)
3040 LOCATE X,Y:PRINT "TRANSFER 7854 WAVEFORM TO THE DISK":COLOR 7,0
3050 LOCATE X+10,Y:ON ERROR GOTO 9510:FILES "*.WFM":LOCATE X+16,1:PRINT "
 THESE WAVEFORMS EXIST ON DISK"
3060 LOCATE X+8,Y+10:PRINT " 7854 W A V E F O R M FILES "
3070 LOCATE 25,1:PRINT "COMMANDS:  <C>ONTINUE    <M>AIN MENU ";
3080 Q$=INKEY$:IF Q$="" THEN 3080
3090 IF Q$="C" THEN 3120
3100 IF Q$="M" THEN RETURN
3110 GOTO 3080
3120 LOCATE 25,1:PRINT STRING$(79,32);:LOCATE X+18,1:INPUT " INPUT FILE NAME
(without extension):",FILE$
3130 CLS:LOCATE 15,10 :PRINT "TRANSFERRING WAVEFORM . . . . . . . . . . "
3140 OPEN FILE$+".PRE" FOR OUTPUT AS #1
3150 OPEN FILE$+".WFM" FOR OUTPUT AS #2
3160 STA%=0
3170 I=1
3180 WRT$="0 WFM SENDX"               ' 7854 is asked to send 0 waveform
3190 CALL IBWRT(DSO%,WRT$)
3200 IF IBSTA%<0 THEN GOSUB 710
3210 RD$=SPACE$(95)
3220 CALL IBRD(DSO%,RD$)              ' the preamble is read first
3230 IF IBSTA%<0 THEN GOSUB 710
3240 PRINT #1,RD$;                    ' preamble is stored on disk (.pre file)
3250 CALL IBRD(DSO%,RD$)              ' waveform is then read in
3260 IF IBSTA%<0 THEN GOSUB 710
3270 PRINT #2,RD$;                    ' waveform is stored on disk (.wfm file)
3280 CALL IBRSP(DSO%,STA%):IF STA%=2 THEN 3320
3290 GOTO 3250                        ' if 7854 is not done then 3240
3300 ' user is given the option of getting another waveform or returning to
main menu
3310 CLS:LOCATE 10,10:PRINT "TRANSFER COMPLETE"
3320 LOCATE 25,1:PRINT "COMMANDS: <R>EPEAT  <M>ENU ";
3330 GOSUB 3380
3340 Q$=INKEY$:IF Q$="" THEN 3330
3350 IF Q$="R" THEN GOTO 3390
3360 IF Q$="M" THEN GOTO 3400
3370 GOTO 3340
3380 DEF SEG=0:POKE 1047,64:DEF SEG:RETURN
3390 CLOSE #1,#2:Q$="":GOTO 3000
3400 CLOSE #1,#2:Q$="":CALL IBLOC(DSO%):RETURN
```

Fig. 2. *BASIC program for transferring waveforms from the 7854 Waveform Processing Oscilloscope to the IBM PC via the National Instruments GPIB card.*

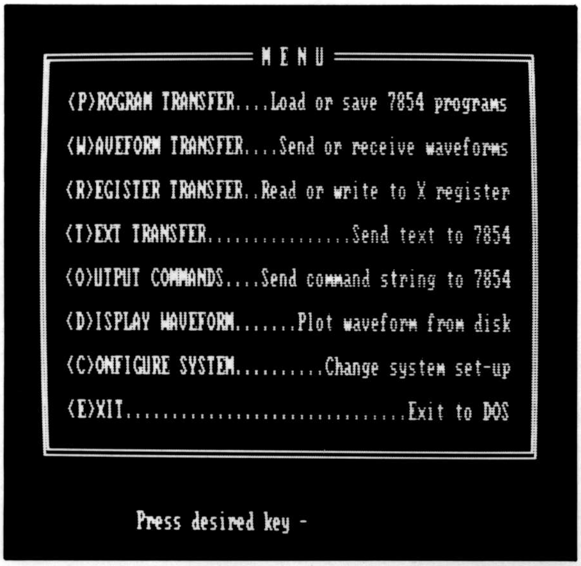

Fig. 3. *The COMMUTE Main Menu lists the major utilities that can be selected; secondary menus support each selection with further options.*

waveform to an IBM compatible dot matrix printer for a hard copy of your data.

Besides being a complete, fully documented software package that sets up 7854 to IBM PC communications for you, COMMUTE offers some further advantages. For example, while COMMUTE is written in IBM PC BASIC, the routines are compiled. This means COMMUTE will execute approximately ten times faster than the same programs in interpretive BASIC. This ten-times speed increase is a substantial advantage.

Another advantage is that you are supplied the COMMUTE source files. This means that you are free to list the programs and modify or extend them to meet special needs. You can run your modified programs as standard interpretive BASIC, but at some sacrifice in speed. Or you can recompile your modified programs to regain the ten-times speed advantage. For this latter approach, you'll need to obtain IBM's BASIC compiler (IBM Order Number 6024003).

Other requirements for using COMMUTE are:

- An IBM PC, XT, Portable PC, or compatible with 256K bytes of RAM, a double-sided, double-density disk drive, and IBM PC DOS Version 2.0 or higher
- GURU or a National GPIB-PC2 board, or equivalent, installed in the PC
- A 7854 Waveform Processing Oscilloscope with connecting GPIB cable

Further technical details, prices, and ordering information for COMMUTE are available from your local Tektronix Field Office. Outside of the US, please contact the Tektronix Sales Representative for your country. A COMMUTE Data Sheet can be obtained by returning the reply card provided in this issue of **HANDSHAKE**.

The next step

As mentioned at the beginning of this article, the IBM PC is a popular choice as an instrument controller for the 7854. To support this, Tektronix offers you a variety of resources, from magazine article reprints and Application Notes to complete software packages such as GURU and COMMUTE.

Also, realizing that personal computers cannot serve all instrument control needs, Tektronix maintains a selection of specialized instrument controllers and software that can be provided stand alone or in configured Waveform Processing Systems. These capabilities are briefly summarized in the box entitled **Advanced instrument controllers and software from Tektronix.** More information on these controllers and systems is available by using the **HANDSHAKE** reply card or contacting your local Tektronix Field Office.

IBM PC as an ATE controller covered in 2-part series

Can the IBM PC really be used as an instrument controller? Is it really effective for measurement data collection and processing?

The answers to these questions are yes...as long as you keep the tasks and controller capabilities in perspective. A recent two-part article series appearing in **EDN** magazine addresses some of the major issues of using the IBM PC in the instrument control and measurement processing environment. Both articles address the issues from a conceptual viewpoint as well as through actual programming examples.

"The IBM PC handles ATE applications," the first article in the series (**EDN**, Feb 7, 1985), covers the major instrument interfacing, control, and data transfer issues involved. Sample routines for instrument control and waveform transfer are included. The second part of the series, "Personal computer analyzes ATE measurements" (**EDN**, Feb. 21, 1985), focuses on processing measurement data. Example BASIC programs are provided for most standard operations such as finding waveform mean, RMS, and level crossings. For reprints of these articles, check the appropriate block on the reply card in this issue of **HANDSHAKE.**

Applications Guide details power supply and device testing

The flexibility of the 7854 Waveform Processing Oscilloscope is exemplified in a 30-page Applications Guide from Tektronix entitled **Power Supply/Device Testing.** This guide details test setups and provides 7854 program listings for a variety of power testing situations.

Section 1 of this Applications Guide briefly introduces power supply and device testing concepts with the 7854. Also included is a discussion of probe delay removal. Section 2 launches immediately into instantaneous power measurement. A switching-supply transistor is used for the example, and a 7854 program listing for power measurement is included.

The X-Y display capabilities of the 7854 are put to use in Section 3, which details measurement of Safe Operating Area for transistors. The program listing here is much more extensive. As a result, five full pages of flow chart and explanation are provided with the listing.

Magnetics in switching power supplies is the topic of Section 4. The purpose here is to measure power supply transformer losses. B/H curves are briefly reviewed, and then a test setup and a program for B/H measurements are given. Power supply output impedance versus frequency is covered in Section 5, and Section 6 closes the Applications Guide with a program for ripple and noise measurement.

To obtain a copy of this Applications Guide, check **Power Supply/Device Testing** on the reply card in this issue of **HANDSHAKE.** For more information on other applications of the 7854 Waveform Processing Oscilloscope, contact your local Tektronix Field Office or the Tektronix Sales Representative for your country.

Continuous automatic laser beam profiling

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This article and the work it covers were done under the auspices of the U.S. Department of Energy and the Defense Advanced Research Projects Agency.

Continuous, automatic laser beam profile measurements are of great value to the laser user. A method of providing these measurements has been developed in the Discharge Lasers and Applications group of the Chemistry Division, Los Alamos National Laboratory, using the Tektronix 7854 digital storage oscilloscope and a Reticon linear photodiode array. This method can be used as a single event device or continuously over long periods of time to monitor spatial stability.

The need to monitor laser output

One of the most common measurements performed on lasers and laser systems is the spatially resolved intensity distribution (beam shape and size). If the laser is a repetitively pulsed or chopped system, pulse duration also becomes a valuable and probably necessary measurement.

Due to the nature of certain types of lasers, the output beam characteristics can change rather rapidly. This is especially true with excimer and other lasers that are gas dependent. In the case of the excimer laser operating on static gas fills, the output energy, spatial intensity distribution, and pulse duration all degrade with increased age of the lasing gases. Also, as is the case with almost all lasers, many other factors such as temperature and voltage can change the output measurably.

Because of the nature of lasers and their continuously changing output characteristics, it is necessary to continually monitor their output for most laboratory applications. Depending on the laser and associated optics, this monitoring can be time consuming and sometimes quite laborious. This is where the Tektronix 7854 digital storage oscilloscope with associated waveform calculator can help.

Measuring laser beam shape

There are two automatic measurements that the 7854 can perform when programmed to do so and when coupled to the proper equipment. The emphasis here will be on the beam shape measurement. However, as will be seen later, the same technique can be applied under certain circumstances for doing pulse duration measurements.

To monitor the spatial intensity distribution continuously while the laser is being used for its primary purpose, a few percent of the laser light is diverted to an alternate route using a 5-degree wedge. The wedge transmits most of the laser light, but reflects a small percentage from each surface. From the wedge, each leg of the setup contains identical beam controlling optics. The final lens in the reference leg (reflected leg) is also the same as that in the higher energy leg. As a result, both beams are brought to focus at approximately the same distance from the wedge. This provides a low energy beam at the focal plane of the reference leg which is the same size and shape as in the high power leg. The spatial intensity distribution of the reference leg is proportional to that of the high-power leg.

To measure the beam size in the reference leg, a Reticon model 256G linear photodiode array with the proper filtration is used. This particular array has 256 individual diodes on 25-micron centers and is scanned at a rate of 2 kHz. The signal from this diode array is sent to the 7854 for analysis.

Figure 1 shows the 7854 program that performs the continuous, automatic profiling. The key in this program is proper cursor positioning. This is performed in lines

```
 000 BOTH 100 AVG STORED
 001 CRS1 MAX >VCRD
 002 CRS2-1 0 >HCRD
 003 CRS1 0 >HCRD CRS2-1
 004 P-P
 005 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
>006 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 007 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 008 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 009 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 010 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 011 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 012 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 013 VPUP VPUP VPUP VPUP VPUP VPUP VPUP
 014 PAUSE PAUSE
 015 2.7183 / >VCRD
 016 CRS1 VCRD + >VCRD
 017 CRS2-1 PAUSE PAUSE
 018 HCRD 2 / 25EEXCHS6 * 2 SQRT *
>019 1EEX6 *
 020 PAUSE PAUSE PAUSE PAUSE PAUSE
 021 PAUSE PAUSE PAUSE PAUSE PAUSE
 022 START
 023 STOP
```

Fig. 1. *7854 program for measuring laser beam shape.*

1, 2, 3, 4, 15, and 16. The mathematics involved is quite simple and is performed in lines 1, 4, 15, 18, and 19. The program starts by averaging 100 scans of the array. Then it does the measurements, performs the calculations, then resets and continues the loop until told to stop. Stopping the program is done simply by pressing the STOP key on the 7854.

The common method of describing the size (diameter) of a Gaussian or near-Gaussian laser beam is the width at the $1/e^2$ points of the intensity distribution curve. This is shown in Fig. 2. Since the array scan rate is 2 kHz and the spacing is 25 microns, 2 microseconds equals 25 microns. This calculation is performed in line 18 after the 1/e width is measured in microseconds. Multiplying this by $2^{1/2}$, also line 18, yields the proper $1/e^2$ width. This information is displayed in the bottom center location of the screen (in mm in this case). At the same time, a beep is sounded to cue the operator to look at the result. As can be seen, the program will automatically reset and start over unless it encounters a manual stop.

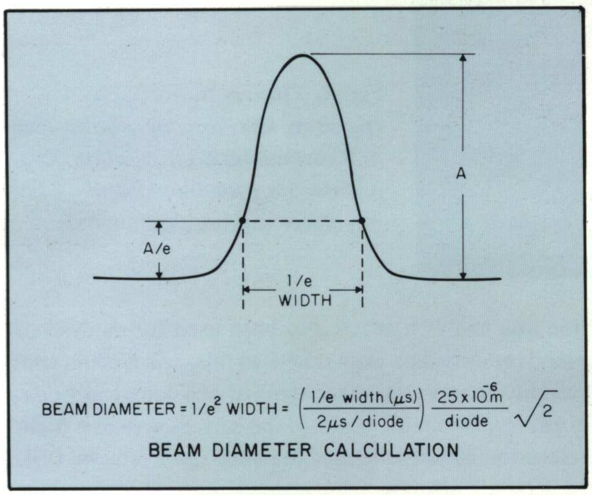

Fig. 2. *Laser beam diameter calculation.*

It is important to note that the program only works if the very first sampled point displayed on the 7854 screen is at the relative baseline of the pulse. This is very important because the 7854 cursor is positioned there to do the initial peak-to-peak measurement. However, as is typical of Reticon arrays, there is an undesirable pulse that appears at the beginning of each scan. This pulse has been carefully moved off screen to the left (using the 7854 horizontal position control) so that this initial pulse is not seen by the waveform processor. Figure 3 shows a typical display after one calculation.

The speed at which all of this is performed depends on the Reticon scan rate, 7854 sweep speed, repetition rate of the laser (or chopper), number of scans averaged, and many other factors. The program in Fig. 1 was

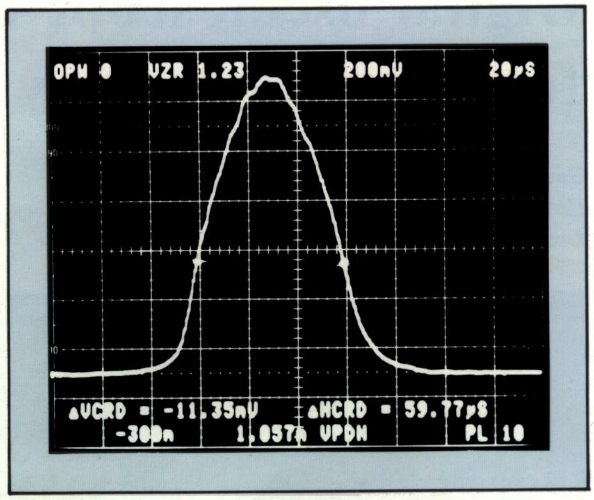

Fig. 3. *Screen output after one calculation (beam diameter = 1.057 mm).*

used with an excimer laser operating at 35 pps and yielded an answer about every 30 seconds. A fifteen second cycle can be achieved by eliminating some of the pauses and "VPUP"s.

Measuring pulse duration

For doing temporal intensity profiles (pulse duration), the program in Fig. 1 needs only slight modification. The standard method of describing pulse duration is by time duration at the full width at half maximum (FWHM). For this, line 15 is changed to "2.0/" instead of "2.7183/". Also, lines 18 and 19 need to be deleted. While the sampling rate of the 7854 provides the limiting factor, it is adequate for pulse measurements down to about 50 microseconds.

Overall, these methods of laser output monitoring over long times have proven very useful. Monitoring has been done over 8- to 9-hour days numerous times without any failures. Also, an upgrade is currently being considered to facilitate two-dimensional measurements. These are presently done by manually turning the array 90 degrees to get either vertical or horizontal measurements.

Digital oscilloscope teamed with mini for neurophysiology system

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Fig. 1. *The Tektronix 5223 Digitizing Oscilloscope, shown here in a rackmount configuration, is a popular tool for biophysical waveform capture and analysis.*

Neuroscientists are using mini- and microcomputers more and more in their work. In part, this is due to the on-line analysis capabilities now available with real-time data acquisition routines in languages such as BASIC, which are easily understood by nonprogrammers. Also, the availability of digital oscilloscopes for interfacing to such systems has captured the interest of physiology and pharmacology laboratories. These oscilloscopes, when interfaced to a small computer, provide flexible and efficient acquisition and analysis of electrophysiological data.

Such a system was developed by the author. The system consists of a Tektronix 5223 Digitizing Oscilloscope (see Fig. 1) interfaced to a DEC MINC 11/23 minicomputer. Software was written in real-time BASIC. This system has been used for analysis of action potential waveforms and spontaneous neuronal activity and serves as a good example of the type of analytic capabilities available for neuroscientists today.

Action potential measurements

The 5223/MINC system developed by the author has been used primarily for neurophysiological data acquisition and analysis. It has also been used for analysis of blood pressure data in anesthetized rats, and it could conceivably be useful in other areas of physiological study. However, the major thrust of the current system is high-resolution measurement of the inter-spike interval (ISI) of action potentials.

For action potentials, the ability to transfer stored waveforms back to the oscilloscope for display is quite useful. For example, the substantia-nigra zona-reticulata contains non-dopaminergic neurons having action potentials approximately 1000 microseconds in duration. But, as reported by Bunney et al. [1] and as shown in Fig. 2, action potentials from the nearby dopamine-containing neurons in the substantia-nigra zona-compacta are quite unique in their long duration of up to 3500 microseconds. As an aid to locating these unique dopamine neurons, the action potential from a previously recorded dopamine neuron can be transferred from the MINC to one channel of the oscilloscope and displayed for comparison to the real-time action potential.

The system is programmable in BASIC, and, given a MINC, does not require sophisticated electronic or pro-

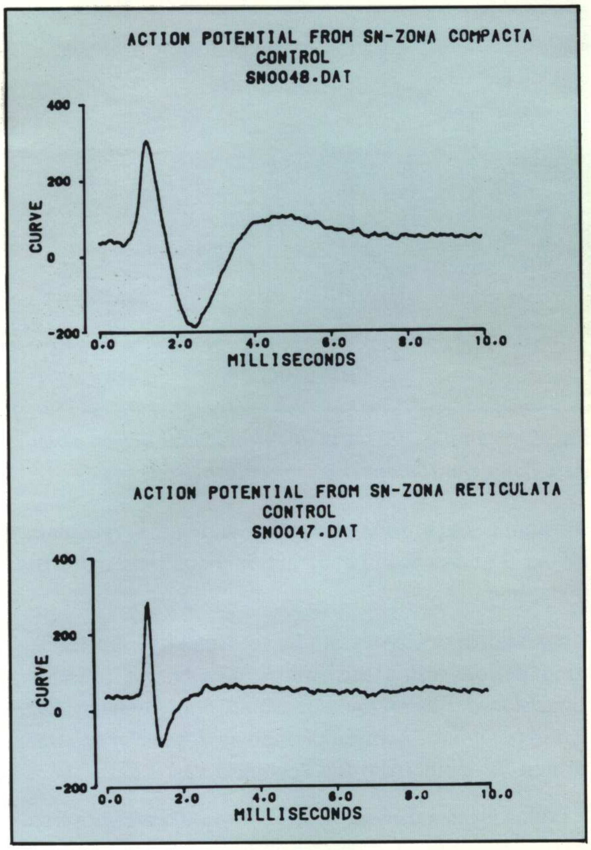

Fig. 2. *Examples of extracellular action potentials as digitized by the Tektronix 5223 Digitizing Oscilloscope and transferred to the DEC MINC 11/23 via an IEEE-488 interface and then to a DEC 11/70 with an interfaced plotter. At top is an action potential from a dopamine containing neuron in the substantia-nigra zona compacta of an anesthetized rat. At bottom is the action potential from the substantia-nigra zona-reticulata of the same rat.*

gramming skills to use or maintain. Also, by using a window-discriminator as an analog-to-digital converter, large amounts of memory are not required for storage and processing of data.

For analysis, a series of programs has been developed in MACRO-11 by Liebold et al. [2] for action potential interval measurements with the MINC. However, a MACRO-11 system requires a good deal more software expertise than MINC-BASIC and is also a moderately costly software upgrade on a MINC system. As an alternative, a set of programs has been developed in real-time BASIC. These programs—11-555 (SPON) and 11-536 (TEKSCP)—are available from DECUS.

A closer look at system components

The Tektronix 5223 Digitizing Oscilloscope, with a 5B25N digital time base plug-in, provides waveform capture facilities for the system. This dual-channel oscilloscope is both an analog and a digitizing oscilloscope, which allows it to serve a dual role in the laboratory. This also makes it an easy instrument to learn for biologists already familiar with conventional analog oscilloscopes. Another convenience is that the vertical and horizontal plug-ins for the 5223 can be interchanged with the other Tektronix 5000 series oscilloscopes commonly used in neurophysiology laboratories.

Waveforms are digitized to 10-bit precision with the 5223 and stored as integers, from -511 to 512, within the 1-kilobyte per channel memory of the oscilloscope. A complete display screen of 5223 data contains 1016 waveform points per channel. A digital delay is also available for viewing up to 100% of the signal prior to the trigger. Other viewing features of particular interest to neuroscientists include independent display of incoming analog and previously stored waveforms for each channel. For recording waveform data on paper, analog outputs of each channel's digitized waveform are available. A pen-lift feature allows data output to an analog plotter.

The IEEE-488 (GPIB) option was chosen for the 5223 to provide two-way communication with the system computer. All input and output functions and access to stored data are controllable via this interface.

A Digital Equipment Corporation MINC 11/23 was chosen as the system computer. Part of the selection criteria was based on a need for compatibility with other DEC CPUs in the research facility. Other considerations included the fact that the MINC is an on-line, real-time data acquisition computer for use in the laboratory environment. Ancillary equipment included a DEC VT105 graphic terminal, two RXO2 floppy disk drives, one clock module, and one digital input (DIN) module.

The operating system, MINC-BASIC V2.0, includes one-line commands for real-time data acquisition through analog and digital input modules. The MINC is also an IEEE-488 controller, and MINC-BASIC includes one-line commands for IEEE-488 communication.

Even though the MINC 11/23 controller and the 5223 Digitizing Oscilloscope are from different manufacturers, interfacing via the IEEE-488 interface was relatively easy. Hardware interfacing consisted of simply connecting a standard cable between the 5223 and the MINC. Software interfacing was equally simple.

Data output from the system took several forms. Hard copy output was obtained with a DECWriter III lineprinter connected to an RS-232 port on the MINC. Additional communication included an RS-232 port to a DEC 11/70 for hard disk or magnetic tape storage of files. A digital plotter was also available through the DEC 11/70. Data transfer to the 11/70 was in the form of ASCII data files and was done with the MINC Virtual Terminal Support program (DECUS 11-417).

Acquiring action potentials

Using methods described by Bunney et al. [1], the 5223/MINC system was used to acquire extracellular action potentials from several brainstem nuclei of anesthetized rats. A Finntronics WDR-420 amplifier/window discriminator was used in this process. The 1000X amplified action potential was input to the left vertical plug-in of the 5223 Digitizing Oscilloscope. Triggering of the oscilloscope was done from either the action potential spike itself or the acceptance pulse from the window discriminator.

Additional connections associated with action potential acquisition consisted of connecting the WDR-420 TTL-acceptable pulse output to bit 0 of the DIN on the MINC. In the case of more than one DIN unit, the WDR-420 pulse connection must be to DIN unit 0. Also, the "overflow" output from the clock module (CLK) connects to bit 1 of the DIN, and the 10-kHz CLK output connects to ST1 of CLK. In the case of 2 CLK units, these connections are made on CLK unit 1.

In acquiring action potentials, a unit of certain anatomical location and waveform class is typically desired. For example, action potentials from the dopaminergic cells of the substantia-nigra zona-compacta are two- to three-milliseconds wide. In contrast, action potentials from the non-dopaminergic cells of the adjacent zona reticulata are less than one-millisecond wide. To deal with the differences, a routine (MINCTEK) was written to display a previously stored action potential on the 5223 oscilloscope for comparison with the "real-time" action potential being considered for acquisition.

Once the desired action potential is located, the routine TEKDEM is used to acquire the waveform from the 5223 oscilloscope. TEKDEM transfers the waveform to the MINC via the IEEE-488 interface bus and graphs the waveform on the upper portion of the VT105 terminal screen. Using the terminal cursors and the index feature of the GRAPH statement, five indices are obtained. These indices are both graphed and printed on the lower half of the VT105 screen and, if desired, output to the line printer. Output of waveform points or indices can also be directed to the floppy disk for storage.

Hard copies of stored waveforms were made by transferring the waveform data to a DEC 11/70 that had a digital plotter as a peripheral. This method was used to plot the examples of action potentials shown in Figs. 2 and 3. Figure 2 shows action potentials from the substantia-nigra zona-compacta and zona reticulata. Figure 3 shows a burst of action potentials from the thalamus.

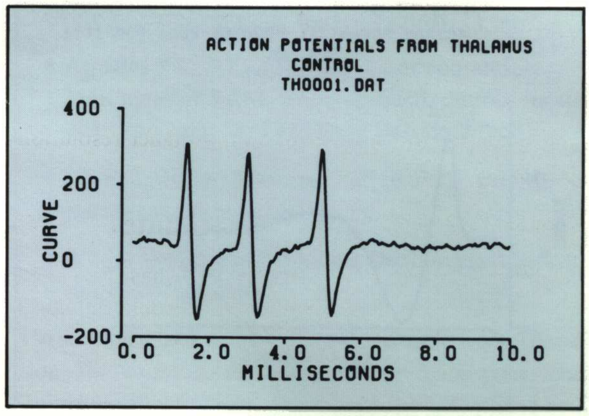

Fig. 3. *Example of a burst of extracellular action potentials from the thalamus of an anesthetized rat.*

Spontaneous activity can be recorded over 30-120 second periods using the routine SPON. As presently dimensioned, this routine can acquire approximately 1000 action potentials. Acquisitions can be stopped at any time desired by input from the keyboard.

Following acquisition, time stamp values are converted to ISIs (interspike intervals). Descriptive statistics are calculated and presented on the terminal and line printer. Both raw and descriptive ISIs can be stored on a floppy disk. Up to nine string descriptors, such as data and animal number, can also be stored by the routine.

The basic data acquisition routine is "DIN" (digital input) in the time stamp, continuous mode with an external time base. This routine is among the fastest of MINC-BASIC real-time routines (Hacker and Jones, 1982 [3]). In the time stamp mode, the DIN and CLK each acquire a digital word. DIN acquires a 16-bit word from inputs to its bits 0-15, and CLK acquires the time in clock ticks. In the continuous mode, data acquisition occurs while other processing is allowed. This mode was used to allow keyboard interrupts for stopping data acquisition as required.

The maximum "internal" time rate for DIN acquisition is 1 kHz, allowing for a resolution of 1 ± 0.5 millisecond. This rate proved too low for the action potentials desired. Therefore, an external time base was needed to provide a higher frequency. A 10-kHz signal is available from CLK once CLK is started with a START_TIME command. This does not interfere with the use of CLK for DIN in the time stamp mode, and it provides a resolution of 100 microseconds (± 50 microseconds). The main disadvantage of this method is that the clock resets frequently at this high time-base rate.

This is because the highest number of counts available on a 16-bit machine is 65,535, which, at 10 kHz, results in the clock resetting every 6.5 seconds. To account for resets, the overflow output of CLK was connected to the 1 bit of the DIN. This allows both a higher resolution and a longer analysis time to be achieved.

Variety of application possibilities

While the above 5223/MINC system has been used primarily for analysis and storage of neurophysiological data, it has also seen some use for analysis of blood pressure data from anesthetized rats. Because of its flexibility, it could be used in a variety of other physiological systems. For example, Stone and Dujardin report using a similar oscilloscope-computer combination for evaluation of cardiovascular data.[4]

Also, Skirboll et al. [5] recently reported a drug-induced change in the shape of the action potential of dopamine neurons. The quantification of waveform shape with cursors, as described in TEKDEM, could be quite useful in analysis of this type of drug action. Also, while the programs developed for the 5223/MINC system are intended for action potential measurements, they are applicable to time interval measurements on any response. Thus they could be used for analyzing ECG and EEG spikes or respiration. The only requirement is that such signals be converted to TTL-acceptable pulses, generally with a voltage-window discriminator.

Acknowledgements

The programs mentioned in this article were developed while the author was at Merrell Dow Research Center, and are available from DECUS (Maynard, MA) or from the author. The author wishes to thank Ms. Bev McCarrell for assistance with this manuscript.

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Computing through leakage to get frequency

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ISI Marketing

Leakage is something that Fast Fourier Transform (FFT) users quickly become familiar with. It's a given when random data is transformed. It also occurs any time an FFT is performed on repetitive waveform data records containing a noninteger number of waveform cycles.

Dealing with overall leakage has nearly always been a matter of changing data windows. However, there are more direct methods that can be used for getting data from individual frequency components. Implementing these more direct methods requires first taking a little closer look at the cause of leakage.

Since all signals are composed of sinusoids, leakage can occur with complex signals if any single sinusoidal component is windowed to include fractional cycles. The harmonic relationship in repetitive waveforms results in all harmonics being subject to leakage if any one harmonic is fractionally represented in the window. In other words, leakage occurs when window duration is not harmonically related to the waveform period. For random signals—any continuous signal with both harmonically and nonharmonically related components—fractional cycles are guaranteed.

Leakage can be understood and explained from the vantage of assumed periodicity and window truncation. These cause points of discontinuity at the edges of the record which can be related to leakage. Another way to understand leakage is by thinking of the RFFT command of TEK BASIC (SPS BASIC or 4041 BASIC) as filling frequency "buckets" based on how much of a given frequency is detected in the input signal. The first bucket is always DC, and the last bucket is always the Nyquist frequency (½ the sampling rate). The buckets between DC and Nyquist are labeled as evenly spaced subharmonics of the Nyquist frequency.

As an example, let's suppose a 1-Hz sinusoid is input to a digitizer and sampled at 4.57 samples per second for a duration of 16 samples. Figure 1 illustrates the digitized record which has been filled in with linearly interpolated points between the 16 samples.

If an FFT is done on the waveform in Fig. 1, "frequency buckets" will be available at DC, the Nyquist frequency (2.29 Hz), and at seven equally spaced locations in between. These seven locations are 0.286, 0.571, 0.857, 1.14, 1.43, 1.71, and 1.99 Hz. Since there is no bucket available for the 1.0 Hz signal of Fig. 1, the FFT must place that signal's energy somewhere else. This is done by spreading the 1-Hz energy into buckets adjacent to 1 Hz. Figure 2 shows the results of this spreading or leaking of signal energy into adjacent points.

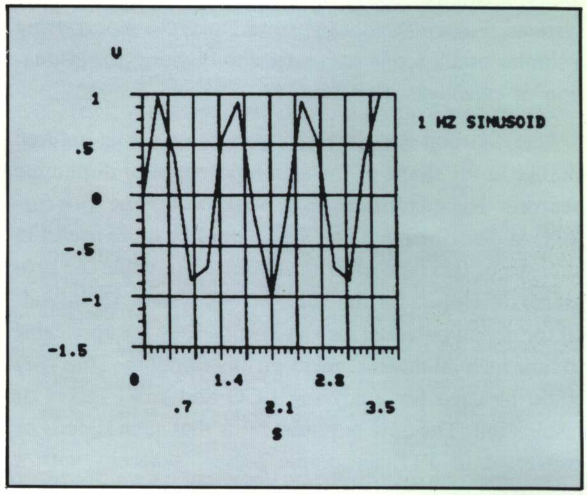

Fig. 1. *A 1-Hertz sinusoid digitized into a 16-point record and graphed with straight-line connection between points.*

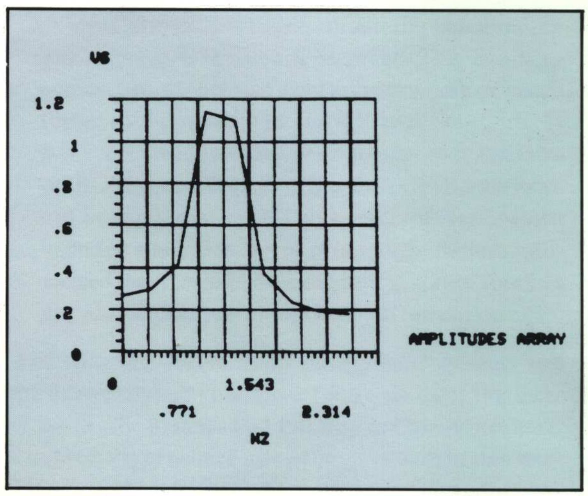

Fig. 2. *Magnitude of the RFFT of the 1-Hertz sinusoid.*

The problem with Fig. 2 is that, because of leakage, it's difficult to tell what the component's frequency and amplitude really are. The information is smeared across several buckets. Trying to determine frequency by the usual method of using the MAX and CRS commands of

```
READY
*PRINT 'THE FREQUENCY IS ';SR*CRS(R,MAX(R));' HZ.'
THE FREQUENCY IS .857143 HZ

READY
*
```

Fig. 3. *Leakage related frequency errors arise from using the maximum value alone to find the component's frequency.*

TEK BASIC, as shown in Fig. 3, results in an error of about 15%.

Using the traditional approach of windowing the data before doing the FFT allows adjustment of leakage across all components. However, windowing just rearranges things and does not get rid of the basic fact that there is a frequency component of 1 Hz but no sample or frequency bucket for its representation.

There are several approaches to obtain the correct frequency and amplitude answer for a given frequency component. One approach is to interpolate new values for the time-domain waveform so that precisely an integer number of cycles falls in the data window. However, this requires some nontrivial programming. The beginning and end points of cycles must be determined and then an interpolation done on the entire waveform to fit the integer number of cycles precisely into the data window.

A second approach, for dealing with specific components in the frequency domain, takes advantage of the inherent fairness of the FFT. The FFT distributes its leakage between adjacent elements depending on how close those elements are to the actual frequency of the component being represented. This means that, if a point can be found where there is as much energy leaked to the right of that point as to the left, that point is a good estimate of the actual frequency of the component. To find this point of energy balance, integrate the leaked component and then find the half-area point. This is demonstrated by the program line in Fig. 4 which was run on the data in Fig. 2.

Notice in Fig. 4 that the result, 1.0028 Hz, matches 1-Hz to within 0.3%. This is a sizeable improvement. The problem with the method, however, is that its accuracy declines as the true frequency varies further from Nyquist/2. An additional step could be used to compensate for this and would provide excellent results regardless of the position of the component in the spectrum. But why bother with more work when there is another still faster method of computing through the leakage?

```
READY
*
*INT R,I

READY
*PRINT 'THE FREQUENCY IS '; SR*CRS(I,MAX(I)/2);' HZ.'
THE FREQUENCY IS 1.0028 HZ.

READY
*
```

Fig. 4. *Closer estimates of true frequency can be made by computing the center of leakage distribution.*

This alternative technique involves looking at the MAX bucket and it's neighbor on either side. Implicit in these three values is the correct frequency, despite the leakage. The formula is:

$$F(true) = F(MAX) + \frac{S(F) * ((V(+)-V(-))}{2 * (2V(0)-V(-)-V(+))}$$

where
- F(true) = true input frequency
- F(MAX) = frequency whose bucket is fullest
- S(F) = frequency-domain sample interval
- V(0) = value in the F(MAX) element
- V(+) = value in the element to the right of F(MAX)
- V(-) = value in the element to the left of F(MAX)

This short computation yields very good estimates of the true input frequency, as demonstrated in Fig. 5. Note that, while the example waveform used here is a sinusoid, the same technique is valid for dealing with individual components of most periodic or almost periodic signals.

```
READY
*FM=CRS(R,MAX(R))\PRINT 'THE FREQUENCY IS ',\FT=FM+((SR*(R(FM+1)-R(FM-1)))/(2*(2*r(FM))-R(FM-1)-R(FM+1)))/PRINT FT,'HZ.'
THE FREQUENCY IS        1        HZ.

READY
*
```

Fig. 5. *Computation by weighting of maximum and adjacent points.*

Test station fills special evaluation test needs

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ISI Marketing
Tektronix, Inc.

The MP 2901 Test Station package consists of a 4041 System Controller, a 4105 Color Computer Display Terminal, and a TM 5006 Six-Wide Mainframe with MI 5010/MX 5010 Programmable Multifunction Interface and Extender, and a PS 5010 Programmable Triple Power Supply.

Product evaluation testing rigorously examines new product specifications under extreme conditions. The tests are repeated several times throughout product development—sometimes over a period of months—and they require accurate records for successful evaluation. However, because of the time lapsed between the first test of a prototype product and the final test of the finished product, and because of the many test iterations in between, several problems can arise in manual (operator controlled) evaluation testing.

Evaluation tests present special problems

Some of the typical problems encountered in evaluation testing are as follows:

What is evaluation testing?

In the engineering phase of product development, evaluation testing begins with checks of prototype circuit boards or assembled products for compliance with five major sets of specifications—

- product performance specifications
- environmental specifications
- FCC and VDE specifications
- Particular product-related specifications (e.g. weatherproofing, ruggedization)
- UL, CSA, or local safety standards

As design engineers refine a product, evaluation testing rechecks the product to verify its performance. This verification ensures that design changes have met their objectives without adversely affecting other specifications. This cycle of check-and-recheck requires a test setup that performs the tests in exactly the same manner as before and produces accurate test records.

Differences in test sequences distort test results. A typical test situation is manual measurement of amplifier gain at various voltage settings for a given temperature and humidity. In one test, an operator may step the voltage up from 10 mV to 10 V, but step it down, from 10 V to 10 mV, in the next test. The differences in power dissipation can distort comparison of the results.

Direct operator control introduces human error. If a product under test is in a humidity chamber which the operator must open to perform a test, the incoming cool air can cause condensation on the product's electrical circuits, invalidating the test results.

From one test to the next, the test data formats may vary. Testing all product operating parameters at several temperature settings, for example, can produce thousands of data points. This much data is nearly impossible to compare from test to test if the data isn't in the same format.

Evaluation testing has special requirements

To successfully evaluate complex products, evaluation test engineers must work under special conditions.

New test procedures must be written for a stream of new products. A profitable business must continually design new products, and a new test procedure must be written for each one. Without effective tools, generating procedures can be very time consuming.

Test setups are used for a few months and then torn down. Test procedures and fixtures may be used for a few months and then shelved for the life of the product unless problems develop after the product is released. However, if they are properly designed, some procedures and fixtures can be used to help manufacturing engineers test the final products.

Test setups are used during only a small part of the product development cycle. Evaluation engineers may test a product several times during a year or more of development, but each test may require test equipment for only a few days. A set of test equipment that is versatile and easy to reconfigure can be used to evaluate many new products during that period.

Many products may undergo environmental tests together, but none alone can financially justify its own test station. In some situations, evaluation engineers may need to test several types of products at nearly the same time. This overlap in product development cycles requires a test setup that is easy to adapt to the products under test, because separate test stations would be too expensive.

Some products require specialized testing under adverse conditions. High humidity, high temperature, and caustic environments are uncomfortable or dangerous for test operators to work in directly.

Test equipment may have to be portable (EMI, environmental, and engineering facilities may be miles apart). Even for large companies, test laboratories are often too expensive to duplicate. The products to be tested must be brought to specialized labs at different locations. Small companies may need to turn to outside laboratory services at remote locations. Portable, easy-to-configure equipment is essential under these conditions.

Often, the test equipment must meet or exceed the specifications of the product under test. Test equipment accuracy and resolution may limit test results. For example, in testing amplifier flatness, the ramp produced by either an attenuator or a voltage source or a programmable power supply must be flatter than the amplifier's voltage characteristic.

Many products require temperature testing. Temperature testing is important in many product evaluations. For some tests, the ambient temperature must be set precisely. For other tests, thermocouples must be attached at various points in the product under test. Test equipment specifically designed for temperature testing simplifies the setup process and standardizes evaluation results.

These special evaluation needs call for special test system solutions.

ATE is the first step

Automatic test equipment (ATE) is the only practical solution to the need for accurate, methodical, consistent, high-speed testing. ATE offers many advantages over manual testing:

- Convenient organization of a series of tests
- Fast test set up and execution
- Data logging of test results for easy comparison to earlier tests
- Repeatability of results, independent of the operator

To ensure that test engineers receive these advantages, their ATE stations should have six key features: modularity, programmability, universal architecture, software tools, readily available general-purpose functions, and easy interfacing between the test engineer and the test station.

Modularity. A system made up of individual but general-purpose components allows the test engineer to quickly configure a unique system for specific requirements.

Programmability. Programmable control gives the test engineer the ability to operate the system under proven software.

Universal architecture. The ability to select stimulus and measurement instruments from several vendors allows the test engineer to use specialized equipment for unique test requirements.

Software tools. Software development aids, such as a test program generator, help test engineers quickly develop test programs tailored to specific needs. By cutting coding time and reducing coding errors, the test engineer has more time to thoroughly plan the tests.

General-purpose functions. Often used hardware and software functions should be ready to use without a lot of custom design. Frequently required functions include analog-to-digital and digital-to-analog conversion, data input/output, memory control, signal switching, temperature measurement, and program development.

Easy interfacing. Convenient front-panel access to signal and control lines allows the test engineer to manage all test lines. This capability ensures effective tests, rapid test setup changes, and quick troubleshooting.

Meeting special evaluation test needs

Tektronix has configured the MP 2901 Test Station package to meet the special needs of test evaluation and general ATE. This advanced test station includes:

- **4041 System Controller,** a powerful 16-bit, MC68000-based controller
- **4041 BASIC,** an easy-to-learn, easy-to-use language designed specifically for measurement systems.
- **TEK EZ-TEST,** a menu-driven software package that assists test program development
- **TM 5006 Six-Wide Mainframe** and **PS 5010 Triple** Power Supply for powering the device under test (DUT)
- **MI 5010/MX 5010 Multifunction Interface** to ease the task of customizing DUT interfacing
- **4105 Color Graphics Terminal** for interaction with the system, including 8-color graphics displays

For more information on the MP 2901 Test Station or additional GPIB instruments available as options to the MP 2901, use the reply card in this issue of **HANDSHAKE** or contact your local Tektronix Field Office.

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