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Recovery of Acoustic Pulse Waveforms Using Calculator-Controlled Signal Processing

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An electronic calculator, a digital recorder, and suitable interfaces have been assembled to provide an inexpensive signal averaging system for the recovery of weak acoustic pulse waveforms. Periodic pulse waveforms between 25 and 300 kHz, with pulse repetition frequency typically less than 50 Hz, are sampled at rates indicated by sampling theory up to a maximum sampling rate of 2 MHz. The highest frequency which can be resolved is thus 1 MHz. Sampled waveforms are accumulated, averaged, and made available via a plotter and paper tape punch.

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RECOVERY OF ACOUSTIC PULSE WAVEFORMS USING CALCULATOR-CONTROLLED SIGNAL PROCESSING

INTRODUCTION

It is more desirable to utilize short pulses in acoustic reflection experiments rather than to approximate steady state conditions with pulses long compared to the reflecting object. Since a short pulse contains a broader frequency spectrum than a long pulse, information about the reflector over a wider range of frequencies is potentially available. The short pulse also increases the usable reflection-free volume in the water or air medium containing the experiment but presents the problem of recording and analyzing transient signals.

An experiment was needed immediately to verify that the form function of a target can be obtained from a single short pulse. It was clear that fast Fourier transform (FFT) techniques could prove helpful in recovering frequency domain information about the target.

The equipment commercially available for doing this job swiftly and accurately is very expensive, so before purchasing such specialized systems, the idea had to be experimentally tested utilizing equipment available within the organization.

This report discusses a system which was fabricated from existing equipment, pieced together to achieve a versatile, high-speed, analog-to-digital (A/D) conversion process employing signal averaging to produce a digitized representation of the desired acoustic signal. The paper tape output of the system is compatible with the NRL computer and, therefore, provides a convenient means of FFT analysis and manipulation. Much data now being published have been taken with the system described, and the system will be a continuing source of data for publication until a more efficient, expensive system can be purchased. Until that time there is a need for a reference detailing how the published data were obtained. This report is that reference.

SYSTEM DESCRIPTION

Digitization

The signals to be handled by the system are short, periodic, acoustic pulses. Signal frequencies normally range from 25 to 300 kHz. Pulse widths rarely exceed 10 cycles of the pulsed frequency and the repetition rate of the pulses is typically less than 50 Hz. Figure 1 shows a typical echo pulse. It is desired to recover this pulse from its noisy environment as quickly and as accurately as possible.

There are many ways to do this. Systems which perform the task can be purchased at considerable expense. It is not intended here to compare the myriad of possible

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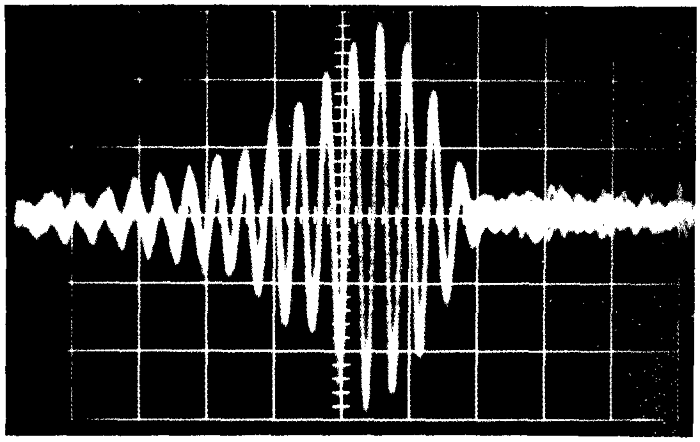

Fig. 1—Typical reflected acoustic waveform

configurations that would yield a like result. This report will restrict itself to one approach which has proved effective and economical. To recover such a signal using digital sampling methods, or digitization, a certain sequence of events must take place.

1. The signal must be quantized. This is a process whereby one of a discrete set of available numerical values (8-bit binary numbers in this case) is assigned to the amplitude of the signal being digitized (1).

2. At specific points in time the quantized amplitude value must be sampled and held in memory.

Figure 2 illustrates the digitization of a three-cycle sine wave pulse $f_j(t)$. The sampling or scanning function is represented by $s(t)$. $s(t)$ is a pulse train which is initiated at time t_0, has a period Δt, and terminates when a specified number of samples, I, has been taken.

The amplitude values of $f_j(t)$ are denoted $x_j(t_i)$ where the i subscript denotes the number of the sample. Obviously i can take integer values between 1 and I. Since Δt is the time between samples, the amplitude $x_j(t_i)$ corresponds to the amplitude of $f_j(t)$ taken at a time equal to $i(\Delta t)$ after t_0. The ith pulse causes the ith quantized value of $x_j(t_i)$ to be shifted into memory. This quantized value is denoted x_{ji}. x_{ji} is, in this case, an 8-bit binary number the value of which most closely equals $x_j(t_i)$. x_{ji} is stored in memory locations m_i until needed to reconstruct the waveform $f_j(t)$. When some predetermined number of samples I has been stored, the digitizing process is complete for waveform $f_j(t)$.

Signal Averaging

This process can be repeated for any number of waveforms. The subscript j denotes the particular waveform being sampled. So, $f_1(t)$ could be a view of a function $f(t)$, and $f_2(t)$ could be a view of that same function at some later time. More specifically, if $f(t)$

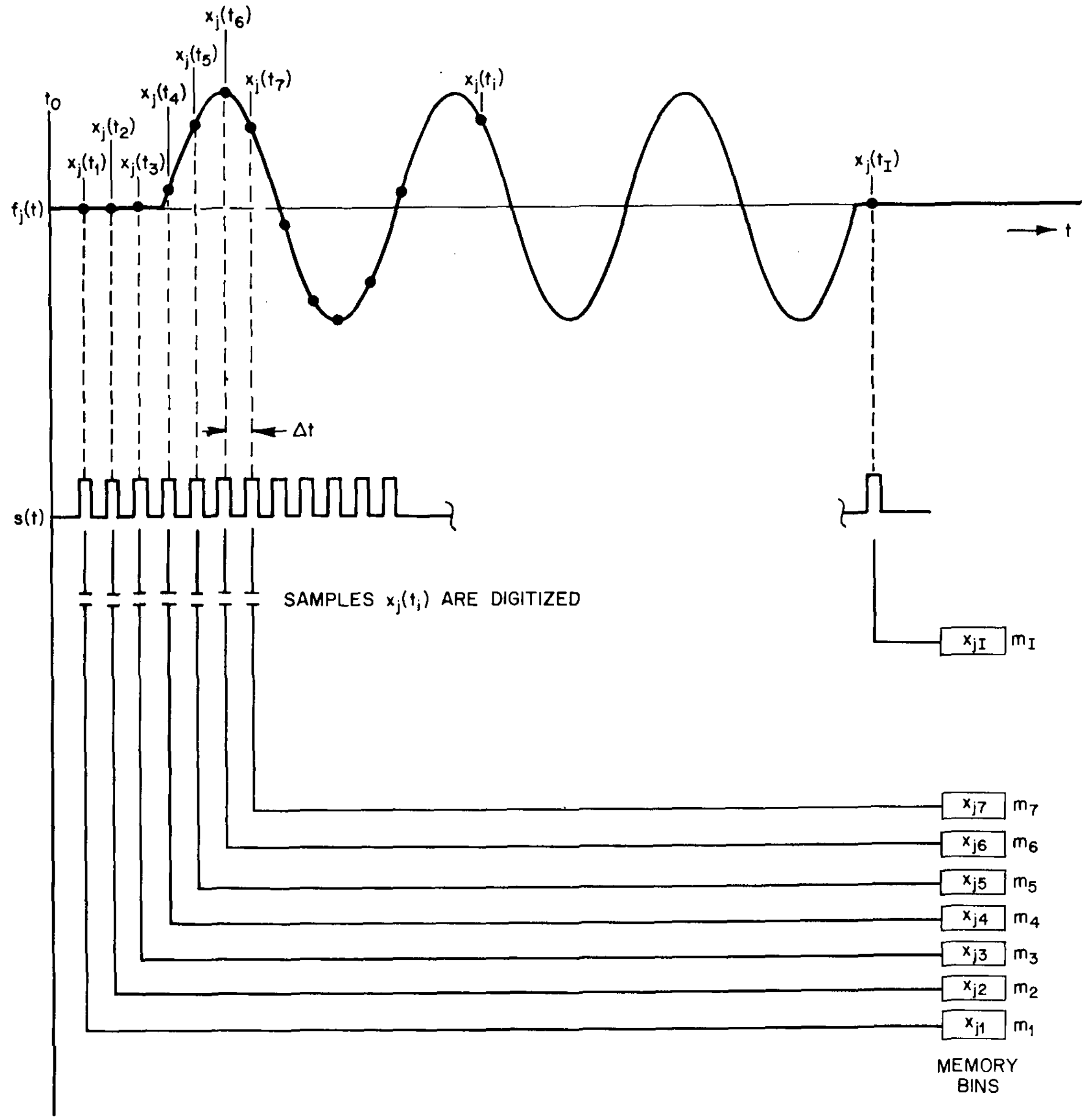

Fig. 2—Sampling and digitization of sample waveforms

is a periodic train of pulsed sinusoids, $f_1(t)$ is the first such pulse, $f_2(t)$ is the second pulse, and so on over j pulses.

Since $f(t)$ is periodic and presumed to be stationary, all pulses should be identical. Because of noise this is not the case, however, since each pulse will contain different amplitude perturbations from the additive effects of random noise. It is possible, in fact, that the noise could completely obscure the desired pulse waveform thus rendering analysis of that particular pulse impossible.

On the other hand, the process of digitization can be repeated over many such pulses and the cumulative result can be averaged. Then one would expect that as the number of repeats j is increased, the amplitude at a given point in time of a noise signal should average to 0 and the periodic amplitude component $x_j(t_i)$ should average to $\overline{x_i}$, the mean amplitude of $f(t)$ at time t_i. Or

$$\overline{x_i} = \frac{\sum_{j=1}^{n} x_{ji}}{n} .$$

A complete plot of all values of $\overline{x_i}$, for $i = 0$ to I, would reconstruct the averaged waveform. Figure 3 illustrates the process for three waveforms $f_j(t)$, $j = 1, 2, 3$, each sampled I times and averaged over j. In this hypothetical case, the random components all averaged to 0 leaving only the waveform shown.

Equipment

This signal averaging process may be achieved using the Hewlett-Packard 9100A calculator system with extended memory and the Biomation 802 transient recorder (2-4). The sequence of events is

1. Biomation samples waveform and stores 1024 points.

2. The first 496 of these points are placed in the memory of the Hewlett-Packard ($I = 496$) (496 data points is the maximum capacity of the extended memory utilizing register splitting) (3).

3. The Biomation is reset and upon being triggered will sample the waveform again.

4. The first 496 points are added to the contents of the 9101A memory, point for point.

5. Steps 3 and 4 repeat N times. Then

6. Contents of each 9101A memory register are divided by N, thus completing the averaging process.

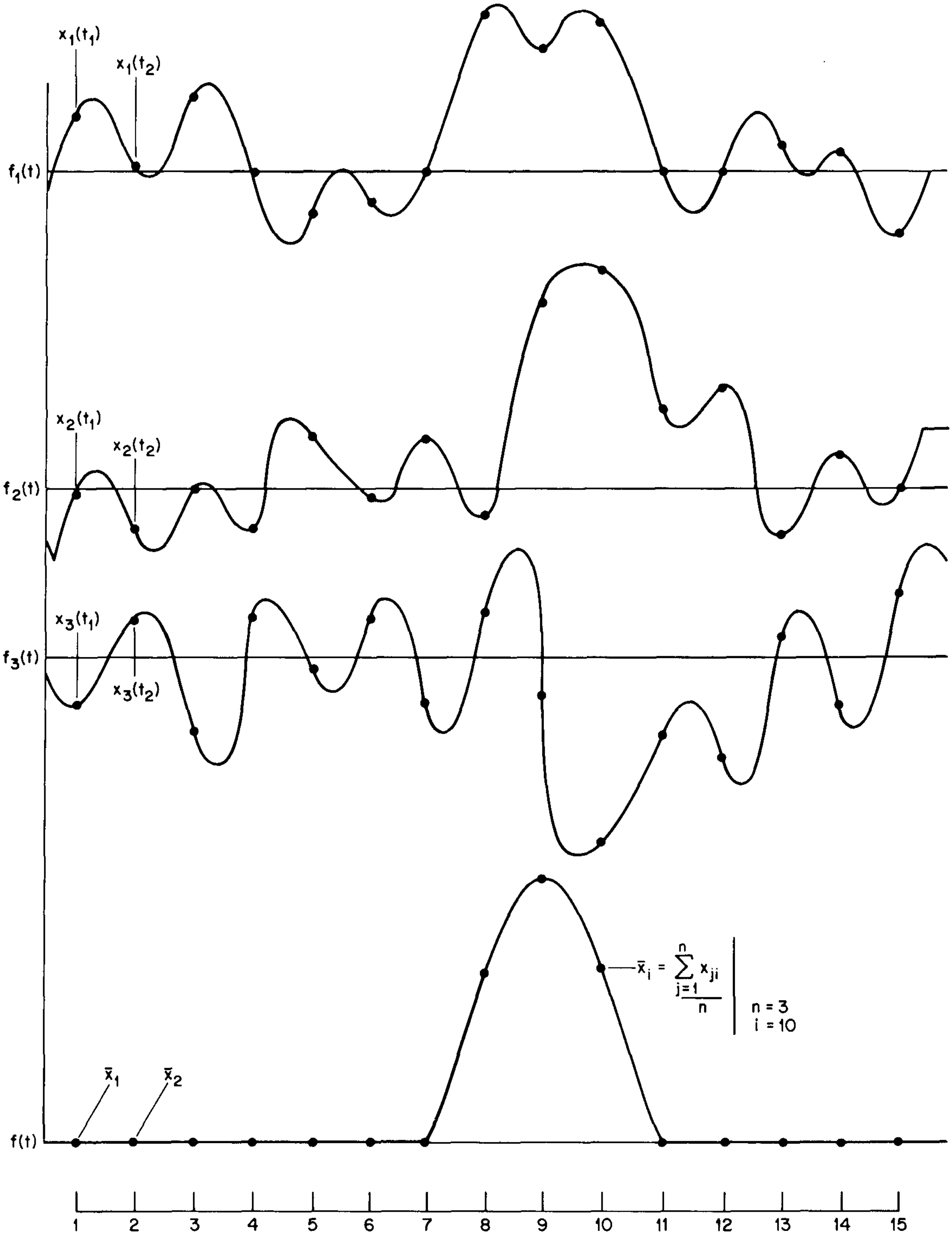

Fig. 3—Signal ensemble averaging

The flowchart of Fig. 4 summarizes the system activities in simplified form. A detailed description of the system follows.

CIRCUIT DESCRIPTION

Interface Timing

Figure 5 is a block diagram of the system. The timing of the various control signals between blocks dictates the design requirements for the alterations made to the Pivan Data Systems interface unit (Dijitscan) used here (5).

The Dijitscan was purchased to allow printout of the Biomation memory using the Hewlett-Packard 5055A printer. A brief look into the circuitry of the Dijitscan reveals that, with minor modification, it can also be used to interface the Biomation to a Hewlett-Packard BCD input kit for use in the Hewlett-Packard 2570A coupler controller (6).

To understand the modifications required, it is necessary to refer to Fig. 6. A program was written for the 9100A calculator which issues two controlling commands to the peripheral system (consult Appendix A for program and calculator setup). An FMT F statement in the program causes the BCD input interface card 2 to receive an encode command. The encode pulse shown in Fig. 6 is not used as an output signal but is shown for timing reference. Upon receipt of the encode command the BCD card causes its holdoff line to go false (0 V). The negative edge of this HO2 signal is used to initiate the control sequence that allows the Biomation to be armed remotely, store a sampled waveform, read out 496 points of that waveform into the calculator according to the point-by-point accumulation technique already discussed, reset upon output of the 496th point, and arm again to start a new cycle.

To accomplish this, circuitry was added to the Dijitscan. Referring to Fig. 7, the circuit diagram of the additional circuitry, and consulting the timing diagram, Fig. 6, we can see the simplicity of this modification.

When HO2 (Fig. 6) goes false, the negative edge fires an SN74121 one-shot multivibrator OS1 (Fig. 7), which issues a positive to 0-V, 100-μs pulse from the $\bar{Q}$ output. This pulse, when applied to the reset line of the Dijitscan, effects a reset of the interface and Biomation output mode circuitry and places the system in the Display Mode. Pulse HO2 also suspends program operation until it is reset. The inverse of this reset pulse is available from the Q output of OS1. This 0 to positive pulse is applied to OS2, and the trailing edge causes OS2 to issue a positive to 0-V, 0.7-μs pulse called "remote arm" (RA) (Fig. 6). RA is applied to the remote arm input of the Biomation (4). This signal readies the Biomation to record a new sampled wave.

A trigger pulse must be available which is fixed relative to the periodic waveform to be sampled. In this case the delayed trigger out of a Tektronix scope is used. This pulse can be positioned anywhere in time relative to the desired waveform, is synchronous with the repetition rate of the acoustic signal, and has good jitter characteristics. It should be noted, however, that this trigger is not synchronous with the interface logic. This condition is perfectly acceptable, since the Biomation will trigger and begin its recording cycle upon receipt of the first trigger pulse following the RA pulse.

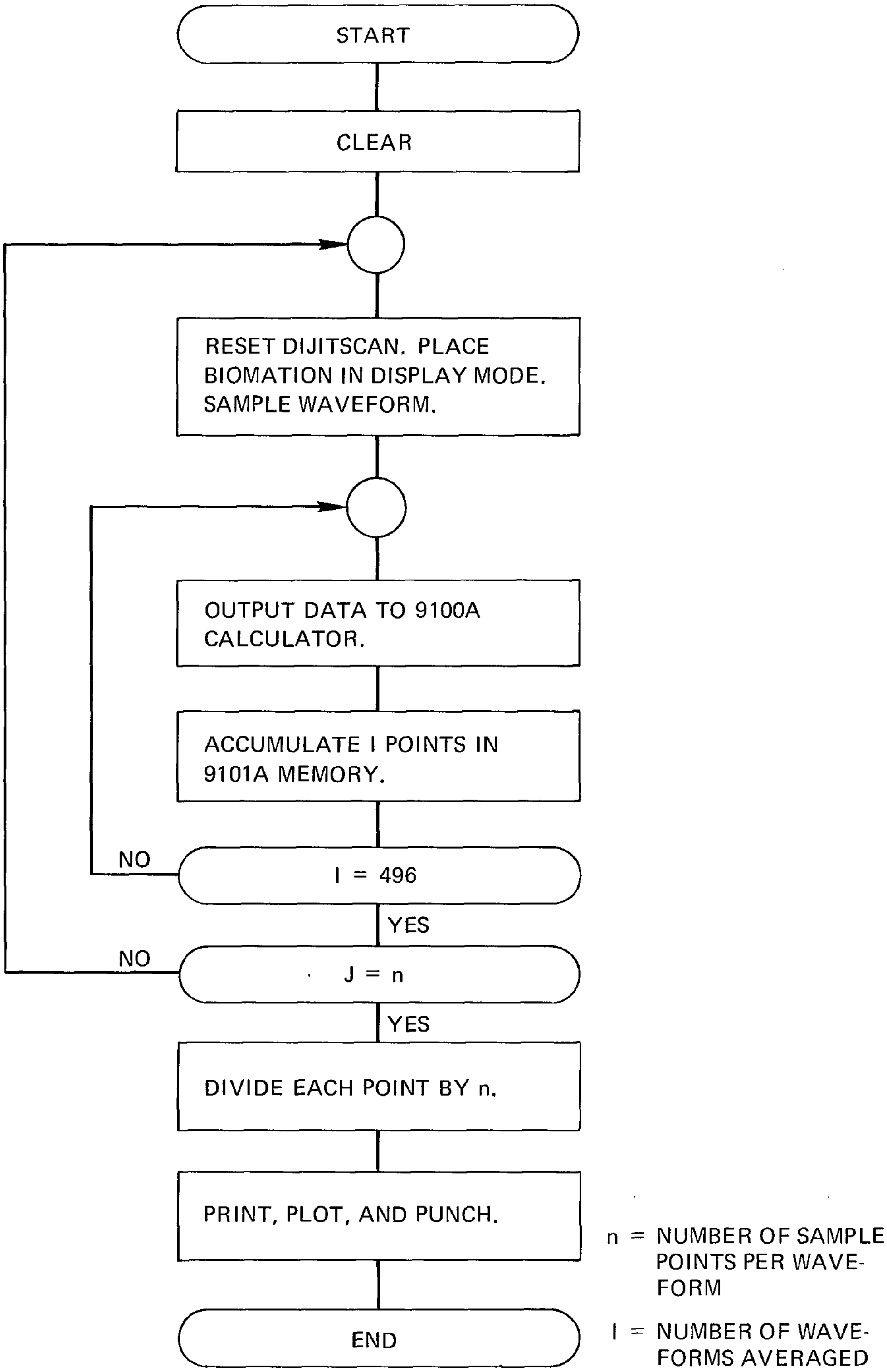

Fig. 4—System flowchart

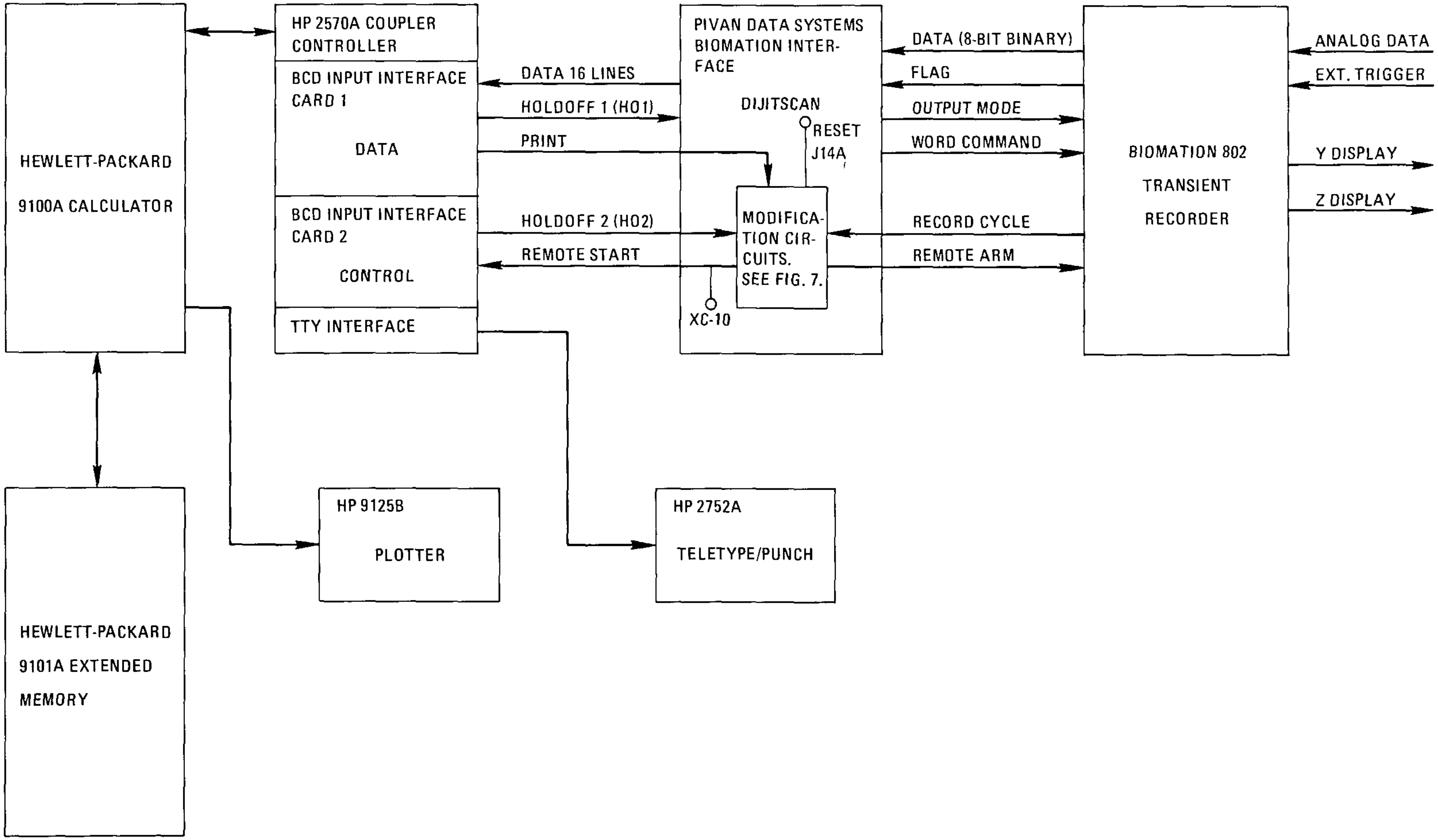

Fig. 5—System block diagram

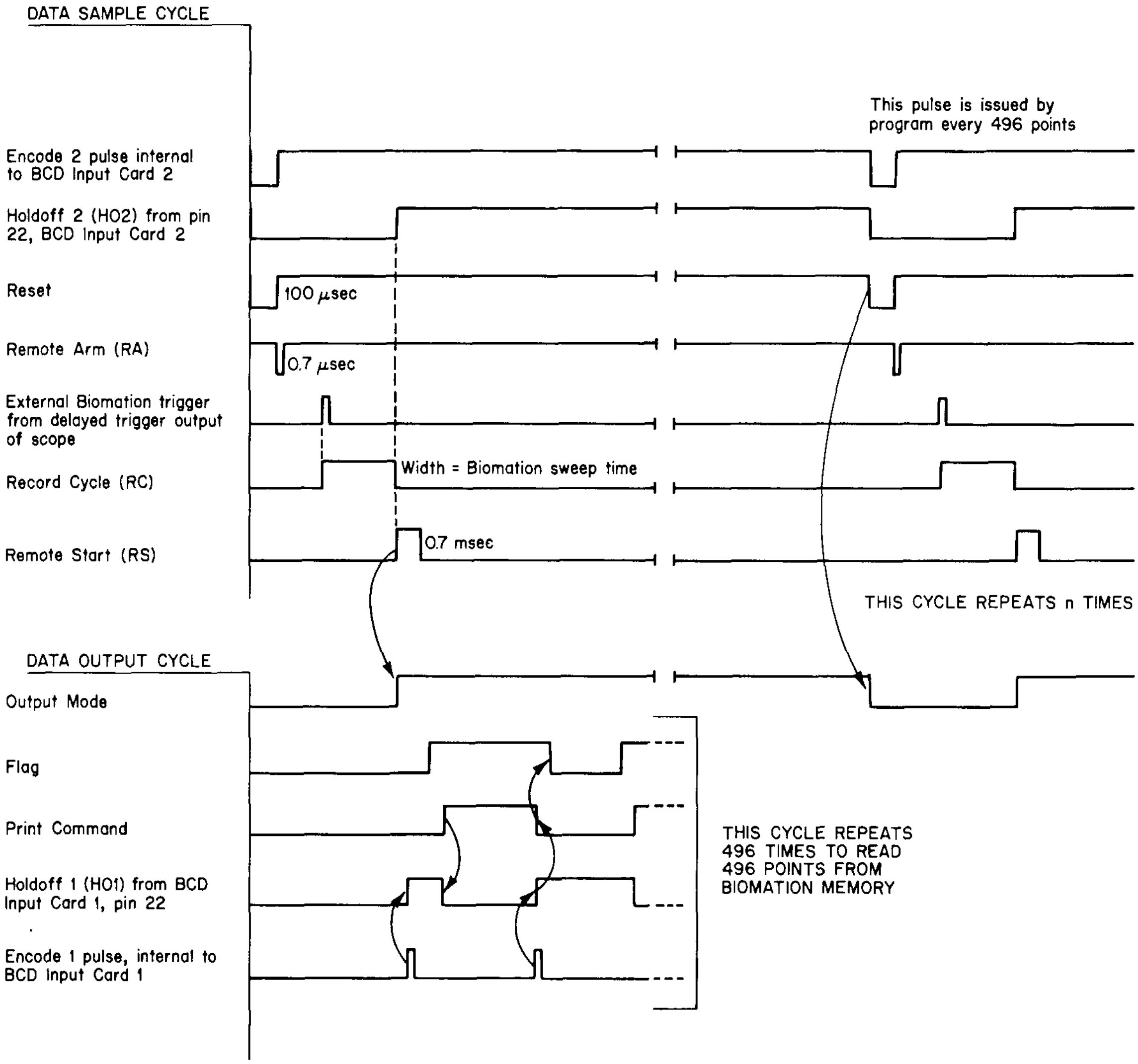

Fig. 6—System timing diagram

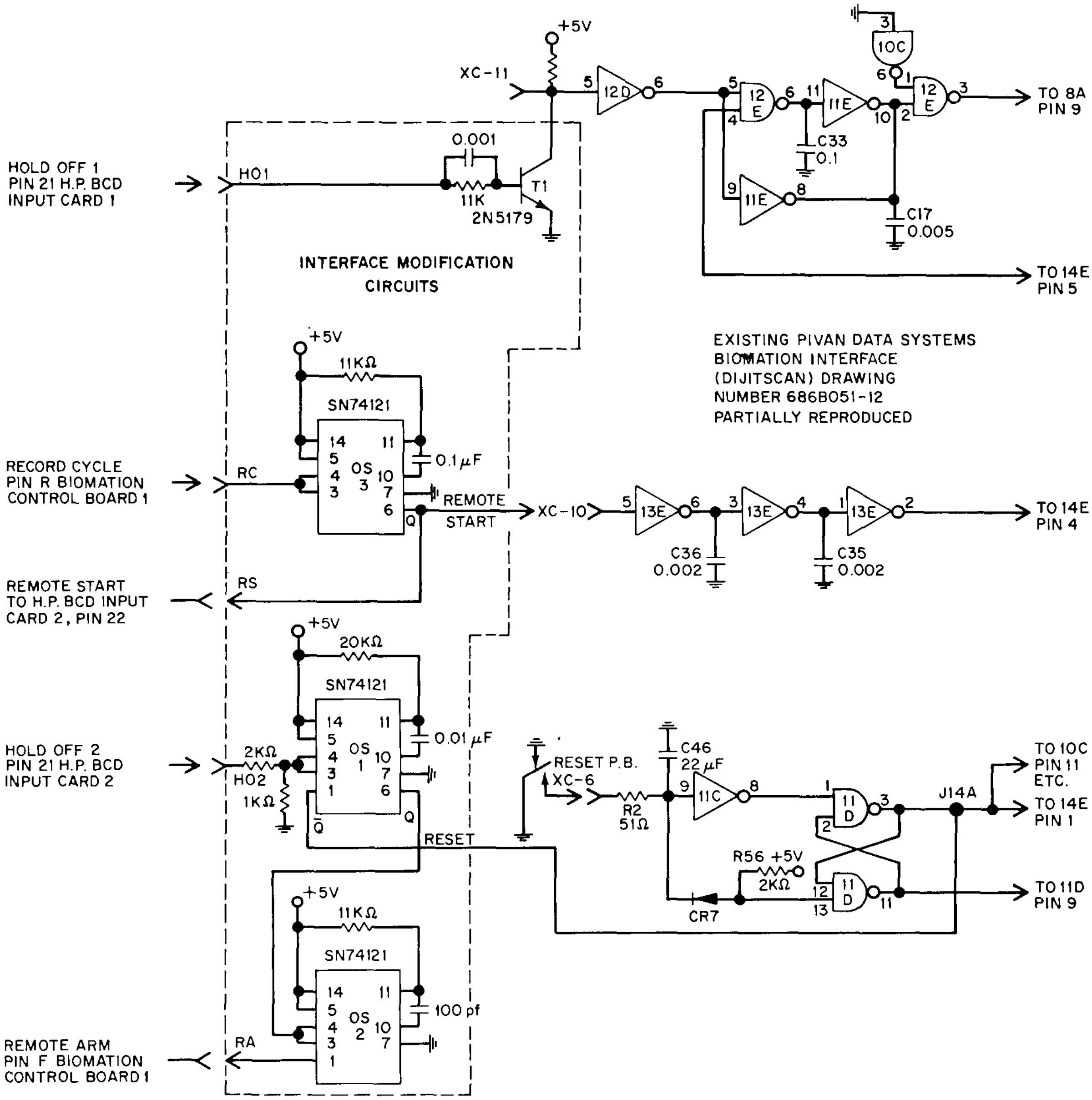

Fig. 7—Interface modification circuits

When triggering occurs, the record cycle (RC), (Fig. 6) output goes high, indicating to the interface modification circuits that the Biomation is sampling and recording a new waveform. The length of the RC output is equal to the sweep time control setting on the Biomation front panel. This signal is not available as an output on the Biomation and must be installed by the user. The signal is available on pin R of the No. 1 control board. (Ref. 4, p. 7.5.)

At the end of the recording cycle the RC output goes to 9 V. This negative transition is used to fire OS3 (Fig. 7). OS3 then issues a 0.7-ms remote start pulse, (RS) to the Dijitscan control circuit. This pulse starts the data output cycle. The RS pulse also resets the HO2 signal (Fig. 6). When HO2 is reset the calculator continues its program sequence. The next program step is an FMT C command which causes BCD input card 1 to receive an encode command. In response to this command, the HO1 signal goes high. This indicates that the BCD card desires a data word.

The output cycle is controlled by the Dijitscan as the manufacturer intended. Only one modification is necessary to make these signals compatible with the Hewlett-Packard BCD input card. Holdoff 1 (HO1), a signal output from the BCD input card, has a +15-V level. Transistor T1 (Fig. 7) is inserted to invert this signal and provide the proper +5-V logic level. The waveform shown in Fig. 6 is HO1 after conversion.

Upon receipt of the RS pulse, the Biomation is placed in the output mode. A data word, or point, is placed in the output buffer of the Biomation. When this is done, the "flag" signal from the Biomation goes high, indicating to the Dijitscan that a word is available. The Dijitscan converts this word from binary (8 bits) to BCD and presents the word to the Hewlett-Packard BCD card. The Dijitscan then issues the "print command" to the Hewlett-Packard BCD card.

When the BCD card sees the print command, it resets the HO1 signal to low and begins programmed manipulation of the data word.

The program will cause the calculator to read the data word and store the word as one point of amplitude information in the 9101A memory. When it has done this, the program with loop back and issue another FMT C command (Appendix A) which will cause HO1 to go positive which in turn resets the print command and flag (Fig. 6). When the next data word becomes available at the Biomation output, the flag will go high and the sequence will repeat.

This sequence of events, then, reads one point at a time into the 9101A memory. The program counts the number of points thus read and when the count reaches 496 the program loops back to the beginning and issues an FMT F command which initiates a new sampling sequence in the Biomation.

The program also counts sampling sequences and will perform the sampling sequence N times. N, of course, is any integer greater than 0 and may be selected by the user. Notes on program use in Appendix A clarify this.

Since each sample point on each sampled wave is added to each corresponding point on each subsequent sampled wave, the memory accumulates the sum of the values each point has for the N samples of that point. Dividing this sum by N yields the average value of that particular point. When each of the 496 sums has been divided by N, the 9101A memory will contain 496 averaged points. If these points are plotted, they will reconstruct the averaged signal. After N sampled waves have been taken and their points accumulated in memory, the program will proceed to perform this averaging operation. Then it will plot the points and punch each point on paper tape.

System Construction

A few comments are necessary to assure that no surprises develop in the system. The Dijitscan is built of high-speed digital integrated circuitry and is vulnerable to noise and crosstalk in signal cables. Cabling between the Biomation and the Dijitscan should be kept to 6 ft in length. The Dijitscan comes with a harness with leads for most of the required signals. The harness works well.

The harness between the Dijitscan and the Hewlett-Packard BCD input card must be built by the user, and it is critical. Length must be kept to a minimum. In the system discussed here, a 6-ft harness is used, but it is marginal. No longer harness should be contemplated without special interfacing precautions.

The holdoff 1, holdoff 2, remote start, record cycle, and remote arm cables are RG58A/U coax with BNC connectors between the Dijitscan and Biomation. The coax leads are wired into standard Hewlett-Packard interface connector kits for the BCD interface cards. It has also been noted that the Biomation is vulnerable to heat. Adequate system ventilation and "clean" cable layout procedures should assure reliable operation.

SYSTEM PERFORMANCE

From the standpoint of computation speed, the Hewlett-Packard 9100A is a slow machine. The operations of storing data points and printing out results are time consuming. The advantage of the system lies not in its absolute speed, but rather in its ability to perform signal averaging at sample rates up to 2 MHz. The limit on this sampling rate is the speed of the A/D converter in the Biomation. Higher speed devices are available and could certainly be incorporated into the system design with proper interfacing.

Multichannel analyzers and other similar devices are limited by their sampling rates since they perform averaging operations as they sample. Internal processing rates in these machines are quite fast, but not fast enough to allow megahertz sampling rates.

Other devices are becoming available which use random sampling techniques, but in these the repetition rate of the sampled wave controls the final time required to reconstruct a signal.

The system described is completely automatic. The user merely starts the program and the system runs until it has finished punching paper tape. Operator time then is minimum. The system requires less than 1 hr to average 100 waveforms and output its data. This time will be improved by using incremental magnetic tape storage in lieu of paper tape and could be greatly improved by using a high-speed minicomputer for control and processing. These are planned objectives.

Examples of waveforms as in Fig. 8 below illustrate the effectiveness of the system. Statistically one may expect a signal-to-noise improvement factor equal to the square root of the number of repetitions $\sqrt{N}$. This is true in the case of random noise. In reality, acoustic experiments are plagued by the existence of extraneous coherent signals within the bandwidth of the desired signal. This system will faithfully reproduce such a signal, since only the noncoherent signals average out. Such a situation can only be avoided by a careful experiment setup.

In Figs. 8a and 8b, two typically noisy waveforms are shown. They vaguely resemble one another. If, however, 50 such waveforms are averaged by the system, the waveform of Fig. 8c results. Looking at Fig. 8c one recognizes a signal.

Figure 8d is another 50-sample average of the same waveform, and it is clear that the two averaged waveforms resemble one another more closely than the two nonaveraged samples of 8a and 8b. There is no coherent noise background in these signals.

CONCLUSION

The system has proved to be a valuable tool. With it, high-quality data have been obtained that provide experimental verification that short pulses can be used to obtain a target form function which agrees with theoretical predictions. For the results of these experiments, see Ref. 7.

ACKNOWLEDGMENT

The author wishes to express his appreciation to Drs. Werner G. Neubauer and Charles M. Davis for their support and confidence in the utility of this short-term solution to the problem of data acquisition.

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3. "Hewlett-Packard Extended Memory 9101A Operating Manual," Hewlett-Packard Co., Loveland, Colo., 1969.
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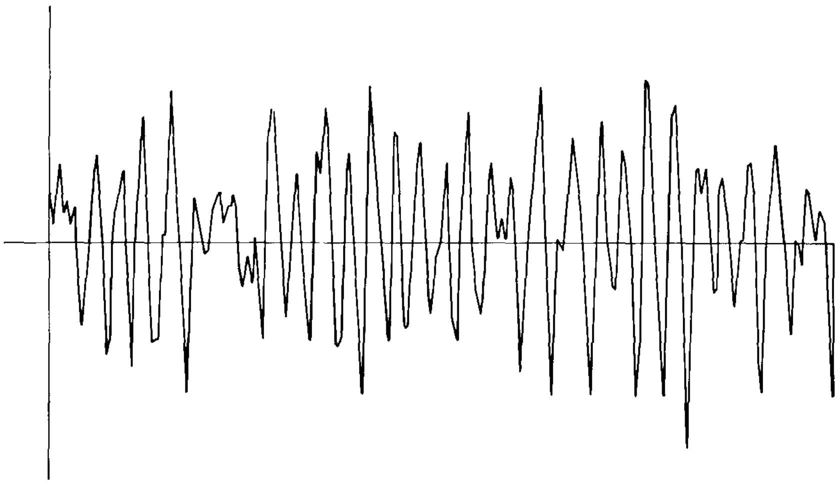
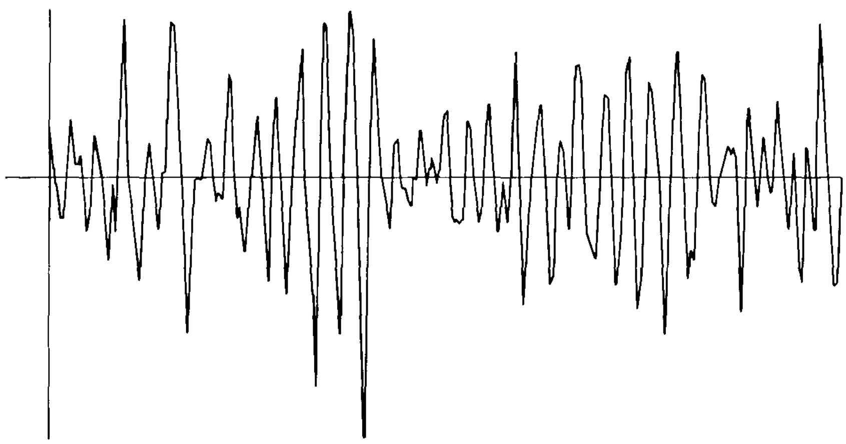
5. "Dijitscan Model B200 Operating Manual," Pivan Data Systems, Chicago, Ill., 1972.
6. "Hewlett-Packard 2570A Coupler/Controller Operating and Service Manual," Hewlett-Packard Co., Palo Alto, Calif., July 1970.
7. W.G. Neubauer, R.H. Vogt, and L.R. Dragonette, "Acoustic Reflection from Elastic Spheres, Part II Transient Analysis," submitted for publication to J. Acoust. Soc. Amer.

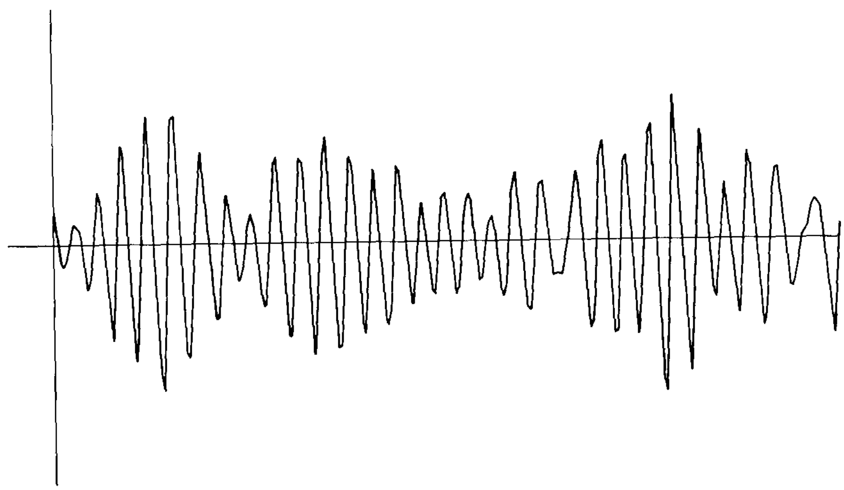


(a) Typical waveform containing acoustic data obscured by noise

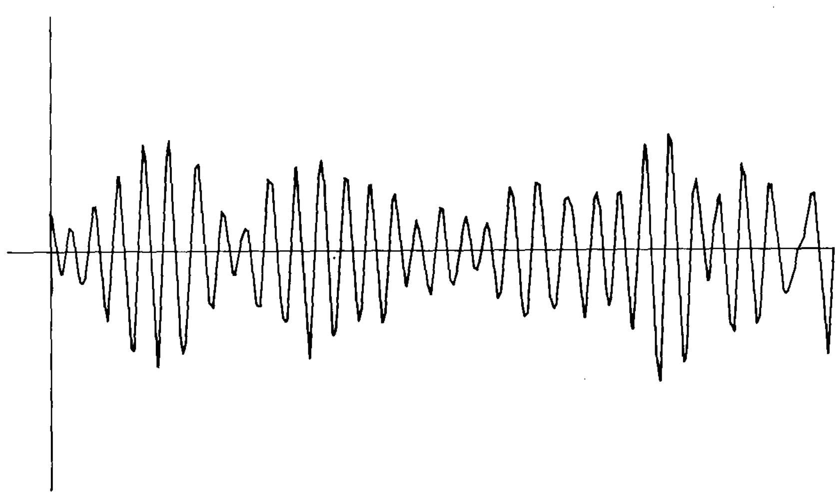


(b) Typical waveform containing acoustic data obscured by noise

Fig. 8—Signal averaging



(c) Signal of Fig. 8a after being averaged



(d) Signal of Fig. 8b after being averaged

Fig. 8—Signal averaging—Continued

Appendix A

HEWLETT-PACKARD 9100A CALCULATOR SYSTEM PROGRAMMING

SYSTEM COMPONENTS

The Hewlett-Packard 9100A calculator system used here consists of the following units:

1. HP 9100A Calculator
2. HP 9101A Extended Memory
3. HP 2570A Coupler/Controller
4. HP 12802A Calculator Interface Kit
5. Two HP 12797A BCD Input Interface Kits
6. HP Teletype Interface Kit
7. HP Buffer
8. HP 9125B Plotter
9. HP 2752A Teletypewriter.

Of these items, three must be programmed to provide the desired system operation. Consulting the proper operating manuals will provide the user with complete information. The discussion which follows will provide only the information necessary to assure that all programmable components are correctly wired.

PROGRAMMING THE HP 12802 CALCULATOR INTERFACE CARD

The HP 12802A calculator interface kit is an assembly of two circuit boards which plug into I/O location 7 of the 2570A coupler/controller main frame. Programming of this assembly is achieved by placing diode jumper pins in appropriate locations on the executive card. Reference A1, pp. 3-9, provides instruction on this program technique. The commands which must be programmed are FMT C and FMT F. The instructions for these commands are tabulated below:

FMT C:	@ 1E First Instruction
	@ 7E Second Instruction
	@ 10 Third Instruction
FMT F:	@ 4E First Instruction
	@ 40 Second Instruction.

A diode pin is inserted in the basic card to eliminate the "comma" in the teletype output format (see Ref. A1, Fig. 5-5).

PROGRAMMING THE HP 12797A BCD INPUT CARDS

Two BCD input cards are used. They are placed in I/O locations 1 and 4 of the HP 2570A coupler/controller main frame.

I/O Location 1

The BCD input card in I/O location 1 is BCD input card 1. This card handles data and generates system control signals. The card utilizes two programming techniques, jumper pins and jumper wires.

Only four jumper pins are used on this card:

Jumper $W_2 = C$

Jumpers $W_3 = \overline{E}$

Jumpers $W_4 = \overline{E}$

Jumpers $W_5 = \overline{E}$.

The user may desire to utilize other features of the card as discussed in Ref. A2. Be sure that nothing is done to require changing jumpers W_2 through W_4.

The wire jumpers determine the format of the output data to be typed on the teletype (Table A1). The scheme shown below provides four digits of data followed by a decimal point. The most significant digit is the left-most digit of the four.

Example 1280.

90.

2560.

Carriage return and line feed controls come from the main program.

Table A1
Wiring for Output Data Format (Example)

Strobes	BCD Input Location
1 wired to	3
2 wired to	2
3 wired to	1
4 wired to end of word	4 wired to end of word

If the data input cable (wire list in Appendix B), is wired differently, reformatting will be necessary.

I/O Location 4

The BCD input card in location 4 is BCD input card 2. This card handles no data; it only provides the HO2 signal as discussed in the text.

Only four jumper pins are required on this card for proper operation, since at no time are data passed by the card.

$$\begin{aligned}\text{Jumper } W_2 &= C\\ \text{Jumpers } W_3 &= \bar{E}\\ \text{Jumpers } W_4 &= \bar{E}\\ \text{Jumpers } W_5 &= \bar{E}.\end{aligned}$$

The card wiring may be identical to BCD input card 1 in I/O location 1 if desired for interchangeability, but it is not necessary. Jumpers W_2 through W_5 are the same on both cards.

PROGRAMMING THE HP 9100A CALCULATOR WITH EXTENDED MEMORY

The main control program steps are listed below with descriptive comments. A few features of this program should be highlighted.

1. Register Splitting. See Ref. A3, p. 110. Steps 1d through 24 of the program (see Program Listing pp. 20-21) combine two data points into one data point. This allows twice as many points to be stored in the 9101A memory.

2. Averaging. The number of samples taken to be averaged *n* is controlled in steps 37 through 39. The user may place any three-digit number in these locations, but it may be understood that for each unit increase in *n* the calculator must perform 496 more additions. Thus, one may wish to limit the size of *n* to something less than 100.

To average over 50 samples the user would place "5" in step 37, "0" in step 38, and "continue" in step 39. Similarly to take one sample, i.e., no average, place "1" in step 37 and "continue" in steps 37 and 38. The user may change *n* any time the program is not running. Normally during initial setup the program will be entered from magnetic card storage. Then the user will choose *n*, press "GO TO," "3," "7," set program/run switch to "program," and enter *n*. Be sure to set program/run switch back to "run" after three digits of *n* are inserted ("continue" is considered a digit here).

3. Initializing Values. Once the program is entered in the 9100A and *n* has been chosen, the user must place initial values in registers "b," "c," and "d."

With program/run switch in "run" position, enter "0" in the b register, "1" in the c register, and "247" in the d register.

The program is now ready to run from starting address "00."

REFERENCES

A1. "Hewlett-Packard 12802A Calculator Interface Kit," Hewlett-Packard Co., Palo Alto, Calif., Aug. 1971.

A2. "Hewlett-Packard 12797A BCD Input Interface Kit for 2570A Coupler/Controller, Operating and Service Manual," Hewlett-Packard Co., Palo Alto, Calif., Aug. 1971.

Title Signal Averaging System Control Program

Step	Key	Code	Display x	Display y	Display z
0 0	CLEAR				
1	FMT				
2	SET FLAG				
3	f				
4	FMT				
5	X				
6	1				
7	ACC +				
8	d				
9	↑		CLEAR 9101A MEMORY		
a	f				
b	IF X > Y				
c	1				
d	5				
1 0	0				
1	↑				
2	GO TO				
3	0				
4	3				
5	CLEAR				
6	FMT		RESET/SAMPLE		
7	f				
8	FMT		OUTPUT DATA		
9	C		POINTS IN		
a	↑		PAIRS		
b	FMT				
c	C				
d	↑				
2 0	ENTEXP		COMBINE 2		
1	6		POINTS PER		
2	÷		REGISTER IN		
3	↓		9101A		
4	+				
5	f		9101A ADDRESS		
6	FMT		ADD POINTS		
7	+		TO MEMORY		
8	↑		ADDRESS CON-		
9	d		TENTS.		
a	X ⇌ Y				
b	IF X = Y		LOOP FOR		
c	3		496 POINTS		
d	7				

Step	Key	Code	Display x	Display y	Display z
3 0	0				
1	↑		TO BE		
2	1		OUTPUT		
3	ACC +				
4	GO TO				
5	1				
6	8				
7	1		N = 100		
8	0		USER MAY		
9	0		ALTER		
a	↑				
b	C				
c	IF X = Y				
d	4		LOOP FOR		
4 0	9		N WAVEFORM		
1	↑		SAMPLES AND		
2	1		ACCUMULA-		
3	+		TIONS		
4	Y → ( )				
5	C				
6	GO TO				
7	1				
8	5				
9	CLEAR				
a	f		9101A ADDRESS		
b	FMT		RECALL		
c	π				
d	↑				
5 0	INT X		SEPARATE		
1	−		SPLIT		
2	X ⇌ Y		REGISTER		
3	↑		CONTENTS		
4	ENTEXP		INTO 2		
5	6		POINTS		
6	X				
7	C		DIVIDE BY N		
8	÷		TO GIVE		
9	X ⇌ Y		AVERAGE		
a	ROLL ↓				
b	÷				
c	ROLL ↓				
d	FMT				

Step	Key	Code	Display x	Display y	Display z
6 0	8				
1	FMT		TTY COMMANDS		
2	9		PRINT AND		
3	ROLL ↓		PUNCH		
4	FMT				
5	8				
6	FMT				
7	9				
8	ROLL ↓				
9	1		PLOTTER Y		
a	ROLL ↓		SCALE FACTOR		
b	9				
c	X				
d	X ⇌ y				
0	ROLL ↓				
1	X				
2	X ⇌ Y				
3	ROLL ↑				
4	↑				
5	b				
6	FMT		PLOT POINT		
7	↓				
8	X ⇌ Y				
9	1		INCREMENT X		
a	5		AXIS LOCATION		
b	+				
c	ROLL ↓				
d	FMT		PLOT NEXT		

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f	9101A ADDRESS ACCUM.
e	NOT USED
d	247
c	N LOOP ACCUMULATOR
b	X PLOT ACCUMULATOR
a	
9	USER:
8	ENTER PROGRAM
7	ENTER 247 IN d
6	1 IN c
5	0 IN b
4	PRESS: GO TO "00"
3	
2	PRESS: CONTINUE FOR
1	OPERATION
0	

Title Signal Averaging System Control Program

Step	Key	Code	Display x	Display y	Display z
80	↓		POINT		
81	ROLL ↑				
82	+				
83	Y → ( )		ACCUMULATE		
84	b		X COORD.		
85	d				
86	↑		COUNT 496		
87	f		POINTS		
88	IF X = Y				
89	9		END WHEN		
8a	4		496 POINTS		
8b	0		ARE PLOTTED		
8c	↑				
8d	1				
90	ACC +				
91	GO TO				
92	4				
93	a				
94	CLEAR				
95	FMT		SET PLOTTER		
96	↑		TO 0.		
97	END		END		

Storage

Appendix B

DATA CABLE, DIJITSCAN TO HP BCD INPUT CARD 1 WIRING LIST

Dijitscan Output Connector Pins		HP BCD Input Card 1 Input Connector Pins
1	BCD	1
2	Data	2
3		A
4		B
5		3
6		4
7		C
8		0
9		5
10		6
11		E
12		F
33	Holdoff	21 coaxial
34	Print Command	22
35	Gnd	BB
36	Gnd	BB