DATA ACQUISITION (SIGNAL AVERAGING) UNDER WIRED-PROGRAM CONTROL

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I. INTRODUCTION

Acquiring free induction decay (FID) or continuous wave (CW) data from an nmr spectrometer with the 1080 system can be likened to the operation of an oscilloscope. Figure 1 shows the flow of information to and from the spectrometer to the various components of the 1080 system. The analytical (FID or CW) signal is fed to the input of the analog-to-digital converter (SD-82) for pre-conditioning and conversion to a discrete number of levels, a form that the 1080 wired program processor can readily assimilate into its magnetic core memory. All of the necessary timing controls which establish the start time (trigger) of the sweep, sweep width or sweep rate are found on the sweep control unit (SW-80).

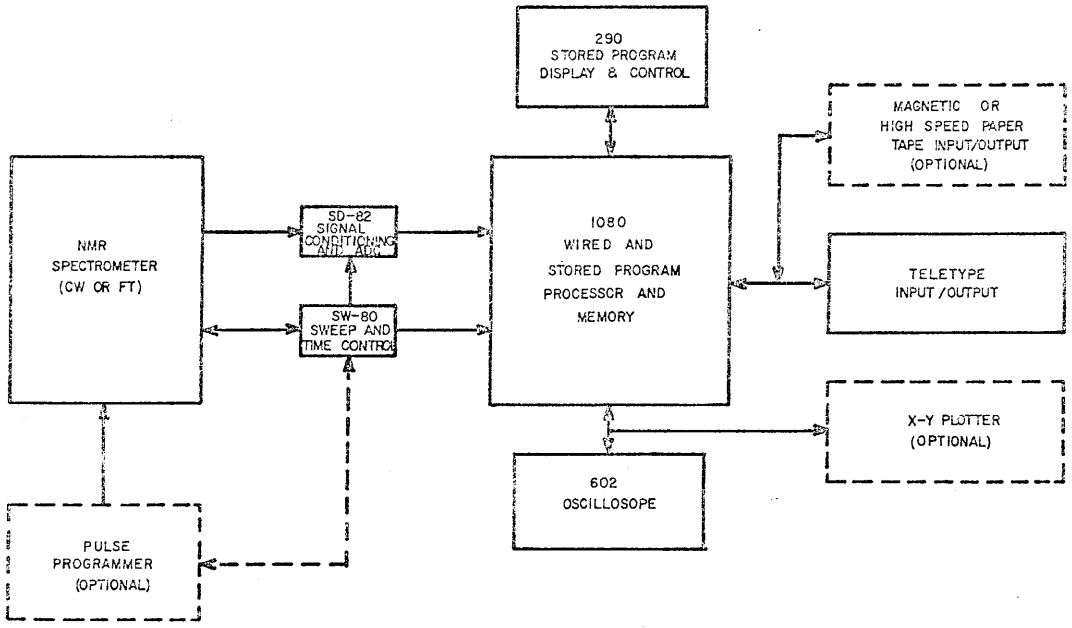


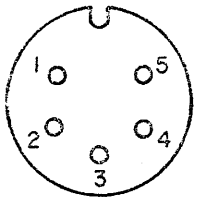
Figure 1. Components of a 1080 NMR Data System.

Parameters relating to acquisition processes such as the number of signals to be averaged, the number and location of storage points as well as factors determining display or readout characteristics are all located on the 1080 main frame.

II. SD-82 SIGNAL CONDITIONING AND ANALOG-TO-DIGITAL CONVERSION

A. Connections

The first step in acquiring data is to connect the spectrometer output signal to the connector marked INPUT CONNECTOR on the front of the SD-82. Although this connector has five terminals, only four of them are used (see Figure 2).



Pin Number	Function
1	Non-Inverting ADC Input
2	Chassis Ground
3	Inverting ADC Input
4	Not Used
5	Circuit Ground

Figure 2. Orientation and Pin Connection List of Front Panel Connector on SD-82 Signal Digitizer

Pins 1 and 3 are the non-inverting and inverting inputs of two operational differential amplifiers whose outputs are fed to a third differential amplifier (see Figure 3). This provides a truly differential input for eliminating common-mode signals (-80 db rejection) that are carried on the analog signal lines. Pin 5 is a "clean" (noise free) common signal ground which should be connected to the signal reference point in the spectrometer. Pin 2 is chassis ground and should be attached to the chassis ground of the spectrometer through the shield of the 3-wire shielded cable to eliminate electrical hazards due to metal housings being at different potentials. Pin 4 is not used. These connections may vary somewhat depending upon spectrometer characteristics.

Figure 3. Block Diagram of SD-82 Signal Conditioning Section

The amplitude of the differential input signal can range from ±250 millivolts to ±16 volts for full scale input. The full scale signal voltage should be close to one of the indicated settings of the FULL SCALE VOLTS switch so that the maximum dynamic range of the digitizer is utilized. The differential input will reject common mode voltages which can be up to ±20 times the full scale input with an absolute maximum of ±50 volts. The input impedance is 400K ohms balanced or 200K ohms unbalanced. If the input signal is connected in a single-ended, unbalanced manner, the unused terminal should be connected to the common terminal. (See Figures 4a and 4b.)

Fig. 4a. Connections for Balanced Input

Fig. 4b. Connections for Unbalanced Input (non-inverting)

B. Controls

VOLTS FULL SCALE -- This control, variable from ±1/4 volt to ±16 volts, determines the requirements of the input signal amplitude to produce a full scale number of counts from the analog-to-digital converter. This switch and the RESOLUTION switch determine the relationship between the sampled input voltage and the number of counts representing that voltage and is expressed

$$\frac{\text{Counts}}{\text{Volt}} = \pm \frac{2^{R-1}}{VFS}$$

where R is the number of bits determined by the setting of the RESOLUTION switch and VFS is the setting of the VOLTS FULL SCALE switch. The plus or minus sign is determined by the polarity of the input signal.

The GND position of this switch disconnects the input signal and connects the inputs of the operational amplifier to the common terminal.

This switch should be positioned during operation such that the maximum excursion of the input signal is close to, but does not exceed, this value. A more definitive procedure is given in a later section.

D. C. LEVEL -- This ten turn control permits a d. c. voltage to be added to or subtracted from the input signal. This allows cancellation of unwanted bias voltages present on the input signal and also provides for offsetting the input signal to permit better utilization of the dynamic range of the analog-to-digital converter. For example, if the input signal is from a CW nmr spectrometer and has a reasonably good signal-to-noise ratio, most of the signal will be positive and subtracting a d. c. voltage from it with this control will improve the resolving capability (resolution) of the analog-to-digital conversion process. In Fourier spectroscopy this control should be adjusted so that the maximum positive and negative excursions of the FID signal come close to but do not exceed the full scale range of the digitizer. Zero d. c. level corresponds to a setting of approximately 5 on the dial with settings of zero and 10 corresponding to minus and plus full scale respectively. This control is <u>not</u> effective when using the Systematic Noise Reduction mode of operation and should be set to position 5 (zero volts) when this mode is being used.

INPUT FILTER -- This is one of the more important controls of the data acquisition system from the standpoint that the selection of the input filtering network can grossly affect the accumulated FID signals, from a signal-to-noise standpoint as well as the effect upon the phase characteristics of the real and imaginary components. A sharp cut-off, low pass filter is essential. For optimum results the cut-off frequency of the filter should be matched to the selected sampling rate (and therefore sweep width) as set on the DWELL TIME control on the SW-80. The cut-off frequency should be set as close as possible to $1/2\Delta t$ where Δt is the dwell time setting. See Technical Data Sheet C050-50-5/70 of Analog Devices Inc., Cambridge, Massachusetts for complete description and specifications of filters.

The SD-82 contains two tunable 4-pole Butterworth plug-in filters which provide a frequency range from 125 to 25,000 Hertz in 24 steps, selected from the front panel by pushing × 1 Hz or × 10 Hz pushbuttons respectively. Contact the factory if different cut-off frequencies are required. If an external filter such as the Kron-Hite 3300 Series is used, the DIRECT pushbutton is depressed. Refer to the section in this instruction manual on Phase Correction for information on changes that can be made to correct for the phase characteristics of different filters.

RESOLUTION -- Digitizer resolution can be defined as the smallest voltage difference that will make a one count difference in the voltage/count relationship of an ADC. It is generally expressed in terms of the full scale number of counts for a full scale input voltage and therefore has a label of bits (binary digits). For example, in the 9 BIT position the SD-82 will resolve an input signal to one part in 2^9 (512). In the 7 BIT position a resolution of 1 part in 128 is achieved and in the 5 BIT position one part in 32.

In actual operation the setting of this control is determined by the signal-to-noise ratio (S/N) of the incoming FID signal and the number of sweeps

(repetitions) that are to be made. In general, coherent signals will reinforce with each sweep and will therefore add linearly with the number of sweeps made, whereas non-coherent data will add in proportion to the square root of the number of sweeps made.

The highest coherent amplitudes in FID signals occur early in time and decay exponentially while the non-coherent components are relatively constant throughout. Therefore the S/N ratio of the FID signal decreases with time. Since frequency resolution increases with time, a balance must be struck between digitizer resolution, the number of sweeps, and the dwell time.

The ultimate limiting factors on S/N ratio improvement are the length of each data word and the systematic noise introduced in the analog to digital conversion process. The algorithm used in computing the average, whether it be the normalized method or straight summation method, will not alleviate the restriction imposed by the word length.

By changing the RESOLUTION control from the 9 BIT position to the 5 BIT position, 16 times as many sweeps can be made and therefore, a theoretical improvement of a factor of 4 in the S/N ratio can be achieved. In actual practice, the improvement in S/N ratio will not be quite as great since the digitizing accuracy has to be considered in relation to the actual FID signal amplitude. Correspondingly, changing the RESOLUTION switch from the 9 BIT position to the 7 BIT position, 4 times as many sweeps can be made and therefore a factor of approximately 2 improvement in S/N ratio can be achieved.

SYSTEMATIC NOISE REDUCTION -- In those applications where an extremely large number of sweeps is to be made, a scheme to reduce coherent noise arising from the digitizing process can be introduced. This technique will only reduce noise generated within the SD-82, and not coherent noise which may be coming from the spectrometer. The theory on which it operates is quite simple: data presented to the input terminals have their polarity inverted on alternate sweeps by means of reed-relay switches.

At the same time the add/subtract logic is switched between add and subtract on alternate sweeps at the end of each sweep. This means that data from the spectrometer will always be added to memory totals, but systematic noise arising inside the digitizer, whose polarity does not get inverted, will be cancelled out due to the alternate addition and subtraction operation.

When this technique is used, a minimum delay of 2 milliseconds must occur between successive sweeps. If no external delay is provided this delay must be set on the DELAY TIME switches of the SW-80 Sweep Control plug-in. This permits the reed relays to "settle down" after being switched.

Figure 5. Front Panel of SD-82 Signal Digitizer

Figure 6. Front Panel of SW-80 Sweep Control

III. SWEEP CONTROL (TIME BASE)

A. Connections

The SWEEP CONTROL CONNECTOR on the front panel of the SW-80 is a female 20 pin AMP Inc. connector, catalog number 201356-1 which mates with a male 20 pin AMP Inc. connector, catalog number 200346-2. Female pins, AMP Inc. catalog number 66104-12P are used in the panel mounted connector and Male pins, AMP Inc. catalog number 66102-12P are used in the mating connector. The following is a list of the signals on this connector.

Front View of Sweep Control Connector

PIN	FUNCTION
A	Delay Flag Output
C	External Address Reset Input
D	External Trigger Input
E	Sweep Ramp Output
F	~~Cursor Reset Input~~ Changed to Dwell/g P.C
H	Cursor Output
K	External Address Advance Input
L	External Clock Input
M	Clock Output
N	Internal Clock Inhibit
P	Measure Address Cursor Inhibit
S	Sweep Flag Output
U	Readout Trigger
V	Extra Delay Enable
W	Chassis Ground
B, J, R, and X	Circuit Ground

Figure 7. Pin Connection List of SW-80 Sweep Control Connector Cable

Pin Signal Description

A DELAY FLAG -- A +10 volt level (enabled only in the Measure mode of operation) is present on this pin for the duration of the delay period as selected on the SW-80 DELAY TIME and DELAY MODE switches. With the DELAY MODE switch in the PRE position, the delay is inserted between the time of triggering a sweep and the start of the sweep. With the DELAY MODE switch in the POST position the delay is inserted between the end of one sweep and the start of the next.

C EXTERNAL ADDRESS RESET -- A +4 volt pulse applied to this pin will cause the termination of a measurement sweep immediately on completion of the next memory cycle.

D EXTERNAL TRIGGER INPUT -- An external trigger signal of from -5 to +5 volts amplitude applied to this pin will initiate a sweep unless a sweep is currently in progress (in which case it is ignored). The start of the sweep occurs as the trigger signal passes through the threshold level selected by the THRESHOLD ADJUSTMENT control on the SW-80 with a slope selected by either the + or - position of the TRIGGER control.

E SWEEP RAMP OUTPUT -- An analog output voltage proportional to the address number during a measurement sweep is provided on this pin. The voltage can start at 0 or +8 volts at the beginning of a sweep and go to +8 volts or 0 at the end of the sweep, as selected by an internal switch. Another internal switch selects the total number of increments (addresses) that the voltage ramp is to include. Two more internal controls allow d. c. offsetting of the voltage ramp by as much as ±10% of full scale and trimming the amplitude of the ramp by ±10% of full scale. If fewer than 32K addresses are used the voltage ramp can be attenuated by setting the internal increment switch to a higher value than the number of addresses actually being used.

F $\overline{\text{CURSOR RESET}}$ -- (See description for pin H) A +5 volt to zero volt pulse applied to this pin causes the CURSOR OUTPUT scaler to reset.

H $\overline{\text{CURSOR OUTPUT}}$ -- A +5 to zero volt pulse with a duration of 2 microseconds is presented on this pin when the sweep enters the address selected by ADDRESS SELECTOR thumbwheel switches. This pulse is present during either the Measure or the Readout modes of operation. During the Measure mode with Continuous Display, the $\overline{\text{CURSOR OUTPUT}}$ signal is present when the CRT display is intensified (i. e. , when the display register passes through the selected address). Connecting pin P of this connector to pin X (gnd) will cause the $\overline{\text{CURSOR OUTPUT}}$ signal to be preserved when the measure address register goes through the selected address number. Instead of a pulse at one address during a sweep it is possible to arrange for this pin to provide a pulse at every n^{th} address where n is the number selected on the ADDRESS SELECTOR switches. To accomplish this, connect the $\overline{\text{CURSOR OUTPUT}}$ signal (pin H) to pin F which is called $\overline{\text{CURSOR RESET}}$. Again, by connecting pin P to pin X this signal will occur every n^{th} measure address.

K EXTERNAL ADDRESS ADVANCE -- A +4 volt pulse applied to this pin will cause the ADC to sample the input signal, convert the sample to a digital value, and add that value into successive addresses of memory. The DWELL TIME decade switch must be in the EXT ADDR ADV position for these pulses to be recognized. The thumbwheel switches will divide the frequency of this signal by the indicated value (range 1 to 9999).

L EXTERNAL CLOCK -- An externally derived clock signal (such as from a frequency synthesizer) can be inserted on this pin. The clock signal will be divided by 10 immediately and can be further divided by the setting of the DWELL TIME thumbwheel switches and decade switch which will then indicate the additional factor by which the frequency of the EXTERNAL CLOCK signal is divided. The actual time between sampling commands will then be equal to 10 times the reciprocal of the divided down external clock frequency. Clock signal should be +5 volts and can have a maximum frequency of 20 MHz. When an EXTERNAL CLOCK signal is used pin N must be connected to ground to inhibit operation of the internal clock.

M CLOCK OUT -- The internal 10 MHz clock or the applied external clock from which all dwell and delay times are derived is available at this pin. This makes possible the exact synchronization of external timing equipment such as pulse programmers.

N $\overline{\text{INTERNAL CLOCK INHIBIT}}$ -- If an external clock signal is to be used on pin L, then the internal clock signal must be inhibited. This is accomplished by connecting pin N to pin X (circuit ground). (See pin L description.)

P $\overline{\text{MEASURE CURSOR}}$ -- When this pin is grounded (by connecting it to pin X) the $\overline{\text{CURSOR OUTPUT}}$ signal (pin H) occurs when the measure address equals the number set on the ADDRESS SELECTOR thumbwheel switches.

However, if the Continuous Display mode is selected on the 1080 main frame and it is desired to intensify the selected address on the CRT display, then pin P should not be connected to pin X (circuit ground). In this case however, there is no time relationship between the $\overline{\text{CURSOR OUTPUT}}$ signal and the actual measure address. (See pin H for further description.)

S SWEEP FLAG -- A +10 volt level is present on this pin for the duration of a wired-program measurement sweep. (Should a negative level be required consult factory for modification information. This modification is required when operating with a Varian XL-100.)

U READOUT TRIGGER -- A transition from +5 volts to ground applied to this pin will cause the start of the Realtime Readout mode (either CRT or PEN) when the TRIGGER switch is in either the + or - position. This allows synchronization of the start of a Pen Readout cycle with external equipment.

V EXTRA DELAY MODE -- Grounding this pin, placing the TRIGGER switch in the + or - position, and placing the DELAY switch in the

Figure 8. Timing Diagram when Using EXTRA DELAY ENABLE mode.

POST position will allow the ADDRESS SELECTOR thumbwheel switches to insert a second delay, i. e. , a pre-delay before the start of data accumulation. This mode would be used when the 1080 is to control the timing of the experiment. (See Figure 8 for timing diagram.) For example, with the ADDRESS SELECTOR switches set at 00004, a DWELL TIME of 100 microseconds, a DELAY TIME of 1804 × 100 microseconds, and 8192 data points (8K) used, the following will be the sequence of events when the MEASURE (WIRED PROGRAM) pushbutton is depressed:

(1) The SWEEP FLAG signal (pin S) will go high (this can be used to trigger the experiment).

(2) For exactly 400 microseconds (ADDRESS SELECTOR switch setting multiplied by DWELL TIME switch setting, i. e. , 4 × 100) no data will be accumulated.

(3) At the end of this delay period data accumulation will start and continue for 819,200 microseconds (number of data points multiplied by DWELL TIME switch setting, i.e., 8192 × 100).

(4) At the end of this sweep period, the SWEEP FLAG signal will go to ground and the DELAY FLAG signal (pin A) will go high for 180,400 (1804 × 100) microseconds.

(5) At the end of this second delay period, the cycle restarts.

When these data are Fourier transformed, the frequency spectra will have an upper frequency value (f_{max}) of 5 KHz (1 / 2×DWELL TIME), and a frequency resolution (Δf) of 1.2207 Hz (1 / Number of data points × DWELL TIME) per data point. The total time of one acquisition cycle is 1 second of which 0.0004 seconds are used for pre-acquisition delay to permit feed-through energy to settle down, 0.8192 seconds for acquisition of the FID signal, and 0.1804 seconds are used to allow the nuclear spin system to relax to its equilibrium state. Note that this pre-acquisition delay of 400 microseconds will cause a contribution to the frequency dependent phase shift term "B" of 720 degrees (number of sampling intervals of delay × 180 degrees).

W CHASSIS GROUND -- This point is connected to the main frame and plug-in metal frame. In general it should not be used as circuit ground for either internally or externally generated signals.

B, J, R, X CIRCUIT GROUND -- All externally applied signals should be referenced to one of these ground connections. All internally generated signals are referenced to these ground connections.

B. Controls

DWELL TIME -- Four thumbwheel switches permit selection of the 4 most significant digits of the sampling period Δt. The rotary switch alongside the thumbwheel switches selects the decade multiplier of the thumbwheel switch settings and therefore determines whether the numbers indicate microseconds, tens of microseconds, etc. With the SD-82 Signal Digitizer the minimum setting for the Measure mode is 20 microseconds. (Any setting less than this will still result in a 20 microsecond dwell time.)

The setting of these switches is the sole determining factor of the sweep width f_{max} in Fourier nmr. The relationship is expressed

$$f_{max} = \frac{1}{2\Delta t}$$

where f_{max} is in Hertz when Δt is in seconds. Therefore to select the Δt setting given the desired sweep width in Hertz the relationship is

$$\Delta t = \frac{1}{2f_{max}}$$

or to select the Δt setting given the desired sweep width in parts per million (δ) the relationship is

$$\Delta t = \frac{1}{2F\delta}$$

where F is the nominal spectrometer frequency in megahertz for the nucleus being observed.

The Δt control along with the selection of the number of data points will affect the resolution of the frequency spectra after the Fourier transform operation. This relationship is

$$\Delta f = \frac{1}{N\Delta t}$$

where Δf is the change in frequency from one value of the frequency spectrum to the next adjacent one, and N is the number of data points selected for storage of the FID signal. Since f_{max} is the maximum frequency in the spectrum and Δf is the increment in frequency, then

$$\frac{f_{max}}{\Delta f} = \frac{1/2\Delta t}{1/N\Delta t} = \frac{N}{2}$$

is the number of frequency values that will be computed in the Fourier transformation.

For a given number of points of data storage (N) of the FID signal, a compromise has to be made between sweep width and resolution. Resolution (Δf) improves with longer observation time ($N\Delta t$) but sweep width (f_{max}) increases with shorter sampling periods (Δt).

Instead of the internally generated time base for sampling the analytical signal it is possible to use an external time base. Two methods are provided for connecting this external time base:

1. The external time base signal can be connected to pin K of the SWEEP CONTROL CONNECTOR and the DWELL TIME decade switch should be put in the EXTERNAL ADDRESS ADVANCE position. The thumbwheel

switches will then select the integer by which the input clock frequency will be divided.

2. If the frequency of the external time base signal has to be divided by any arbitrary integer, it can be connected to pin L of the SWEEP CONTROL CONNECTOR. The divisor is selected with the DWELL TIME thumbwheel switches and decade switch. In this case, pin N must be connected to pin X to inhibit the internal clock. The DELAY TIME thumbwheel and decade switches will now select the number of periods (× 10) of the external clock signal as the delay time.

DELAY TIME -- Four thumbwheel switches permit the selection of the 4 most significant digits of a delay time that can be inserted between the trigger signal and the start of a measurement sweep or between the end of a sweep and the beginning of a new sweep. The rotary switch alongside the thumbwheel switches selects the decade multiplier of the thumbwheel switch settings and therefore determines whether the thumbwheel numbers indicate microseconds, tens of microseconds, etc. up to 99.99 seconds.

DELAY MODE -- A selectable time delay may be inserted before the start of a measure sweep or at the end of a measure sweep if this switch is in the PRE or POST positions. If this switch is in the OFF position any setting of the DELAY TIME switches is ignored and a measure sweep begins immediately upon presentation of a trigger signal if the TRIGGER switch is in the + or - position or immediately upon completion of a sweep if the TRIGGER switch is in the AUTO position. (This continues until the preset number of sweeps as set on the main frame AUTOSTOP switch is reached.) Figures 9, 10, 11 and 12 show the timing relationships between the delay and sweep times when using external or autorecurrent trigger and PRE and POST delay modes.

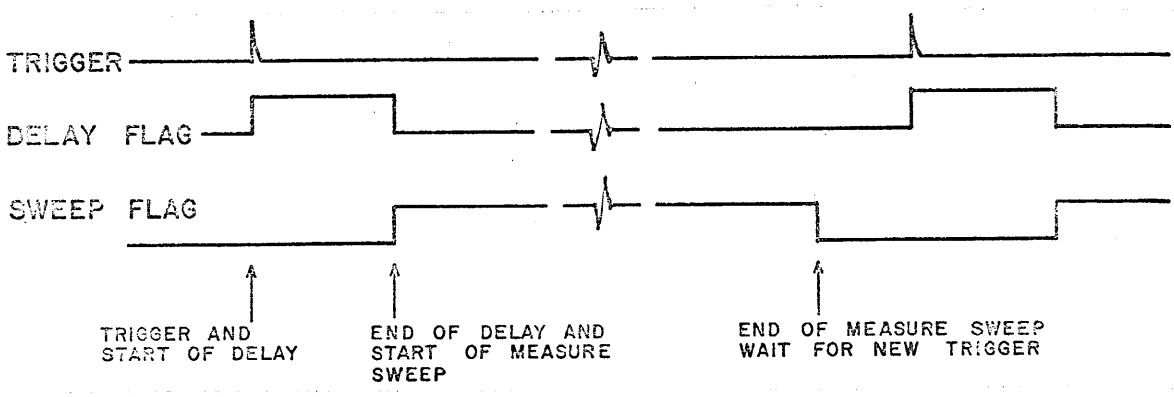


Figure 9. Timing Diagram when Using Delay Time with External Trigger and Predelay Mode

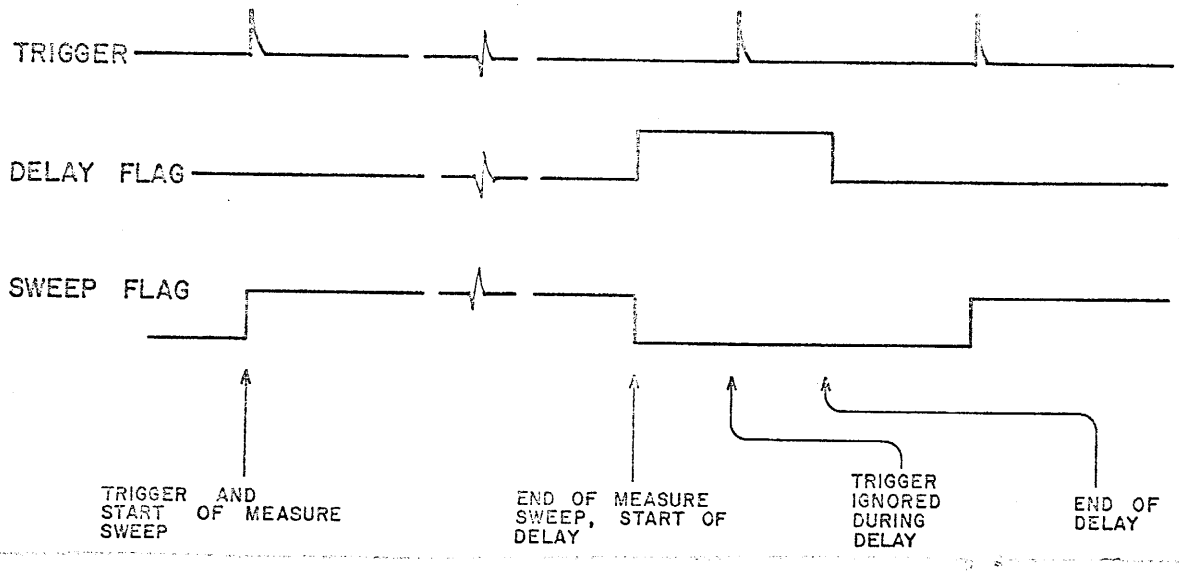


Figure 10. Timing Diagram When Using Delay Time with External Trigger and Postdelay Mode

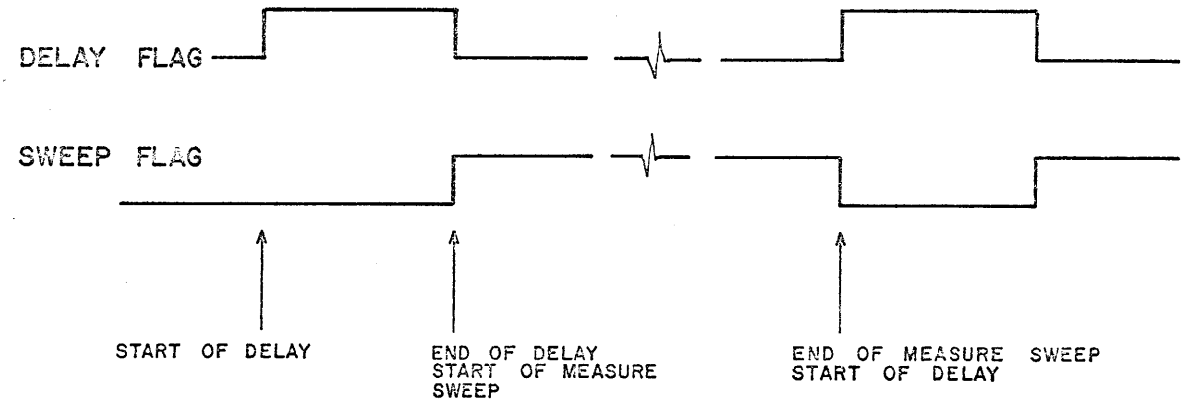


Figure 11. Timing Diagram When Using Delay Time with Autorecurrent Trigger and Predelay Mode

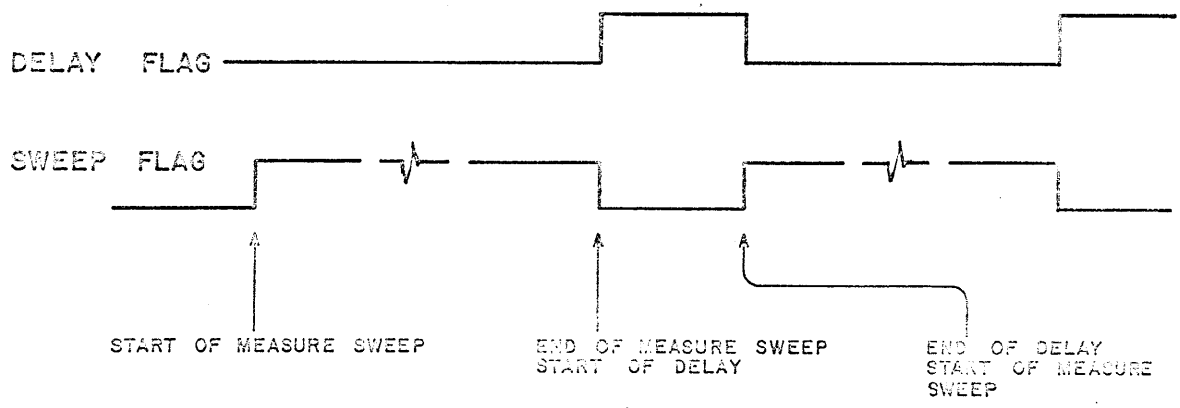


Figure 12. Timing Diagram When Using Delay Time with Autorecurrent Trigger and Postdelay Mode

TRIGGER -- These are two concentric controls with the small outer knob providing adjustment at trigger threshold level and the large inner knob selecting the mode of triggering a measure sweep. The modes of triggering the sweep may be either on the positive or negative slopes of an externally supplied trigger signal (connected to pin D of SWEEP CONTROL CONNECTOR) when the mode control is in the + or - position. When this mode switch is in the AUTO position a measure sweep is automatically started when the main frame WIRED PROGRAM START pushbutton is depressed and also when a sweep is completed. This will continue until a preset number of sweeps as set by the main frame AUTOSTOP has been made or until the main frame WIRED PROGRAM STOP button has been pushed.

The relationship between the + and - slope control and the threshold control is shown in Figure 13.

ADDRESS SELECTOR -- Five thumbwheel switches permit selection of a 5 digit decimal number for either display purposes or for timing purposes when in the Measure mode of operation.

When in the WIRED PROGRAM CRT READOUT mode, these switches will indicate the number of the relative address in memory which is being intensified on the CRT display. To determine the absolute address number, the number of addresses as indicated by the STARTING READOUT MEMORY ALLOCATION switch on the main frame must be added to the indicated number on the thumbwheel switches. There is a one address discrepancy due to the fact that when the switches are all set to zero, this signal is inhibited. That is, a thumbwheel settinf of 00001 will select address 0, a setting of 00002 address 1, etc.

Another use of these switches is for timing signals when in the WIRED PROGRAM MEASURE mode of operation. A +5 volt pulse will appear on pin H of the SWEEP CONTROL CONNECTOR when the sweep reaches the address number indicated by the thumbwheel switches. This pulse can then be used for external timing purposes.

If it is desired to have a pulse output after every n addresses after starting a measurement sweep, this can be accomplished by connecting pin J to pin F of the SWEEP CONTROL CONNECTOR and the output pulse again appears on pin H of this connector. In this case "n" is the number selected by the ADDRESS SELECTOR thumbwheel switches.

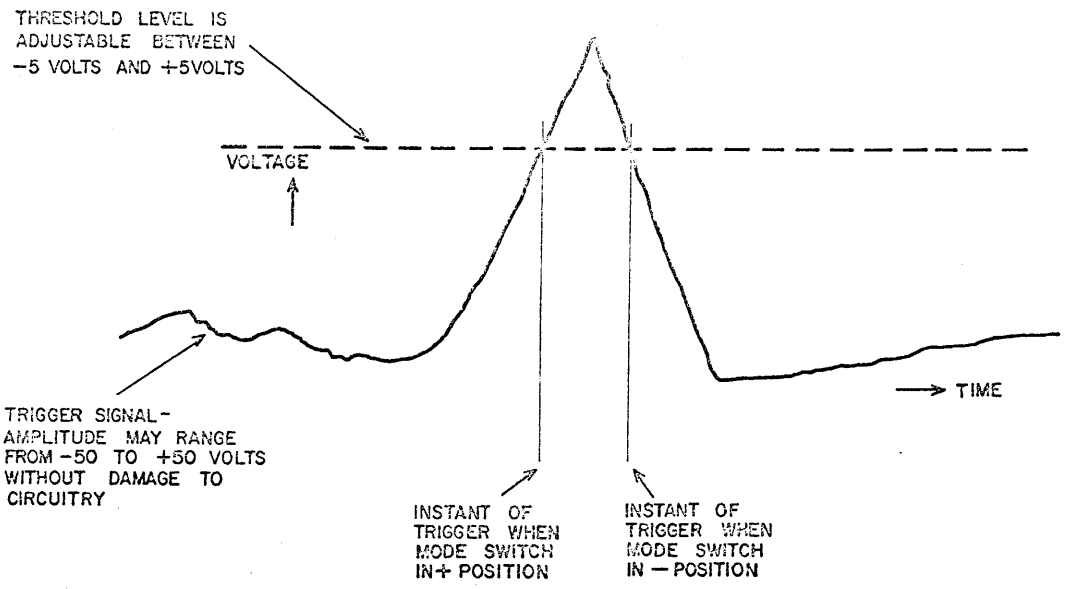


Figure 13. Illustration of Effect of Trigger Mode and Threshold Controls on Instant of Trigger

IV. 1080 MAIN FRAME

A. Connections

The SD-82 Signal Digitizer and SW-80 Sweep Control plug-ins are constructed so that either plug-in can be inserted on either the right or left hand 1080 main frame cavities.

Interconnections between the 1080 main frame rear panel and the Model 290 Display/Control unit are as follows:

1. Connect 80-pin printed circuit type cable connector labeled TO 1080 R3 to connector R3 marked INPUT/OUTPUT TO NIC-290 on the 1080 and the other end marked TO NIC-290 INPUT/OUTPUT to the Model 290 connector labeled INPUT/OUTPUT.

2. Connect 80-pin printed circuit type cable connector labeled TO NIC-1080 R4 to connector R4 marked DISPLAY CONTROL TO NIC-290 on the 1080 and the other end marked TO NIC-290 DISPLAY CONTROL to the Model 290 connector marked DISPLAY CONTROL.

3. Connect 80-pin terminator cord to connector labeled INPUT/OUTPUT on the 290.

4. Connect 24-pin connector cable between connector marked D. C. COMPUTER POWER on the 1080 and connector marked D. C. COMPUTER POWER on the Model 290.

5. Connect cable from Teletype I/O device to 1080 rear panel connector marked INPUT/OUTPUT DEVICE 1.

6. Connect Teletype power cord to Model 290 rear panel A. C. accessory power connector.

7. If extended memory unit Model 1080E is used, connect 80-pin printed circuit type connector cable labeled TO NIC-1080 R1 to R1 marked MEMORY CONTROL TO NIC-1080E on the 1080 and the other end marked TO NIC-1080E to the connector marked MEMORY CONTROL FROM NIC-1080 on the 1080E.

8. Connect 1080E power cord to Model 290 rear panel A. C. accessory power connector.

9. Connect three dual banana (BNC on later models) shielded cables from the rear panel 1080 connectors marked CRT DISPLAY HORIZ, VERT and J2 to the Tektronix 602 oscilloscope rear panel connectors marked X, Y and Z respectively.

10. Connect oscilloscope power cord to Model 290 rear panel A. C. accessory power connector. Operating procedure for the oscilloscope can be found in the Tektronix Model 602 Operating Manual.

11. If an X-Y recorder is to be used with this system, connections are made to the 1080 rear panel connectors marked PEN RECORDER HORIZ and VERT. Normally the Vertical Pen Output signal is a positive voltage. If a negative Vertical Pen Output signal is required, consult factory for modification information. (This modification is required when operating with a Varian XL-100.)

B. Controls

SWEEPS COMPLETED -- An electronic (light emitting diode), seven-digit decimal display indicates the number of measurement sweeps completed. Display is updated at the beginning of each sweep. (Maximum count is 9,999,999.) Once this counter has reached the preset value (see AUTOSTOP control) continued measurement sweeps cannot be accomplished until the counter is reset by means of the CLEAR SWEEP COUNTER control.

WIRED PROGRAM -- MEASURE, STOP and READ pushbuttons select the basic mode of wired program operation. The MEASURE button starts the wired program measurement operation. The STOP button will stop the wired program measurement after completion of the sweep in progress or will stop the wired program readout mode. The READ button initiates one of the following wired program readout operations.

Wired Program READ Modes:

CRT READOUT permits linear CRT display of data stored in memory.

CRT REAL TIME allows the CRT readout rate to be selected by the DWELL TIME controls on the SW-80 Sweep Control plug-in. Minimum DWELL TIME setting is approximately 10 microseconds and depends upon the setting of the VERTICAL DISPLAY SCALE switch. Dwell times of 20 microseconds or slower may be selected at any VERTICAL DISPLAY SCALE switch setting.

PLOTTER REAL TIME provides XY readout of data stored in memory to pen recorder output jacks on rear panel. In this mode, rate of address advance (X-axis scan) is determined either by DWELL TIME setting of the SW-80 Sweep Control or by external address advance commands applied to the sweep control unit.

PLOTTER AUTOSLEW provides XY readout of data stored in memory to pen recorder output jacks on rear panel. In this mode, rate of address advance is controlled by an internal readout clock. Readout rate is nominally 10 points per second in data regions where there is no change in Y-axis values from point to point, but where large changes occur between adjacent data points, the readout rate slows to approximately one point in two seconds. Readout rate and slew rate are internally adjustable. See section on internal adjustments. Between these extremes, the time between successive address advances is approximately proportional to the change in deflection voltage.

DIGITAL READOUT is available for initiating wired program digital readout.

DIGITAL READ-IN is available for initiating wired program digital read-in.

GENERAL: All of the above wired program read operations will operate only on the section of memory selected by the READOUT MEMORY ALLOCATION STARTING and SIZE pushbuttons.

CALIBRATE facilitates calibration of X and Y inputs to analog recording devices. HORIZONTAL pushbuttons permit selection of zero (LEFT), center (MIDDLE) or full-scale (RIGHT) X-axis outputs. VERTICAL pushbuttons permit selection of plus full-scale (TOP), zero (MIDDLE) or minus full scale (BOTTOM) Y-axis outputs. Any of nine possible combinations of these X and Y outputs may be selected. Selected deflection voltages appear at both X and Y output jacks on rear panel. The 1000 memory in the WIRED PROGRAM STOP mode may calibration voltages to be stored.

STORED PROGRAM -- START and STOP pushbuttons allow initiation and termination of operation under stored program control. (See Stored Program Operation section.) The stored program mode cannot be initiated unless the wired program mode is stopped.

ENABLE -- This pushbutton when depressed in conjunction with the CLEAR MEMORY and/or CLEAR SWEEP COUNTER pushbuttons will clear the section of memory being displayed and/or the SWEEPS COMPLETED indicator. The purpose of this pushbutton is to prevent accidental erasure of valuable information.

CLEAR MEMORY -- When this pushbutton is depressed simultaneously with the ENABLE pushbutton, the contents of the memory subgroup selected by the READOUT MEMORY ALLOCATION pushbuttons only will be erased. Operable only in CRT READOUT mode.

CLEAR SWEEP COUNTER -- When this pushbutton is depressed simultaneously with the ENABLE pushbutton, the contents of the SWEEPS COMPLETED indicator is set to zero.

INPUT DATA -- ADD/SUBTRACT pushbuttons determine whether digital data acquired under wired program control are to be added to or subtracted from prior contents of memory (if any) in MEASURE mode.

PROGRAM PROTECT -- When this button is depressed the ILLEGAL MEMORY warning lamp is illuminated when operator selects for display or data storage a non-existent section of memory or the portion of memory in which the stored program instructions are located. It is good practice to keep this button depressed except to display the section of memory reserved for program storage.

VERTICAL DISPLAY SCALE -- Selects the 12 most significant bits of memory contents to be presented to the digital-to-analog converter. The converted analog signal is used for both the Y-axis CRT display and the Y-axis PEN output. Vertical display scale ranges of 4, 8, 16, 32, 64, 128, 256, 512, 1K, 2K, 4K, 8K, 16K, 32K, 65K or 131K counts/division (8 divisions) are switch selectable. This in effect is a digital attenuator control on the displayed data. Memory contents are not affected by the position of this control, only the manner in which they are decoded. It may be used in both wired program and stored program display modes, but must be programmed to be used during stored program operation.

READOUT MEMORY ALLOCATION -- Two banks of pushbuttons permit selection of STARTING addresses (0, 1K, 2K, 4K or 8K) and SIZE (1K, 2K, 4K, 8K or 16K) of memory which may be used for data readout and/or stored program READ modes of operation. More than one STARTING address pushbutton may be pushed in each bank to obtain a summing address additively up to 16K. These switches also establish the section of memory that will be operated on during stored program operation.

AUTOSTOP -- Permits preselection, for automatic stop, of a number of measurement sweeps equal to 2^n, n being any integer from 0 to 20. (Autostop range is selectable from 1 to 1,048,576 in powers of two.) An OFF position enables continuous sweeping until manually stopped. The number of sweeps completed is stored in an auxiliary register and is displayed on the SWEEPS COMPLETED numerical display.

MEASURE MEMORY ALLOCATION -- Two banks of pushbuttons permit selection of STARTING address (0, 1K, 2K, 4K or 8K) and SIZE (1K, 2K, 4K, 8K or 16K) of memory subgroup to be used for data storage in wired program MEASURE mode of operation. Two or more STARTING address pushbuttons may be depressed to select any starting address in integral multiples of 1K up to 15K.

HORIZONTAL DISPLAY SCALE -- Selects the portion of memory to be displayed over full scale horizontal deflection of CRT. Horizontal display scale ranges of 1K, 2K, 4K, 8K and 16K are switch selectable, and can affect both wired and stored display operations without programming.

VIEW INPUT/MEMORY/CONTINUOUS -- Three pushbuttons allow selection of digitized input signal (INPUT), live display of accumulation of data in the memory addresses (MEMORY) or continuously updated display of entire contents of all addresses in the selected memory subgroup (CONTINUOUS) for presentation on the CRT during wired program MEASURE mode of operation.

ADJUSTMENT OF STACK SIZE SWITCH -- The small Printed-Circuit switch at the rear of 1080 Board 2 marked "Stack" adjusts the memory protect electronics of the 1080. The purpose of the memory protect is to prevent the 1080 hard-wired programs from destroying the stored-program. The switch is set by the following table:

1081	4K
1082	8K
1083	12K
1084	16K
1085	20K
1086	24K
1087	28K
1088	32K
1089	36K
10810	36K