Extending Frequency Range and Increasing Effective Sample Rate on the 5180A Waveform Recorder
**Introduction**

This note describes a 5180A based system that can be used with repetitive inputs to extend the unaliased frequency measurement range beyond 10 MHz (10 MHz is the 5180A's stand-alone unaliased range limit) and provide effective sample rates in excess of 20 MegaSamples/Second (20 MS/S is the maximum sample rate possible on the 5180A). This system enhances 5180A capability in the same way that a sampling oscilloscope enhances oscilloscope capability. Like the sampling scope, the "sampling 5180A" is useful for extending the frequency measurement range and for providing more complete sampling of any repetitive input.

A feature of the 5180A Sampling System is that fast effective digitizing rates are achieved without sacrificing amplitude resolution. Traditionally, to adequately sample higher frequency input signals, waveform recorders with faster maximum digitizing rates have provided the only solution. A drawback of these faster waveform recorders is that they sometimes don't provide sufficient amplitude resolution to obtain useful measurement results. The 5180A Sampling System can, when the input is repetitive, make these measurements with very good resolution in both amplitude and time. An example of the enhancement that this system can provide appears in Figure 1.

![Figure 1](attachment:image.png)

**Figure 1.** Top display shows pulse train data captured by waveform recorder alone (20 MHz conversion rate). Lower display shows same input captured using system described in this note.
Performance characteristics for the 5180A Sampling System are summarized in the table below:

<table>
<thead>
<tr>
<th>5180A Input Channel</th>
<th>Maximum Recommended Input Frequency (3 dB Bandwidth)</th>
<th>Maximum Effective Sample Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>A or B</td>
<td>40 MHz</td>
<td>20 GHz</td>
</tr>
<tr>
<td>Auxiliary</td>
<td>70 MHz</td>
<td></td>
</tr>
</tbody>
</table>

An indication of the quality of the data as a function of the input frequency (dynamic performance) for the system is shown in Figure 9, which summarizes the results of extensive sine wave curvefit testing.*

**Highlights of System Operation**

In addition to the 5180A Waveform Recorder, the 5180A Sampling System requires a programmable timing generator and an instrument controller. The system implementation described in this note uses a 5359A Time Synthesizer and a 9826 Controller. Figure 2 shows the set-up.

![Figure 2. 5180A sampling system.](image)

The measurement technique is similar to that used in a sampling scope – the sample point is walked through the input by successively increasing the delay between the occurrence of an input trigger and the time the input is sampled. As can be seen from Figure 2, the 5359A is externally triggered by the input signal. **The time between occurrence of this trigger and the output of a pulse from the 5359A is precisely controllable (increments as small as 50 picoseconds), so the 5359A provides the variable delay capability.** The output pulse from the 5359A is the input that tells the 5180A when to sample the input signal. A detailed description of the system operation appears in the next section.

*The sine wave curvefit test is an ADC (Analog-to-Digital Converter) performance measure used by Hewlett-Packard and other waveform recorder producers to evaluate the overall quality of the analog-to-digital conversion process. This test is particularly meaningful because it incorporates many of the error factors that can degrade ADC performance.

**For repetitive inputs that don't have a uniquely definable trigger within one period of the input waveform, such as phase coherent pulsed RF (no unique trigger is definable because the signal passes through the same level with the same slope many times within one period), another trigger signal must be generated. For example, with phase coherent pulsed RF, the modulating signal could be used as the trigger.**
Here’s How it Works

When the 5180A Sampling system is collecting data it iterates through a simple procedure that can be described in chronological steps:

**STEP A:** The input passes through the external trigger level set on the 5359A Time Synthesizer, thus triggering it.

**STEP B:** The amount of delay time that has been programmed into the 5359A elapses.

**STEP C:** At the end of the delay time the 5359A generates a pulse.

**STEP D:** The output pulse, being the timebase for the 5180A, causes the 5180A to sample the input once.

**STEP E:** After the 5359A output pulse has occurred, the 5359A is automatically re-armed and again becomes ready to accept an external trigger.

Steps A-E are repeated as many times as there are data points in the 5180A record (determined by 5180A RECORD LENGTH value).

**STEP F:** Once the record has filled, the data is output to the 9826 Controller and the 5359A delay time is increased. Steps A-E are then repeated again.

The process continues until the desired number of measurements have been taken.

**STEP G:** The measurement data is processed and the results are written to the 5180A, or may be plotted on the 9826 display.

The 9826 Controller oversees the entire measurement process. This sequence of steps is depicted in Figure 3. Figures 4 and 5 show the signal timing relationships.

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**Figure 3.** Flow diagram for measurement process.
Figure 4. Timing relationships for 5180A sampling system. $T_D$ is 5359A delay time. • indicates the value of the input when the sample occurs.

Figure 5. Successive data records are collected at successive time delays for complete sampling of input.

### Processing the Data

As each data record is output to the 9826 Controller, the data may be averaged and the average saved or a single data point can be saved. Averaging the data is useful for removing noise (random) components from the input signal. The "smoothing" effect of averaging is illustrated in Figure 6.

Whether the data is averaged or not, the input signal is reconstructed by plotting or displaying the saved data point from each record versus the value of the time delay associated with that record.

Figure 6. Averaging reduces the effect of random noise.
Putting the System Together

The equipment set-up and required interconnections are shown in Figure 2. A step-by-step procedure for making the 5180A Sampling System operational is provided below:

1. Complete the system interconnections according to Figure 2. HP-IB device addresses are: 04 for the 5180A, and 10 for the 5359A.

2. A rotary switch near the 5180A's timebase-in input can be set to sample at various input levels: -1, -.3, 0, or 1.8 volts into 50 ohms. Since the 5359A has flexible output level capability, any of the 5180A's timebase-in threshold levels could be used. The simplest choice is to set the rotary switch for a zero volt threshold (position 3).

3. Set the 5180A by pressing the SHIFT key followed by the key marked PRESET. Position the rear-panel INT/EXT timebase switch to EXT, and select the AUTO sweep arming mode.

4. Set the 5359A front panel to:
   - Sync Delay ................. Preset
   - Polarity ..................... Norm and Pos
   - Offset ........................ On

5. On power-up the 5359A outputs a 1 MHz repetitive pulse train. This signal is convenient for establishing that the 5359A output is actually causing the 5180A to sample. Set the output level on the 5359A by pressing DISPLAY LEVELS to bring up the amplitude and offset values on the 5359A display. Adjust the amplitude to about 2 volts with a -1 volt offset. This should cause the output pulse to change from -1 to 1 volt, thus assuring that the 5180A timebase-in threshold level is crossed. If sampling is occurring the input signal will be changing on the XYZ display and the ARM and TRIG annunciators on the 5180A will be flashing. If the 5180A isn't sampling, check and adjust the 5359A output levels.

6. Having verified that the 5359A output is causing the 5180A to sample, the final hardware step is to set the external trigger level on the 5359A. With input signal applied press the DELAY key on the 5359A. The 5359A display will blank, indicating that it's waiting for you to input a delay value. Press 10 (data entry section) followed by ns (units section). This entry specifies that the 5359A will output a pulse 10 nanoseconds after the occurrence of an external trigger (there is some additional fixed delay, but this isn't important). Use the external trigger level adjustment to set an appropriate external trigger level. To verify that an unambiguous trigger level has been chosen, view the captured waveform on the XYZ display. The waveform should be live and essentially a horizontal line. The display represents the data for one sample point of the repetitive input. Since all the data is being taken at the same delay time after the 5359A is externally triggered, you would expect the displayed waveform to be a horizontal line (see Figure 4). If it isn't horizontal, or if the 5180A isn't sampling, adjust the external trigger level on the 5359A.

Once the previous six steps have been successfully completed the system hardware is operational. The system software remains to be loaded into the 9826 Controller. The system software, with documentation and a variable list, is presented in the appendix.

Some of the key features of the 5180A Sampling System software are:

- Softkeys are used to control all system functions.
- Using the softkeys the following parameters can be controlled by the user:
  1) Effective sample rate
  2) Number of samples per measurement
  3) Extent of averaging per sample point
  4) 5180A record location for storing measurement results
  5) High-speed or Normal acquisition mode. The normal acquisition mode uses the measurement procedure of Figure 3. The high-speed mode employs a slightly different procedure, using the 5180A's AUTO ADVANCE feature to sample up to 32 points before any data is output from the 5180A.
Once the data is collected and processed in the 9826 it is automatically written back into the 5180A. The 5180A display controls can then be used to examine the captured waveform. The amplitude levels are accurate but no time per sample information is available from this display.

The PLOT softkey displays the measurement result on the 9826 display. An advantage of this display over the data as stored and displayed by the 5180A is that the scaling is optimized on the 9826 display for the actual amplitude and time range of the measurement. A dot/line mode similar to this feature on the 5180A is provided on the 9826 display. Also, a cursor may be enabled for simultaneous time and voltage readout of the data on the 9826 display. These readouts appear in the softkey menu area. Positioning of the cursor is controlled via the 9826 control knob. Illustrations of the 9826 display plot appear below.

Figure 7. The cursor voltage and time values appear in the softkey menu.
8A. Square wave output captured using sampling technique. Effective sample rate is 667 MHz. (1.5 nanoseconds/sample).

8B. 53.64 MHz sine wave captured using sampling technique. Effective sample rate is 4 GHz. (250 picoseconds/sample).

8C. Output captured using sampling technique. Effective sample rate is 1 GHz. (1 nanosecond/sample).

Figure 8. Examples of system output.
Measurement Considerations

An indication of typical dynamic performance for the 5180A Sampling System is shown in Figure 9, which plots input frequency versus effective bits (an excellent description of "effective bits" and the test that determines this result appears in 5180A Product Note 5180-2).

![Effective Bit Performance of 5180A Sampling System](image)

Figure 9. Dynamic Performance data for 5180A Sampling System. Effective sample rate was 500 MHz.

Other important considerations regarding the performance of the 5180A Sampling System are described below.

1. **5180A INPUT BANDWIDTH**
   The input bandwidths of the 5180A (see table, page 2) impose an upper limit on the frequency extension range of the system. Since the 5180A front-end can be modeled as a single-pole low pass filter (for any of the input channels), data can be collected beyond the 3 dB point, but attenuation and phase-shifting will affect the data according to Figures 10 and 11.

2. **5359A EXTERNAL TRIGGER BANDWIDTH**
   Since the 5359A Time Synthesizer is externally triggered by the input signal in most implementations of the system (for an exception see the footnote on page 4), the external trigger bandwidth can impose limitations. Measurements taken to evaluate this limitation indicate that the 5359A will trigger reliably for inputs up to 100 MHz.

3. **5359A MINIMUM DELAY STEP SIZE**
   The 5359A delay step is the effective time per sample of the 5180A Sampling System. Since the minimum delay step size on the 5359A is 50 picoseconds, the maximum effective sample rate is 1/50 picoseconds = 20 GHz. NOTE: This doesn't mean, of course, that inputs in the GHz range can be captured using the 5180A Sampling System (see the previous two points for the reasons). It does mean that lower frequency, repetitive inputs can be sampled at a 20 GHz rate.
Figure 10. $A_{OUT}$: Output magnitude (value measured in 5180A)  $A_{IN}$: Input magnitude

Figure 11.
4. 5359A OUTPUT STABILITY

Since the 5359A controls the sampling of the 5180A Waveform Recorder, the output jitter of the 5359A is actually the aperture uncertainty of the 5180A Sampling System. The effect of aperture uncertainty is a factor in the effective bit measurement. 5359A output jitter (specified at 100 pico-seconds TYPICAL) is probably the main cause of performance degradation with increasing input frequency.

5. SYSTEM ACQUISITION TIME

Since the measurement technique requires multiple passes through the input signal before the data can be processed, the time to acquire the signal is an important measurement consideration. The acquisition time is the time between collecting the first data point in the first data record and the last data point in the last record. Acquisition times for the 5180A Sampling System are shown in Figure 12.
Appendix : 5180A Sampling System Software

The 5180A Sampling System is controlled by the system software listed in this appendix. The program is written for BASIC as implemented in the 9826A controller. The structure of the software should be evident from the variable list and documentation included alongside the program listing. To operate the system software is simple: after pressing RUN all of the user options appear in the softkey menu. To modify a parameter, press the appropriate softkey, respond to the prompt, and press CONTINUE on the 9826.

The DISPLAY, PLOT, and CURSOR subroutines are useful as general purpose subroutines and could be used with the 5180A in any application to bring the data up on the 9826 display. Although not implemented in this listing, it should be possible to modify the HISPEED subroutine to sample more than 32 points. This could be accomplished using a DMA data transfer from the 5180A to the 9826 following each filling of the 5180A memory. The transferred data could be held in the controller while another series of 32 measurements is taken. This process could be repeated many times (the 9826 has plenty of memory to hold the unprocessed data) and then finally, all the data in the 9826 could be processed to obtain the measurement result.

Variable List and Definitions : in Order of Appearance in the Program

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>C[*]</td>
<td>used to store 5180A teach strings</td>
</tr>
<tr>
<td>Code(*)</td>
<td>Data array (if memory limitations become important, Code(*) could be ALLOCATED (see 9826 manual) instead of being dimensioned).</td>
</tr>
<tr>
<td>Location</td>
<td>5180A record location where processed data will be stored</td>
</tr>
<tr>
<td>Average</td>
<td>Number of averages per sample point</td>
</tr>
<tr>
<td>R</td>
<td>Effective sample rate</td>
</tr>
<tr>
<td>Samples</td>
<td>Number of samples per measurement</td>
</tr>
<tr>
<td>Length</td>
<td>5180A record length</td>
</tr>
<tr>
<td>Flag</td>
<td>Indicates high-speed or normal measurement mode</td>
</tr>
<tr>
<td>C</td>
<td>Temporary data storage</td>
</tr>
<tr>
<td>Stay</td>
<td>Flag to allow new display plot on 9826</td>
</tr>
<tr>
<td>Channel</td>
<td>5180A input channel (1=A, 2=B, 4=auxiliary)</td>
</tr>
<tr>
<td>Range</td>
<td>5180A input range</td>
</tr>
<tr>
<td>Offset</td>
<td>5180A offset</td>
</tr>
<tr>
<td>Minimum</td>
<td>Minimum Code(*)</td>
</tr>
<tr>
<td>Maximum</td>
<td>Maximum Code(*)</td>
</tr>
<tr>
<td>V_{max}</td>
<td>Maximum voltage of data</td>
</tr>
<tr>
<td>V_{min}</td>
<td>Minimum voltage of data</td>
</tr>
<tr>
<td>Connect</td>
<td>Flag identifying dot or line mode for 9826 display plot</td>
</tr>
<tr>
<td>Mov</td>
<td>Variable indicating cursor position for 9826 display plot</td>
</tr>
<tr>
<td>Old</td>
<td>Previous value of Mov</td>
</tr>
<tr>
<td>Left</td>
<td>Indicates Sample range over which data must be re-plotted on 9826 display following a cursor erase</td>
</tr>
</tbody>
</table>
10 !
20 "5180A SAMPLING SYSTEM"
30 !
40 'Main:
50 DIM, CS[300], Code(16384)
60 A$="NORMAL"
70 Length=512
80 Location=l
90 Average=1
100 GRAPHICS OFF
110 ASSIGN @H5180 TO 704
120 ASSIGN @H5359 TO 710
130 ON KEY 0 LABEL "TIME/PT" GOSUB Sample
140 ON KEY 2 LABEL "SAMP="/VAL$(Samples) GOSUB Number
150 ON KEY 3 LABEL A$ GOSUB Mode
160 ON KEY 4 LABEL "MEASURE" GOSUB Measure
170 ON KEY 5 LABEL VAL$(R) GOSUB Sample
180 ON KEY 7 LABEL "REC="/VAL$(Location) GOSUB Record
190 ON KEY 8 LABEL "AVE="/VAL$(Average) GOSUB Average
200 ON KEY 9 LABEL "PLOT" GOTO 1110
210 DISP "SELECT DESIRED FUNCTION"
220 OFF KEY
230 GOTO 130
240 !
250 Sample: !
260 INPUT "ENTER SAMPLE RATE",R
270 OUTPUT @H5359; "DSS",R
280 RETURN
290 !
300 Number: !
310 INPUT "ENTER NUMBER OF SAMPLES", Samples
320 RETURN
330 !
340 Average: !
350 INPUT "ENTER AVERAGES PER SAMPLE", Average
360 FOR I=9 TO 14
370 IF Average<2^I THEN GOTO 390
380 NEXT I
390 Length=2^I
400 RETJRN
410 !
420 Mode: !
430 IF Flag=0 THEN
440 A$="HI-SPEED"
450 Flag=1
460 ELSE
470 A$="NORMAL"
480 Flag=0
490 END IF
500 RETURN
510 !
520 Measure: !
530 DISP "MEASUREMENT IN PROGRESS"
540 OUTPUT @H5359; "DOE-9,20E-9"
550 OUTPUT @H5180; "TEL,SA3,SE1,PP5,LE",Length
560 FOR I=1 TO Samples
570 Code(I)=0
580 NEXT I
590 IF Flag=1 THEN GOTO Hispeed
600 OUTPUT @Hp5180;"LO","Location
610 FOR I=1 TO Samples
620 OUTPUT @Hp5180;"MT"
630 IF BIT(SPOLL(704),3)=0 THEN GOTO 630
640 OUTPUT @Hp5180;"OS","Location
650 OUTPUT @Hp5180;0,Average
660 FOR J=1 TO Average
670 ENTER @Hp5180;C
680 Code(I)=Code(I)+C
690 NEXT J
700 Code(I)=Code(I)/Average
710 OUTPUT @Hp5180;"DSU"
720 NEXT I
730 GOSUB Display
740 LOCAL @Hp5180
750 RETURN
760 !
770 Hispeed: !
780 OUTPUT @Hp5180;"ADO,LO1,\A1"
790 OUTPUT @Hp5180;"SA3"
800 Samples=(16384/INT(Length))
810 DISP "MEASUREMENT IN PROGRESS"
820 FOR I=1 TO Samples
830 OUTPUT @Hp5180;"MT"
840 IF BIT(SPOLL(704),3)=0 THEN GOTO 840
850 OUTPUT @Hp5180;"DSU"
860 NEXT I
870 FOR I=1 TO Samples
880 DISP "ACQUISITION COMPLETE"
890 OUTPUT @Hp5180;"OS","I
900 OUTPUT @Hp5180;0,Average
910 FOR J=1 TO Average
920 ENTER @Hp5180;C
930 Code(I)=Code(I)+C
940 NEXT J
950 Code(I)=Code(I)/Average
960 NEXT I
970 GOTO 730
980 !
990 Display: !
1000 FOR I=Samples+1 TO Length
1010 IF Samples=Length THEN GOTO 1040
1020 Code(I)=512
1030 NEXT I
1040 OUTPUT @Hp5180;"JB","Location
1050 FOR I=1 TO Length
1060 OUTPUT @Hp5180;Code(I)
1070 NEXT I
1080 OUTPUT @Hp5180;"TL","Location
1090 RETURN
1100 !
1110 Plot: !
1120 Stay=0
1130 DISP ","
1140 OFF KEY
1150 OFF KNOB
1160 ON KEY 0 LABEL "EXIT" GOTO 100
1170 ON KEY 2 LABEL "CURSOR" GOTO 1890
ON KEY 4 LABEL "DOT" GOTO 1810
ON KEY 5 LABEL "PLOT" GOTO 100
ON KEY 9 LABEL "LINE" GOTO 1850
IF Stay=1 THEN GOTO 1210
GCLEAR
GRAPHICS ON
VIEWPORT 20,125,20,90
WINDOW 0,100,0,100
CLIP ON
AXES 20,10,0,0
CLIP OFF
CSIZE 5
MOVE 50,-15
LABEL "TIME (SECONDS)"
DESC
LDIR 90
MOVE -17,50
LABEL "VOLTAGE"
LDIR 0
CSIZE 3.4
LORG 5
OUTPUT @hp5180:"OI",Location
ENTER @hp5180;C$
FOR I=1 TO LEN(CS)
IF C$[I,I]=" " THEN C$[I,I]="+
NEXT I
Channel=VAL(C$[POS(C$,"ch")]+2)
IF Channel=1 THEN B$="a"
IF Channel=2 THEN B$="b"
Range=VAL(C$[POS(C$,"r")]+2)
Offset=VAL.(C$[POS(C$,"o")]+2)
IF Channel=4 THEN Range=1
IF Channel=4 THEN Offset=0
Minimum=1023
FOR I=1 TO Samples
IF Code (I) >Maximum THEN Maximum=Code (I)
IF Code (I) <Minimum THEN Minimum=Code (I)
NEXT I
Vmax=Range* (Maximum-512)*.002-Offset
Vmin=Range* (Minimum-512)*.002-Offset
WINDOW 0,R*Samples,Vmin,Vmax
FOR I=1 TO 10
MOVE -.1*R*Samples,Vmin+( (Vmax-Vmin)*I/10)
LABEL USING "SDD.0D";Vmin+( (Vmax-Vmin)*I/10)
NEXT I
FOR I=1 TO 5
MOVE R*Samples*I/5,Vmin-.07*(Vmax-Vmin)
LABEL R*Samples*I/5
NEXT I
FOR I=1 TO Samples
IF Connect=1 AND I>1 THEN GOTO 1710
MOVE I*R,Range*(Code(I)-512)*.002-Offset
DRAW I*R,Range*(Code(I)-512)*.002-Offset
NEXT I
IF Stay=1
GOTO 1130
Determine 5180A record location for data storage

Don't connect the data points

Connect the data points

Determine new cursor position

Erase old cursor

Re-plot data destroyed by cursor erase

Put cursor information in Soft Key label area

DRAW Old*R, Range*(Code(Old) - 512)*.002-Offset

DRAW Old*R, Range*(Code(Old) - 512)*.002-Offset

DRAW Old*R, Range*(Code(Old) - 512)*.002-Offset

Put cursor information in Soft Key label area

Old=Mov

SAVE Cursor

END