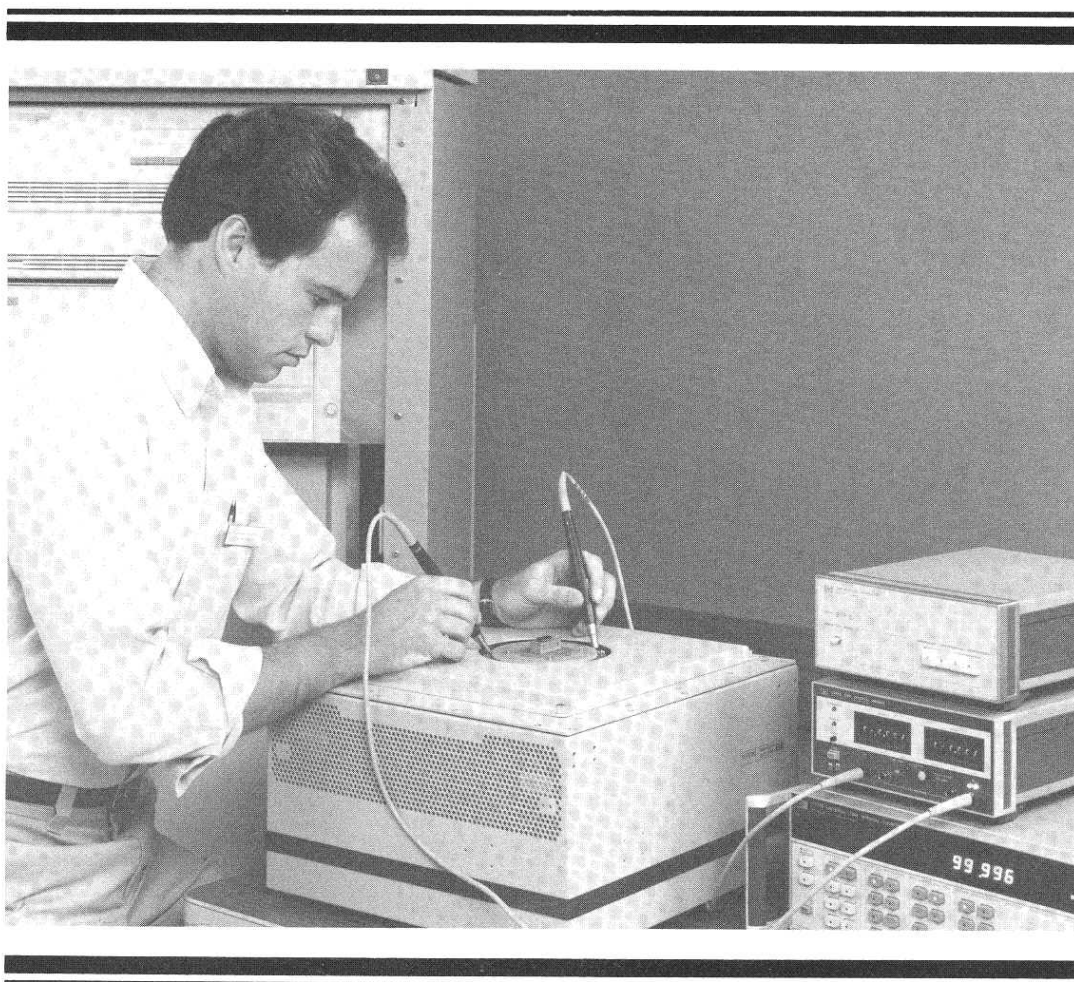# Better than 100 ps Accuracy

in HP 5370B Time Interval Measurements

Through Bias Error Reduction

5370B UNIVERSAL TIME INTERVAL COUNTER

Contents

Introduction

When you make precision time interval measurements with the HP 5370B, the most significant errors are usually systematic (or bias) errors. These can add up to 1 ns of uncertainty to a measurement. Averaging is the technique which is used to reduce random (or resolution) errors. Here we will show you techniques to reduce systematic errors, so that you can make time interval measurements with absolute accuracies on the order of ±100 ps.
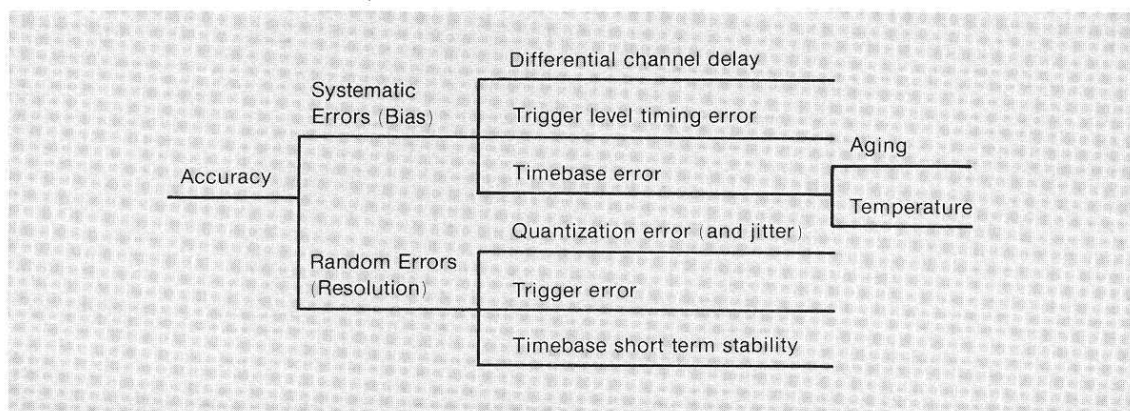

Figure 1. These are the sources of error in time interval measurements. For more detailed information, refer to Application Notes 200-3 and 200-4.

As can be seen from Figure 1, systematic errors are caused primarily by differences in start and stop channel path lengths, and by trigger level timing error. All of these are influenced by slope selection, slew rate and trigger level setting. (Timebase error is rarely a limiting factor, and is easily calibrated.) This product note, then, will focus on the reduction of systematic errors.
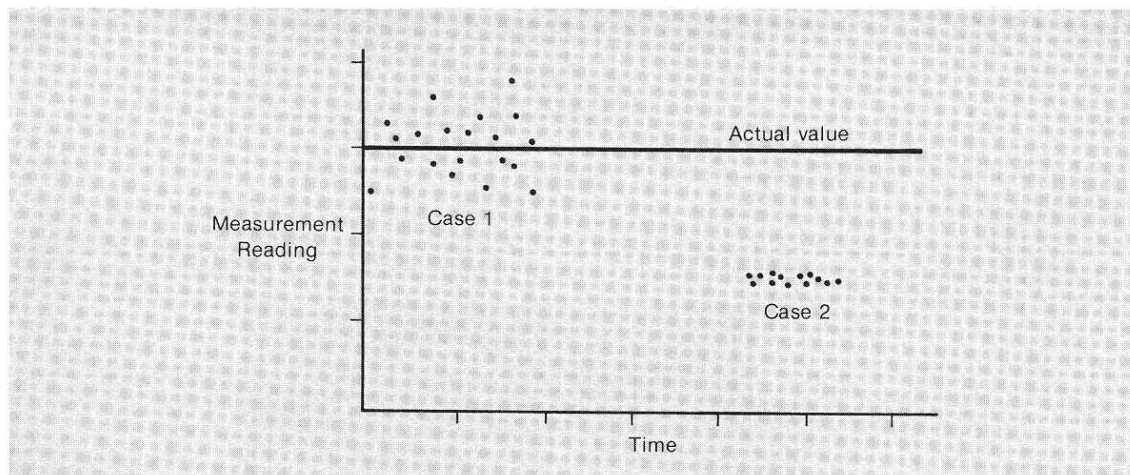

Figure 2. Case 1 shows the results of a random error limited measurement, which can be improved by averaging. Case 2 shows the results of a systematic error limited measurement. Systematic errors must be measured in order to remove them.

1

Applications

ATE Calibration:

Automatic Test Equipment — such as IC Testers — often need to measure propagation delays, pulse widths and rise/fall times with accuracies on the order of ±1 ns. To verify performance of these systems, frequent calibrations with a Time Interval Counter with an order of magnitude better accuracy (±100 ps) is required. This is an excellent application for the HP 5370B with the calibration scheme described below.
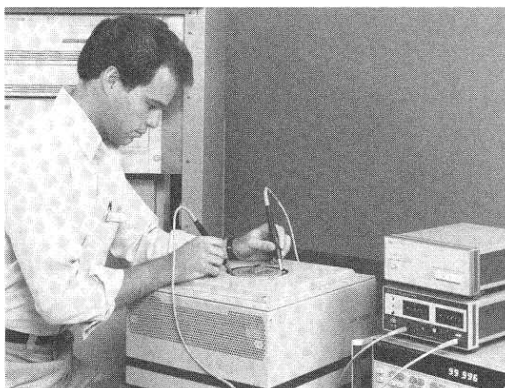
IC Characterization:

When characterizing faster IC's with, for example, propagation delays on the order of 10 ns, a measurement uncertainty of only ±1% means a measurement accuracy of ±100 ps. This is a good match to a calibrated HP 5370B.
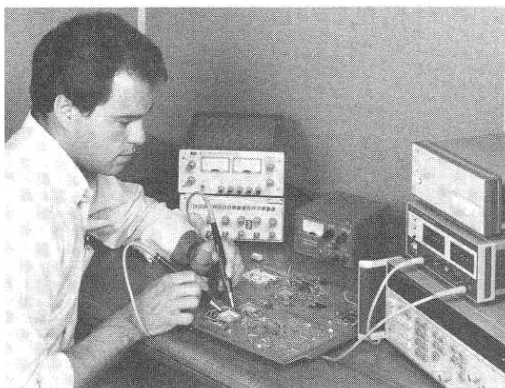
Magnetic Disc Drive and Media Test:

When measuring peak-shift on a disc drive, a histogram technique is often applied. For newer drives, the bin size in the histogram can be as small as 1 ns. For an accurate measurement, the measuring instrument should have an order of magnitude better accuracy, namely ±100 ps — the domain of a calibrated HP 5370B.

Systematic Error Reduction

If you use the following calibration technique, you can measure the systematic errors and subtract these from your subsequent measurements. This reduction of systematic errors can improve the accuracy of the HP 5370B to better than ±100 ps.

Determining the Systematic Error:

You can determine the systematic error associated with any measurement by sending edges, which are separated precisely by a measurable time, into the Start and Stop signal paths of the counter. The counter measures the difference in time between the start and stop events. This difference leads us to the systematic error for a particular set of measurement conditions. Note that systematic errors are influenced by edge transition rates, trigger levels and triggering edge (or slope) selection, so for any change in these conditions, new calibration factors must be determined.

The following pages show you the practice and theory of systematic error reduction as it applies to Time Interval, Pulse Width and Transition (Rise/Fall) Time measurements.
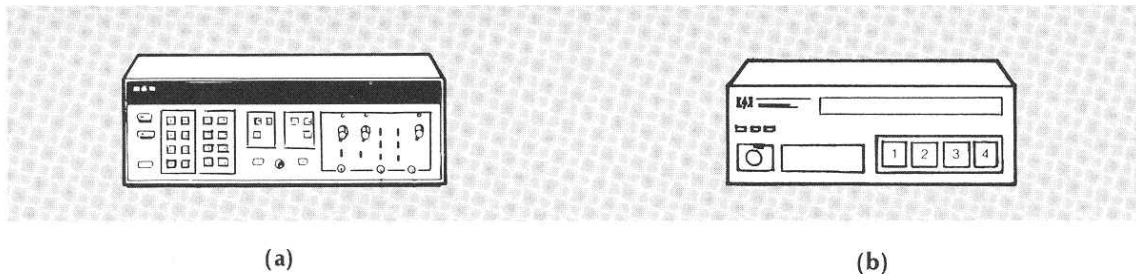
Necessary Equipment:

(a)   (b)

Figure 3. (a) The 5370B counter has the necessary resolution and accuracy to benefit from this calibration process. **(b)** The J06-59992A Time Interval Calibrator is the heart of this calibration process.

(a)   (b)
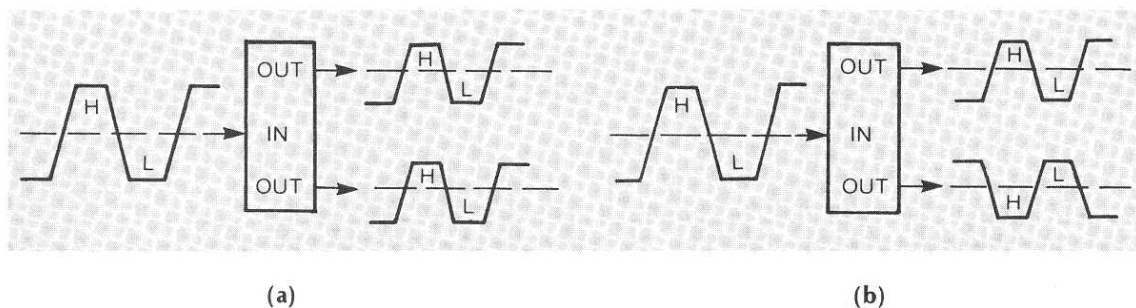
Figure 4. (a) The P calibrator is an in phase power splitter, which produces two signals with a small relative time offset. **(b)** The N calibrator is an inverting power splitter which produces two signals exactly mirrored about zero volts, and with a small relative time offset.

Other requirements are:
> A Stable Pulse Source — which can duplicate the edges you are to measure and generate a 50% duty cycle in the range 100 kHz to 50 MHz.
> 5363B Time Interval Probes — optional depending on your measurement needs
> A DC Voltage Reference — optional depending on your measurement needs
> 50 ohm terminations — optional depending on your measurement needs

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Time Interval Measurement Calibration ———

Time Interval calibration is the most direct and most accurate of the calibration procedures described in this product note. First we will present the procedure for you to follow to make time interval measurements with accuracies better than ±100 ps. Then, for those interested, we will present the basic theory behind the procedure.
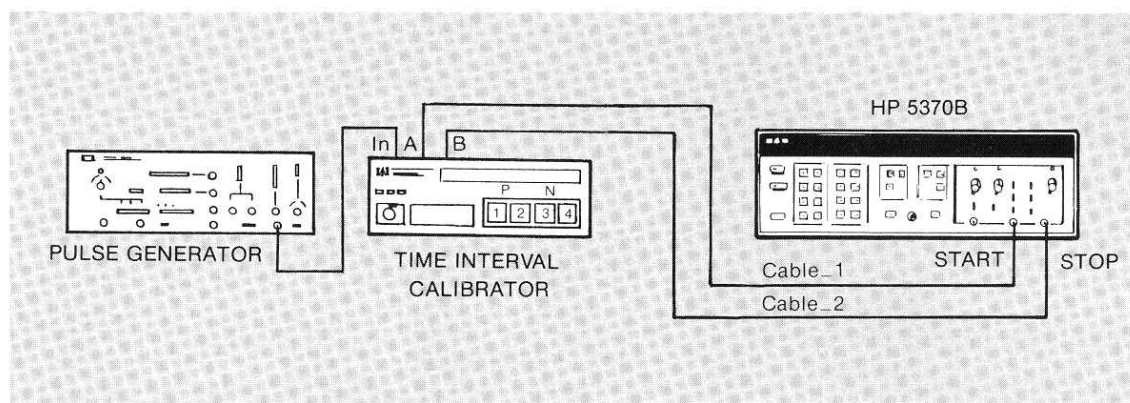

Figure 5. Equipment set-up for time interval calibration

Procedure

1) Connect the equipment as shown in Figure 5. Cable_1 will always be part of the START input channel for calibration, and for your measurements after calibration. Cable_2 similarly will always be part of the STOP input channel. (To change these cables requires re-calibration.) (If you need to use the Time Interval Probes, see page 14.)

Connect Cable_1 to the calibrator connector A and Cable_2 to B. Connect the pulse generator to the calibrator connector INPUT.

Note: Select cable lengths to ensure that each measurement result is >|1.5 ns|, for maximum accuracy of calibration. For example, you would make Cable_2 one foot longer than Cable_1.

2) Set up the pulse generator to give you:
   • about 10 MHz repetition rate
   • 50% duty cycle
   • 1.5 times the voltage that the signal you are going to measure will have, and centered on zero volts
   • transition rates that duplicate the signal you are going to measure
3) Set the counter up to make time interval measurements with:
   • trigger levels PRESET (for non-zero trigger levels, see page 14)
   • SEPARATE, 50Ω, DC, Attenuator as appropriate, ±TI, 1000 samples

4) Select start slope $\int$, stop slope $\int$ and push button 1 on the calibrator. Record the measured time as Result_1.
5) Select start slope $\rceil$, stop slope $\rceil$. Record Result_2
6) Select start slope $\int$, stop slope $\rceil$ and push button 3. Record Result_3
7) Select start slope $\rceil$, stop slope $\int$. Record Result_4
8) Select start slope $\int$, stop slope $\int$ and push button 2. Record Result_5
9) Select start slope $\int$, stop slope $\rceil$ and push button 4. Record Result_6
10) Compute the calibration constants as follows:

C++ = Result_1 – 0.5 × (Result_1 – Result_5)
C–– = Result_2 – 0.5 × (Result_1 – Result_5)
C+– = Result_3 – 0.5 × (Result_3 – Result_6)
C–+ = Result_4 – 0.5 × (Result_3 – Result_6)

11) Use the calibration constants as follows:

for a $\int$ slope to $\int$ slope measurement, subtract C++
for a $\rceil$ slope to $\rceil$ slope measurement, subtract C––
for a $\int$ slope to $\rceil$ slope measurement, subtract C+–
for a $\rceil$ slope to $\int$ slope measurement, subtract C–+

Example

Suppose we wish to measure a gate propagation delay from a $\int$ edge to a $\rceil$ edge. The signals we wish to measure are 2 volts peak to peak (between –1 volt and +1 volt) with 0.2 volt/ns transition rates. We would calibrate with a 3.0 volt (–1.5 volt to +1.5 volt) 0.2 volt/ns signal.

If the calibration constant C+– were 425 ps, and the measured propagation delay were 5.75 ns, the propagation delay, corrected for systematic errors, would be 5.325 ns ± 100 ps.

Theory
(You may skip this section)

The calibration process measures the combined systematic errors of Differential Channel Delay and Trigger Level Timing Error, so that they may subsequently be subtracted from the final measurement result. These errors will vary with:

- signal transition rates
- signal amplitudes
- trigger slopes and
- trigger levels,

so it is important to calibrate with signals that duplicate your measurement conditions.
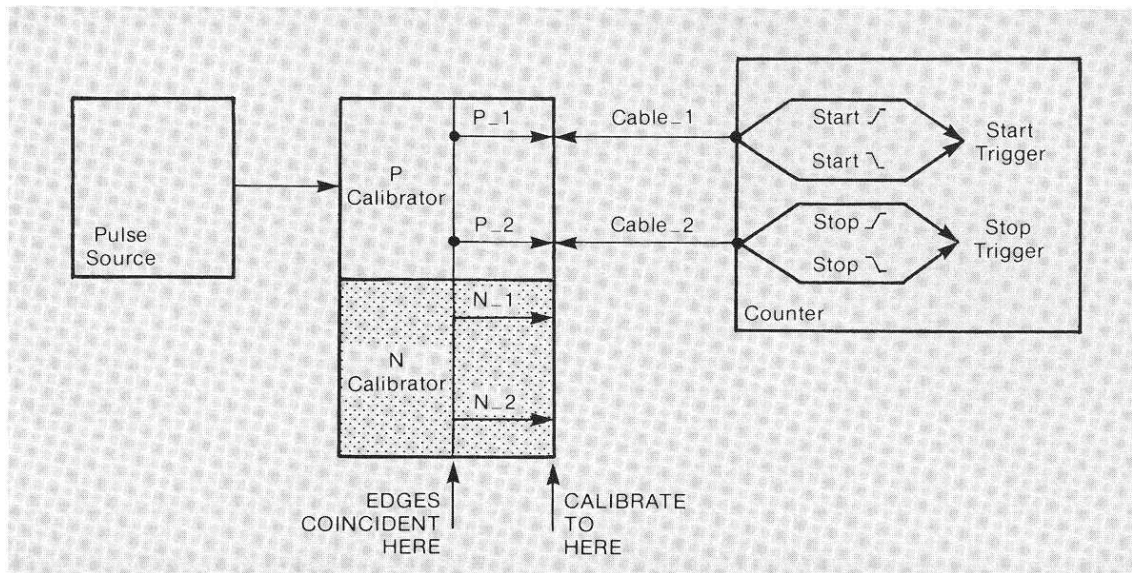
Figure 6. Model of the delays which constitute systematic errors for time interval measurements. The calibrator contains a switching matrix which will connect each cable to each calibrator port. The delays in the matrix are either matched on each channel, or calibrated out as appropriate.

Let us first examine the case of using the P calibrator with the counter measuring from $\int$ slope to $\int$ slope. The two edges from each port of the perfect calibrator occur simultaneously. The start and stop edges each then experience different delays before triggering the counter. This difference is the measurement, Result_1.

time to start trigger = P_1 + Cable_1 + Start $\int$
time to stop trigger = P_2 + Cable_2 + Stop $\int$
Result_1 = (P_2 + Cable_2 + Stop $\int$) − (P_1 + Cable_1 + Start $\int$)

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Rearranging:

Result_1 = (Cable_2 + Stop ⟋) – (Cable_1 + Start ⟋) + (P_2 – P_1)

Notice that the quantity (Cable_2 + Stop ⟋) – (Cable_1 + Start ⟋) is the systematic error, C++, to subtract from your subsequent measurement from ⟋ slope to ⟋ slope. (P_2 – P_1) is the small differential delay between ports of the P calibrator.

By changing slope selection, calibrators and calibrator ports, and making measurements for each of these conditions, we will similarly derive:

Result_2 = (Cable_2 + Stop ⟍) – (Cable_1 + Start ⟍) + (P_2 – P_1)
Result_3 = (Cable_2 + Stop ⟍) – (Cable_1 + Start ⟋) + (N_2 – N_1)
Result_4 = (Cable_2 + Stop ⟋) – (Cable_1 + Start ⟍) + (N_2 – N_1)
Result_5 = (Cable_2 + Stop ⟋) – (Cable_1 + Start ⟋) + (P_1 – P_2)
Result_6 = (Cable_2 + Stop ⟍) – (Cable_1 + Start ⟋) + (N_1 – N_2)

We now have six equations which we can solve easily for the four calibration constants C++, C––, C+– and C–+. We can also solve for the calibrator port differential delays.
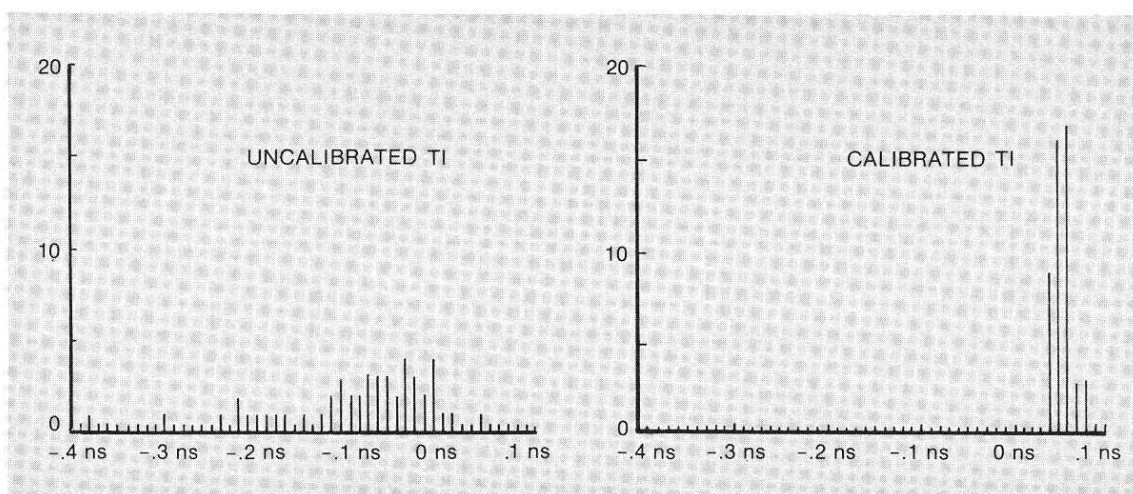
Figure 7. Here is an illustration of the dramatic improvements that can be derived from careful calibration. (a) shows a fixed time interval measured by 48 different counters. (b) shows the results with the same counters after following this calibration scheme.

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Pulse Width Measurement Calibration ──────

Pulse Width calibration is similar to time interval calibration. You first measure the systematic errors, and then you subtract them from your measurement results. Again, we will first describe the procedure used to make pulse width measurements with accuracies of better than ±100 ps, and then for those interested, describe the theory behind the calibration.
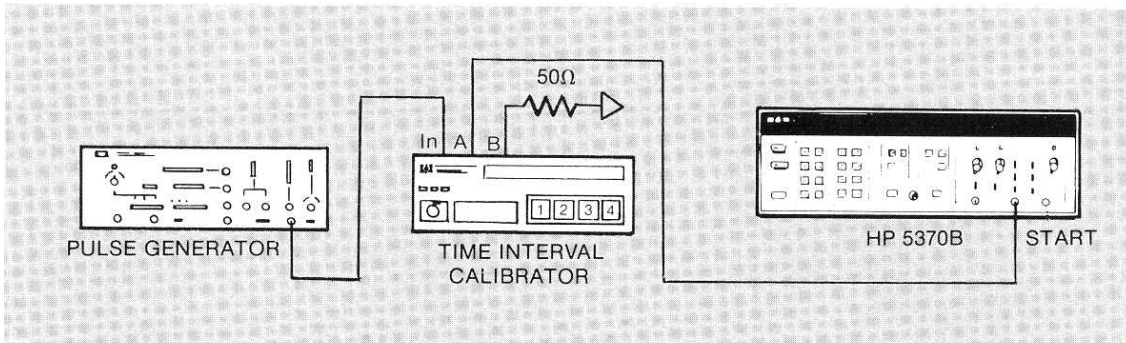
Figure 8. Equipment set-up for pulse width calibration

Procedure

1) Connect the equipment as shown in Figure 8. Only one cable will be used to connect between the START input channel on the counter and the A connector on the calibrator. A 50Ω termination is connected to the B connector on the calibrator.
2) Set up the pulse generator to give you:
   - about 10 MHz repetition rate
   - 50% duty cycle
   - 1.5 times the voltage of the signal you are going to measure and centered on zero volts
   - transition rates that duplicate the signal you are going to measure
3) Set the counter up to make time interval measurement with:
   - trigger levels PRESET (for non-zero trigger levels, see page 14)
   - COMMON, 50Ω, DC, Attenuator as appropriate, ±TI, 1000 samples

4) Select start slope $\smile$, stop slope $\mathrel{\rceil\,}$, and push button 3 on the calibrator. Record the measurement time as Pulse_1.
5) Select start slope $\mathrel{\rceil\,}$, stop slope $\smile$. Record the result as Pulse_2.
6) Push button 4. Record the result as Pulse_3.
7) Select Start slope $\smile$, stop slope $\mathrel{\rceil\,}$. Record the result as Pulse_4.
8) Select Period measurement with 1 second gate time. Record result as Period.
9) Compute the calibration constants as follows:

W+− = 0.5 × (Pulse_1 + Pulse_4 − Period)
W−+ = 0.5 × (Pulse_2 + Pulse_3 − Period)

10) Use the calibration constants as follows:

for a positive pulse ($\smile$ slope to $\mathrel{\rceil\,}$ slope) measurement, subtract W+−
for a negative pulse ($\mathrel{\rceil\,}$ sope to $\smile$ slope) measurement, subract W−+

Theory

(You may skip this section)

For pulse width calibration, the theory is similar to the time interval case, but there are two significant differences. The first is that the counter uses an internal power splitter in the signal path for single channel measurements such as pulse width (see Figure 9). The second difference is that when we measure the systematic errors, we must always include one pulse width in the measurement (see Figure 10).

Remember that errors will vary with:
- signal transition rates
- signal amplitudes
- trigger slopes and
- trigger levels,

so it is important to calibrate with signals that duplicate your measurement conditions.
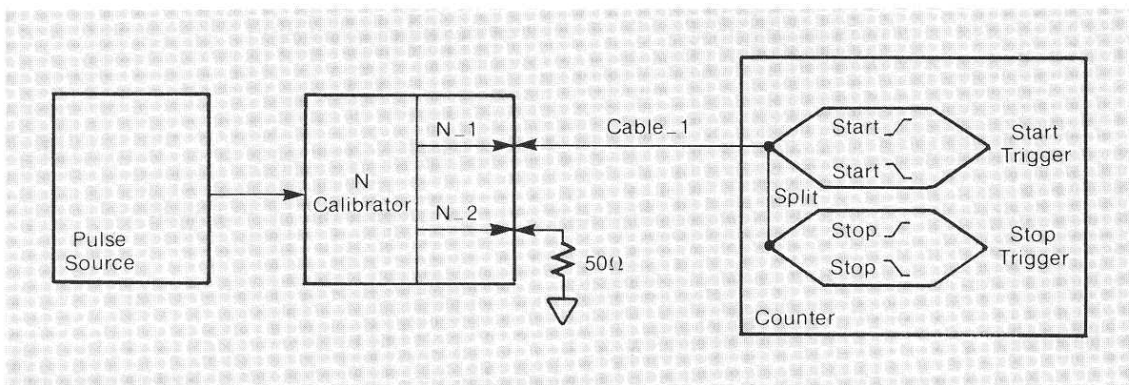
Figure 9. Model of the delays which constitute systematic errors for pulse width measurements.
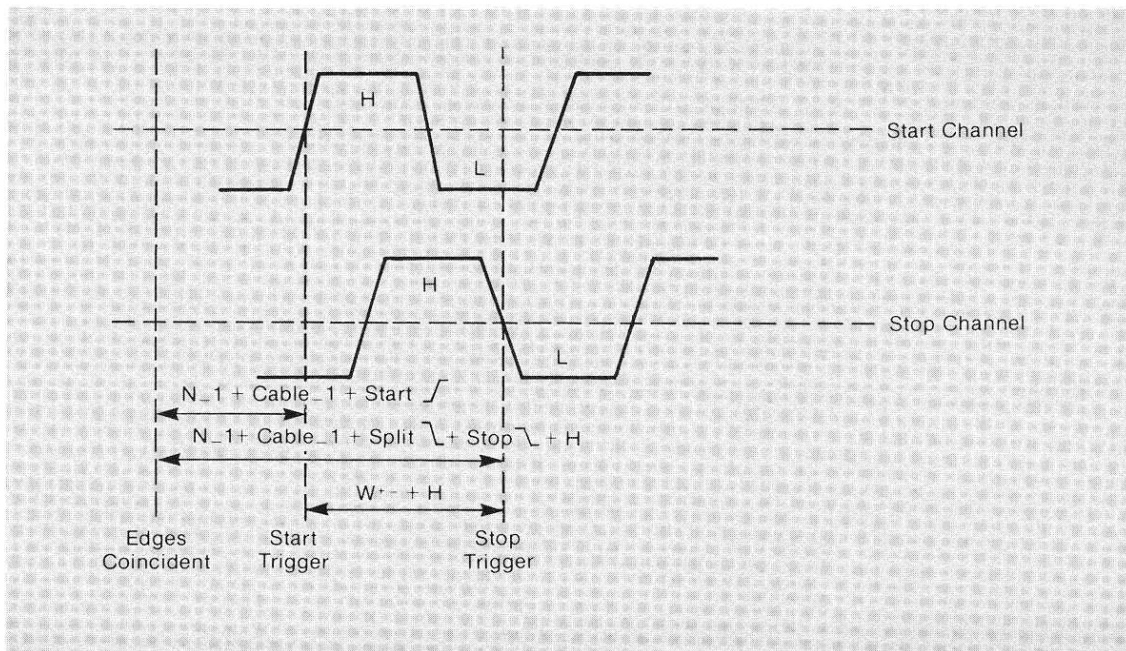
Figure 10. Timing diagram showing the relationships of edges from the N calibrator (port 1), as they pass through the system.

Let us first examine the case of using port 1 of the N calibrator with the counter measuring a positive pulse (from slope $\int$ to slope L). There is coincidence up to the counter's internal power splitter. From then on the (split) signals experience different delays. The time measured, Pulse_1, will be the difference in delays between each channel, plus one pulse width (H in this case).

  time to start trigger = N_1 + Cable_1 + Start $\int$
  time to stop trigger = N_1 + Cable_1 + Split L + Stop L + H
  Pulse_1 = H + (Split L + Stop L) – (Start $\int$)

Notice that the quantity (Split L + Stop L) – (Start $\int$) is the systematic error, W+–, for positive going pulses.

By changing slope selection and N calibrator port, and making measurements for each of these conditions, we will similarly derive:

  Pulse_2 = L + (Split $\int$ + Stop $\int$) – (Start L)
  Pulse_3 = H + (Split $\int$ + Stop $\int$) – (Start L)
  Pulse_4 = L + (Split L + Stop L) – (Start $\int$)

By making a period measurement with a long gate time, we can very accurately know the quantity:

  Period = (H + L)

We have five equations which we can solve easily for the calibration constants W+– and W–+.

Note:

Since we are assuming that H, L and Period are constant throughout these measurements, it is imperative that the pulse source be stable. Any drift in the source adds directly into calibration error.

(a)   (b)
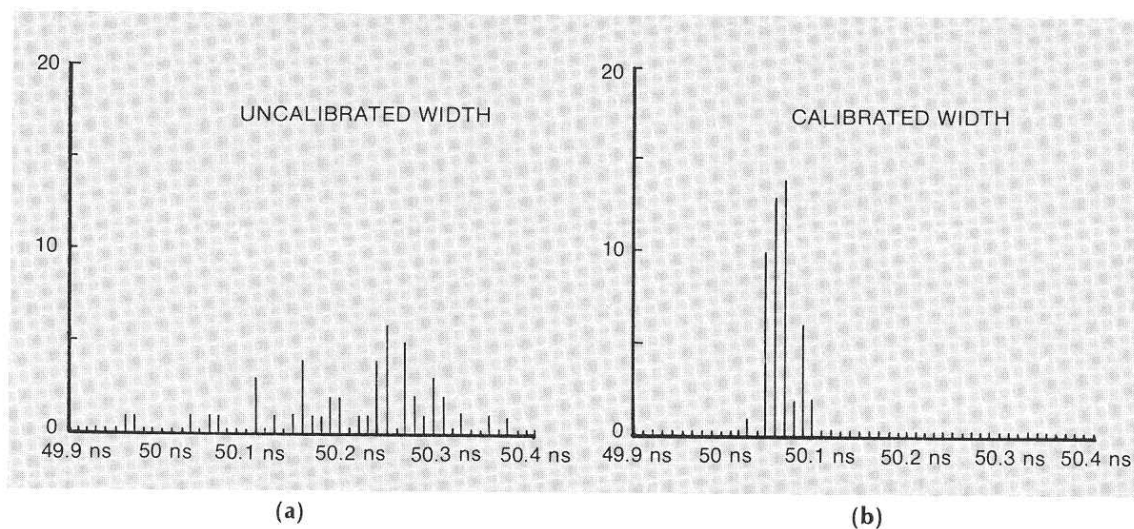
Figure 11. Here is an illustration of the dramatic improvements that can be derived from careful calibration. (a) shows a fixed pulse width measured by 48 different counters. (b) shows the results with the same counters after following this calibration scheme.

Transition Time Measurement Calibration

Transition (Rise/Fall) Time measurement calibration is similar to the one for pulse width, because it uses a single channel and the counter internal power splitter, but there are two differences. First, you do not need the calibrator (but you can leave it in the system if it is more convenient). Second, because rise and fall time measurements operate on the same slope, there is no inclusion of a pulse width in the measured time. This simplifies the process.

Again we will first describe the procedure used to make transition time measurements with accuracies of better than ±300 ps. (Note this is a less precise characterization than time interval or pulse width.) Then for those interested, we will describe the theory.
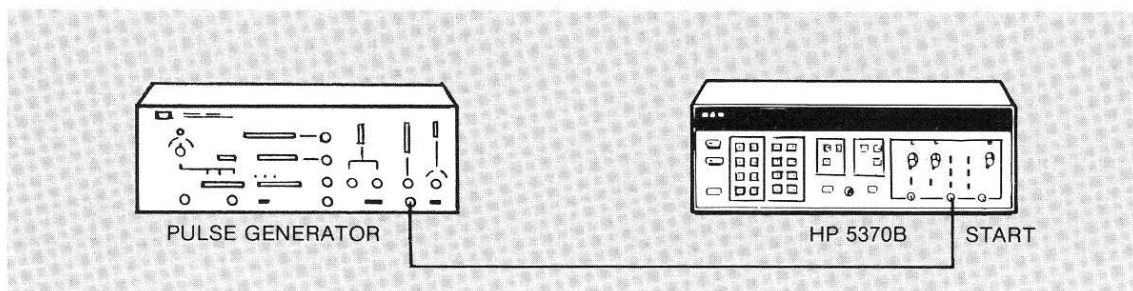
Figure 12. Equipment set-up for transition time calibration.

Procedure

1) Connect the equipment as shown in Figure 12.
2) Set up the pulse generator to give you:
   - about 10 MHz repetition rate
   - 50% duty cycle
   - the same voltage as the signal you are going to measure (centered on zero volts if you are leaving the calibrator in the circuit)
   - transition times that duplicate the signal you are going to measure
3) Set the counter up to make a time interval measurement with:
   - trigger levels at 50% of the peak to peak voltage
   - COMMON, 50Ω, DC, Attenuator as appropriate, ±TI, 1000 samples

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4) Select start slope $\int$ and stop slope $\int$. Record the result as **Rise**
5) Select start slope $\mathrm{\mathsf{L}}$ and stop slope $\mathrm{\mathsf{L}}$. Record the result as **Fall**
6) Use the calibration constants as follows:
   for a rise time measurement, subtract **Rise**
   for a fall time measurement, subtract **Fall**

Theory
(You may skip this section)

For a transition time measurement, the theory is similar to the pulse width case. This time, however, we would not have a pulse width to remove from the calibration measurement (to separate out the systematic errors), but a transition time.

This removal is not practical, and so a compromise is used. The rise time is set to zero by selecting both the start and stop to be the same (the 50%) point on each edge. The times measured then are simply the systematic errors at the 50% point.

Now we see the reason for the reduced precision. You will make the eventual measurement at the 20% to 80%, or 10% to 90% points, not at the points at which you calibrated. We know that the systematic errors will vary with:
- signal transition rates
- signal amplitudes
- trigger slopes and
- trigger levels,

and you will change several of these when going from calibration to measurement.
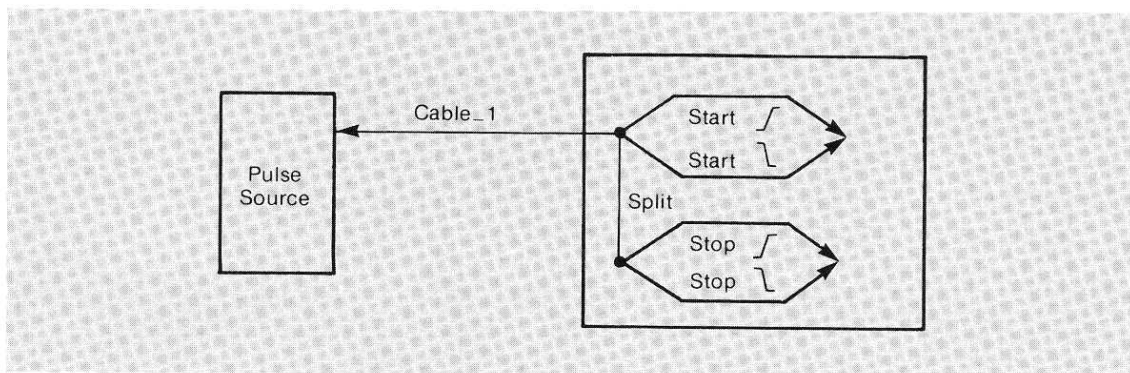
Figure 13. Model of the delays which constitute the systematic errors for transition time measurements.

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Deviations in Measurement Conditions ━━━━

In the calibration discussions just completed, we have assumed certain conditions that may not, in fact, simulate your actual measurement. These conditions — trigger levels of zero volts and Time Interval Probes not used — were assumed for the sake of simplicity. How to set triggering at different voltage levels, and how to calibrate when using probes, is shown below.

Using HP 5363B Time Interval Probes

HP 5363B Time Interval Probes are often used in conjunction with the HP 5370B counter. To include the probes in the calibration, follow Figure 14, and be sure to terminate the outputs of the calibrator with 50Ω.
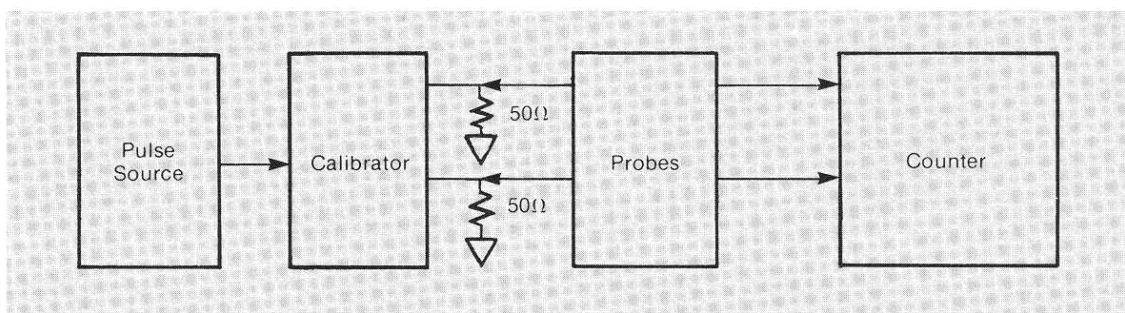
Figure 14. This is the schematic showing the calibration set-up if HP 5363B probes are used for time interval and pulse width measurements.

Since calibrators are not used when performing rise and fall time measurement calibration, if you use probes you must terminate the output of the pulse source directly with 50Ω.
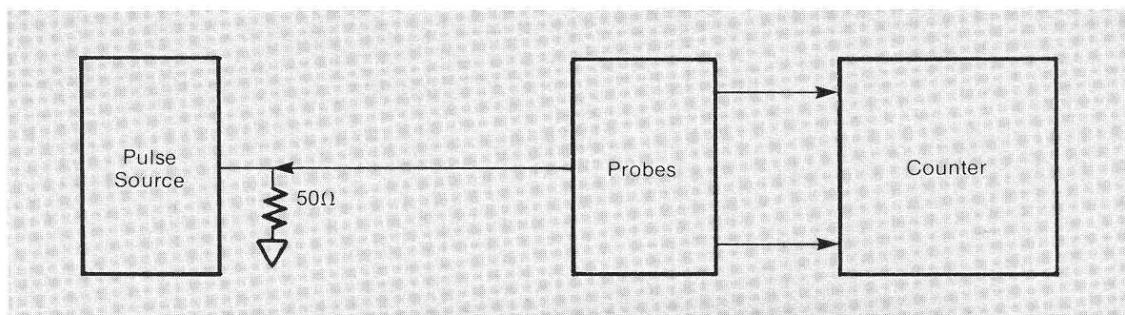
Figure 15. This is the schematic showing the calibration set-up if HP 5363B probes are used for rise and fall time measurements.

Triggering at other than zero volts

It is also possible that you will not want to trigger at zero volts. This requirement changes matters only slightly. The calibrators are passive linear devices so as to be repeatable, but because they include transformers, they will not pass DC. As a result, in order to output calibration signals suitably offset to calibrate at other than zero volts, you must apply an offset voltage to the calibrator signals equal to your required trigger level voltage.
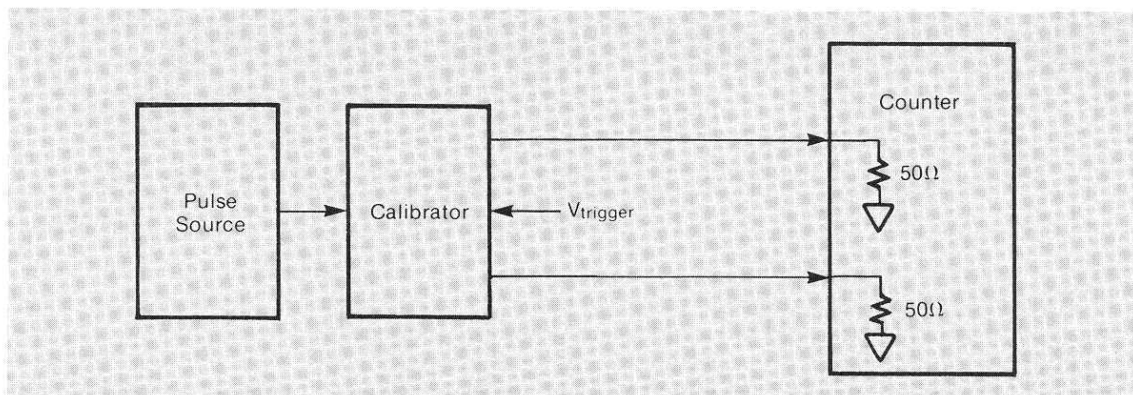
Figure 16. This is the schematic showing the calibration set-up if non-zero trigger levels are required for time interval measurements.
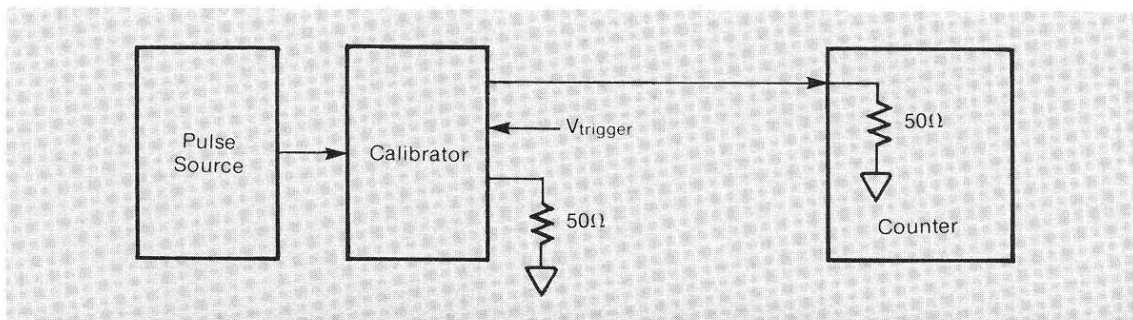
Figure 17. This is the schematic showing the calibration set-up if non-zero trigger levels are required for pulse width measurements.

You need only apply an offset voltage equal to the desired trigger level voltage to the connector on the rear of the calibrator. Then if you set the trigger levels on the counter to this voltage, the calibration process is carried out as previously described. If you are also using the HP 5363B Time Interval Probes, there is a convenient source of precise offset voltage available from the rear panel trigger level output connectors.

Since rise and fall time measurements do not require the use of the calibrator, simply adjust the output of the pulse generator to match the signal you will measure, set the trigger level voltages on the counter and follow the calibration procedure.

Conclusion

When you use the HP 5370B Time Interval Counter, you can improve the accuracy of time interval and pulse width measurements to better than ±100 ps, by using the described calibration process. Transition time measurements can be improved to better than ±300 ps.

The process requires a modest amount of additional equipment: an HP J06-59992A Time Interval Calibrator, a stable pulse source (10 MHz is a good frequency), 50Ω terminations and a dc voltage source. The result is an inexpensive solution to an important measurement problem.

Appendix

Automating the Procedure

The following section will show you sample programs written in BASIC, to run on the HP series 200 computers, that will automate the calibration process. These programs will take care of instrument control and solution of the equations necessary to give you the calibration constants. (We have added a little more complexity to the equations here, compared to those explained earlier, in order to add a consistency check on the results.) The result is calibration, with or without HP 5363B Time Interval probes, at the touch of a few keys.

A. Using the 5370A/B Counter

Description:

This routine automatically determines the calibration constants for the 5370A/B counter. In this calibration procedure, known signals from the calibrator are fed into the 5370A/B. Counter readings, which depict measured errors, are represented as "calibration constants." The eight constants generated by the program apply to measurements with SEP and COM counter configurations and with combinations of "+" and "−" slopes.

The calibration signal duty cycle is always at 50%; however, voltage swing, mid-pulse voltage offset, transition rate, and pulse rate can be adjusted by the user to simulate actual measurement conditions.

Equipment Required:

- HP 5370A/B Time Interval Counter
- DC Voltage Source—to provide an offset voltage if making measurements at non-zero trigger levels.
- HP Series 200 Controller such as HP 9836, 9826, 9817*, 9816* with BASIC
- HP-IB Cables
- Pulse Generator—must be capable of generating a signal which:
    1. Simulates the voltage swing X1.5 and the transition rates (rise/fall times) of the desired signal to be measured.
    2. Has a 50% duty cycle, approximately, but the duty cycle must not change during the few seconds of calibration.
    3. Has a constant rate of at least 1 MHz. User decides the rate at which to calibrate.

*Requires separate disc drive
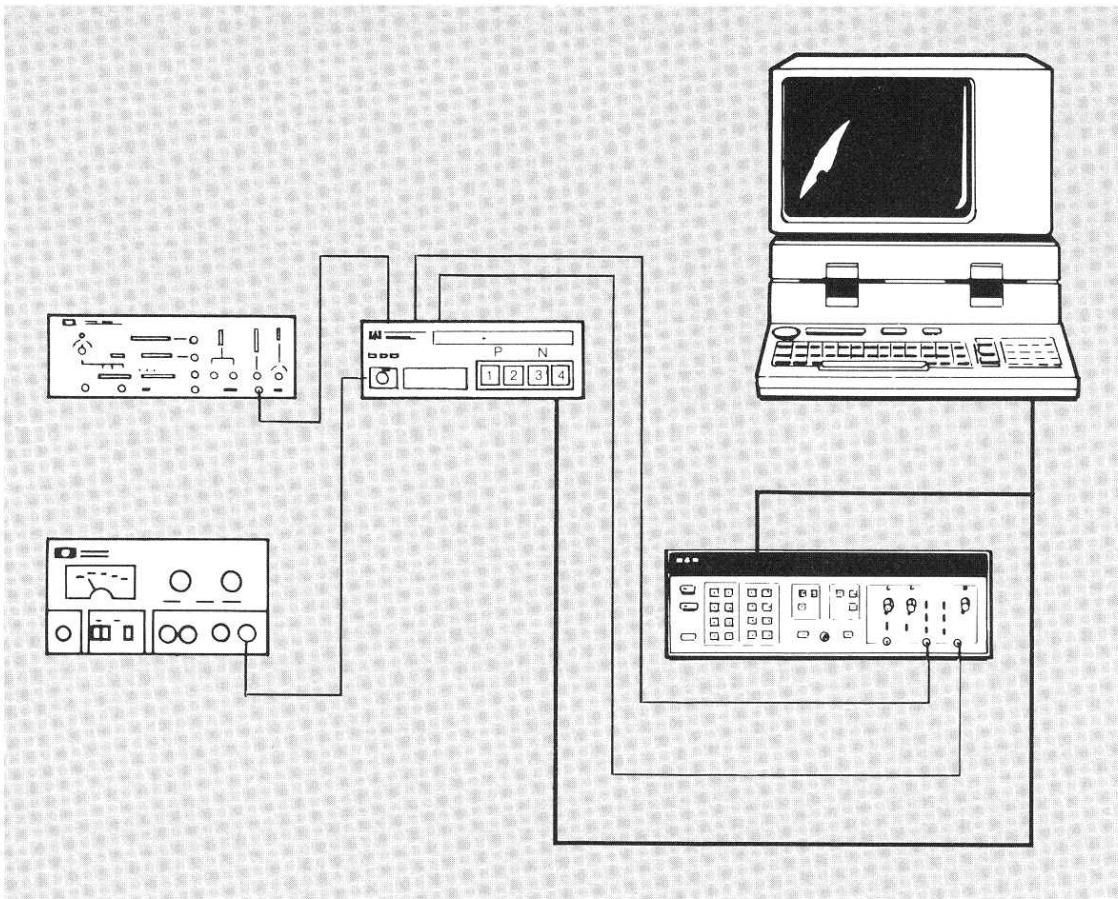
Figure 18. Calibration Using the 'CAL5370' Program.

1) The signal swing at this point from the Pulse Generator should be 1.5 times the desired signal to be measured.
2) The signal at this point going from the Time Interval Calibrator to the Counter should simulate the actual signal to be measured later.

Procedure:

a. Connect the HP-IB cables between the J06-59992A, the HP 5370A/B counter, and the controller. Set the HP-IB address of the J06-59992A to 0.5. Set the HP-IB address of the counter to 07.
b. Power up the pulse generator and the instruments connected by the HP-IB bus.
c. Connect a pair of cables from the J06-59992A calibrator outputs A and B to the counter's START and STOP inputs.

Note:

In order for the calibration to be valid, these same cables must be used for the measurements which follow the calibration routine.

d. Set counter to SEPARATE, set START and STOP channels to DC, 50 OHM, DIVIDE-BY-1 ATTENUATION, and TRIGGER LEVEL to desired level (consistent with dc offset voltage applied).

Note:

To allow an offset voltage limit of ±10V, the counter should be set to 1 Megohm, which means the pulse generator must be a good 50 ohm source, and the counter should be set to Divide-By-10, which also necessitates changing two program lines. Add an exclamation point in front of line 320, and remove the exclamation point from in front of line 330 in "CAL5370."

   e. Set the pulse generator to produce a signal with a 50% duty cycle at a frequency selected by the user. Adjust amplitude to be 1.5 times that of the desired signal.
   f. Connect this signal to the Input of the J06-59992A.
   g. If using an offset voltage, connect this voltage to the Offset Voltage Input on the rear panel of the Time Interval Calibrator. This dc voltage should be identical to the trigger level voltage of the signal to be measured.
   h. Load the "CAL5370" calibration routine program into memory of the controller.
   i. Run the program. The user will need to respond to prompts displayed on the CRT. This involves entering the offset voltage value used and operating the SEP/START COM switch on the counter.
   j. The display provides a summary of the calibration constants to be subtracted from the counter measurements, depending on the type of measurement to be made. Also included is a list of the consistency parameters. These provide a measure of the typical experimental error that can be expected when using the calibration constants.

Example of results:

CAL 70
  CALIBRATION CONSTANTS:
(TO BE SUBTRACTED FROM COUNTER READINGS)

TIME INTERVAL + TO +	−18 ps
TIME INTERVAL − TO −	−73 ps
TIME INTERVAL + TO −	−52 ps
TIME INTERVAL − TO +	−48 ps
WIDTH + TO −	235 ps
WIDTH − TO +	250 ps
RISE-TIME SKEW	168 ps
FALL-TIME SKEW	107 ps

CALIBRATED AT 50 MHz with OFFSET @ .5 VOLTS
CONSISTENCY:

   TI ++,−−:   −1 ps
   TI+−,+−:   16 ps
   WIDTH: 2 ps

B. Using HP 5363B Probes

Description:

This routine automatically determines the calibration constants for the HP 5370A/B counter when used with the HP 5363B Time Interval Probes. In this calibration procedure, known signals from the calibrator are fed into the 5370A/B. Counter readings, which depict measured errors, are represented as "calibration constants." The eight constants generated by the program apply to measurements with SEP and COM counter configurations and with combinations of "+" and "−" slopes.

The calibration signal duty cycle is always at 50%; however, voltage swing, mid-pulse voltage offset, transition rate, and pulse rate can be adjusted by user to simulate actual measurement conditions.

Equipment Required:

- HP 5370A/B Time Interval Counter
- HP 5363B Time Interval Probes
- HP Series 200 Controller such as HP 9836, 9826, 9817*, 9816* with BASIC
- HP-IB Cables
- Pulse Generator—must be capable of generating a signal which:
    1. Simulates the voltage swing X1.5 and the transition rates (rise/fall times) of the desired signal to be measured.
    2. Has a 50% duty cycle, approximately, but the duty cycle must not change during the few seconds of calibration.
    3. Has a constant rate of at least 1 MHz. User decides the rate at which to calibrate.

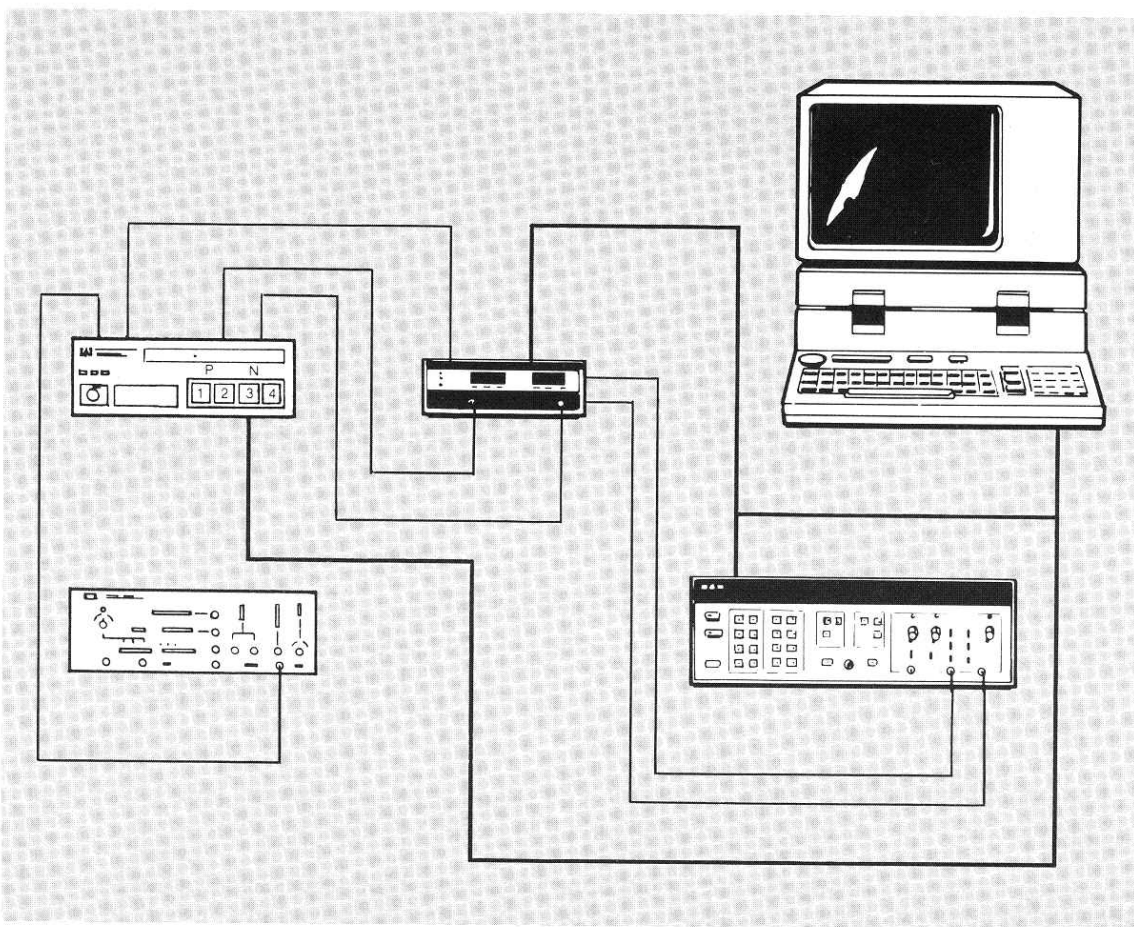*Requires separate disc drive

Figure 19. Calibration Using the 'CAL5363' Program.

1) The signal swing at this point from the Pulse Generator should be 1.5 times the desired signal to be measured.
2) The signals at this point going from the Time Interval Calibrator to the Counter should simulate the actual signal to be measured later.

Procedure:

    a. Connect the HP-IB cables between the J06-59992A, the HP 5370A/B counter, HP 5363B Time Interval Probes, and the Controller. Set the HP-IB address of the J06-59992A to 05. Set the HP-IB address of the HP 5363B Time Interval Probes to 04, and the address of the counter to 07.

    b. Power up the pulse generator and the instruments connected by the HP-IB bus.

    c. Connect a pair of cables from the 5363B Probe outputs to the counter's START and STOP inputs.

Note:

In order for the calibration to be valid, these same cables must be used for the measurements which follow the calibration routine.

    d. The Time Interval Probes should be pre-calibrated for trigger-level accuracy as explained in the HP 5363B Operating and Service Manual. (Insert probes into 5363B and press "Level" switch down for several seconds.)

    e. Connect a 50-ohm load and a Time Interval Probe to each of the J06-59992A A and B Outputs using the special tee adapters available with the Time Interval Probes.

    f. Set counter to SEPARATE, set both START and STOP channels to DC, 50 OHM, DIVIDE-BY-1 ATTENUATION, and TRIGGER LEVEL to PRESET.

Note:

To allow an offset voltage limit of ±10V, the 50 ohm loads at the Outputs of the J06-59992A should be removed. In this case, the pulse generator must be a good 50 ohm source.

    g. Set the pulse generator to produce a signal with a 50% duty cycle at a frequency selected by the user. Adjust amplitude to be 1.5 times that of the desired signal.

    h. Connect this signal to the Input of the J06-59992A.

    i. Connect the Trigger Level Output START voltage from the Time Interval Probes rear panel to the Offset Voltage Input on the rear panel of the Time Interval Calibrator. This dc voltage, set through the program, should be identical to the trigger level voltage of the signal to be measured. The Time Zero knob can be set to any position, but it must remain at that setting during calibration and the measurements which follow.

Note:

When using the 5363B Time Interval Probes to produce the offset voltage, the trigger level of the counter must be set to 0.00V. The program automatically sets the trigger level of the counter to this value regardless of the Probes trigger level.

    j. Load "CAL5363" calibration routine program into memory of the controller.

    k. Run the program. The user will need to respond to a prompt displayed on the CRT. This involves entering the offset voltage value used.

    l. The display provides a summary of the calibration constants to be subtracted from the measurements of the probe/counter combination depending on the type of measurement to be made. Also included is a list of the consistency parameters. These provide a measure of the typical experimental error that can be expected when using the calibration constants.

Example of results:

CAL5363
   CALIBRATION CONSTANTS:
(TO BE SUBRACTED FROM COUNTER READINGS)

TIME INTERVAL + TO +	74 ps
TIME INTERVAL – TO –	46 ps
TIME INTERVAL + TO –	224 ps
TIME INTERVAL – TO +	–86 ps
WIDTH + TO –	152 ps
WIDTH – TO +	13 ps
RISE-TIME SKEW	–142 ps
FALL-TIME SKEW	–239 ps

CALIBRATED AT 50 MHz with OFFSET @ –1.3 VOLTS CONSISTENCY:
   TI ++,––:   23 ps
   TI+–,+–: –42ps
   WIDTH: 22 ps

Troubleshooting Hints and General Comments.

A typical calibration takes about 7 seconds. If the programs should "hang up", check for the following:

- Verify that all electrical connections between test instruments are correct.
- Verify that all test instruments are set properly.
- Verify that the instrument HP-IB addresses correspond to those in the HP-IB programs.
- Verify that the trigger level is not greater than ±2V for a 50 ohm output load.
- When using a dc voltage source to provide an offset voltage it must agree with the voltage level entered by the user at the program prompt.

HP-IB Program Listings

Following are the listings of the two programs referenced in this section to run the automated calibration routines with the HP J06-59992A Time Interval Calibrator.

   a. Calibration Routine using HP 5370A/B

       File "CAL5370"

   b. Calibration Routine using HP 5363B Time Interval Probes

       File "CAL5363"

```
 10!   RE-STORE "CAL5370"
 20    PRINT "CAL5370 REV 12 JUN 85"
 30   ! ORIG 6 DEC 84
 40   ! THIS PROGRAM EXECUTES THE CALIBRATION ALGORITHM DESCRIBED IN D. CHU'S
 50   ! PAPER "CALIBRATION OF SYSTEMATIC ERRORS IN PRECISION TIME-INTERVAL
 60   ! COUNTERS", INTERNATIONAL TEST CONFERENCE, PHILADELPHIA, 1985;
 70   !
 80   !                    SET-UP PROCEDURE
 90   ! 1) CONNECT A PULSE SOURCE TO THE INPUT OF CALIBRATOR, 3 DB LARGER
100   !      THAN THE DESIRED SIGNAL TO BE MEASURED AND APPROXIMATELY THE
110   !      SAME RISE/FALL TIMES, ~50% DUTY-CYCLE, STABLE 1 TO 100 MHz.
120   ! 2) CONNECT A PAIR OF CABLES FROM CALIBRATOR OUTPUTS A & B
130   !      TO COUNTER START & STOP INPUTS RESPECTIVELY
140   !      (NOTE: CABLE MISMATCHES ARE INCLUDED IN THE CALIBRATION CONSTANTS,
150   !             AND SAME CABLES SHOULD BE USED LATER FOR DOING MEASUREMENTS;
160   !             ALSO "CABLES" INCLUDE LINEAR, PASSIVE OR ACTIVE PROBES)
170   ! 3) SET COUNTER TO SEPERATE;  DC/50 ohms/X1/PRESET to BOTH CHANNELS
180   ! 4) HPIB ADDRESSES: COUNTER-707, CALIBRATOR-705
190   ! 5) CONNECT A PRECISE OFFSET VOLTAGE SOURCE TO THE OFFSET INPUT; ENTER
200   !      THE EXACT SAME VALUE WHEN PROMPTED.  DEFAULT IS 0.00 VOLT
210   !
220   !_____
230   !                     INITIALIZATION
240   !
250 Ctr=707                          !HPIB ADDRESSES
260 Cal=705
270 Ps=1.E+12
280 OUTPUT Cal;"B1"
290 OUTPUT Ctr;"FN1"
300 INPUT "Type in OFFSET (volts); set counter to ""SEP"" and ""CONTINUE""",Ofs
310 OUTPUT Ctr;"ST6"                 !CLEARS ANY PREVIOUS REFERENCE (IF DESIRED)
320 Level=Ofs                        !THIS LINE USED WITH X1 ATTENUATION
330 !Level=Ofs*.1                     !THIS LINE USED WITH X10 ATTENUATION
340 OUTPUT Ctr;"FN2TR"               !SET COUNTER TRIGGER LEVEL TO MATCH OFFSET
350 OUTPUT Ctr USING """TA""",SD.DD";Level
360 OUTPUT Ctr USING """TO""",SD.DD";Level
370 OUTPUT Ctr;"FN4GT2MD2MR"         !MEASURE FREQUENCY/PERIOD
380 OUTPUT Ctr;"MR"
390 ENTER Ctr;Per                    !PERIOD/FREQUENCY
400   !
410   !_____
420 DISP "       TIME-INTERVAL CALIBRATION IN PROGRESS"
430 OUTPUT Ctr;"FN1ST1SS3AR2EA0MR"
440 OUTPUT Ctr;"SRSA1SO1MR"
450 OUTPUT Ctr;"MR"
460 T1=FNTi(Per,Ctr)                 ! +  +  DIRECT
470 OUTPUT Ctr;"SA2SO2MR"
480 OUTPUT Ctr;"MR"
490 T2=FNTi(Per,Ctr)                 ! -  -  DIRECT
500 OUTPUT Cal;"B2"
510 WAIT .004
520 OUTPUT Ctr;"MR"
530 T3=FNTi(Per,Ctr)                 ! -  -  SWAPPED
540 OUTPUT Ctr;"SA1SO1MR"
550 OUTPUT Ctr;"MR"
560 T4=FNTi(Per,Ctr)                 ! +  +  SWAPPED
570 OUTPUT Cal;"B3"
580 WAIT .004
590 OUTPUT Ctr;"SA1SO2MR"
600 OUTPUT Ctr;"MR"
610 T5=FNTi(Per,Ctr)                 ! +  -  DIRECT
620 OUTPUT Ctr;"SA2SO1MR"
630 OUTPUT Ctr;"MR"                  !
640 T6=FNTi(Per,Ctr)                 ! -  +  DIRECT
650 OUTPUT Cal;"B4"
660 WAIT .004
```

```
670 OUTPUT Ctr;"MR"
680 T7=FNTi(Per,Ctr)                    ! - +  SWAPPED
690 OUTPUT Ctr;"SA1SO2MR"
700 OUTPUT Ctr;"MR"
710 T8=FNTi(Per,Ctr)                    ! + -  SWAPPED
720 !                 END TIME-INTERVAL CALIBRATION
730 !_____
740 !
750 OUTPUT Ctr USING """TA"",SD.DD";Level*.5  !START COM DIVIDES BY 2 @ 50 OHM
760 OUTPUT Ctr USING """TO"",SD.DD";Level*.5  !START COM DIVIDES BY 2 @ 50 OHM
770 DISP "Set counter to ""START COM"", and ""CONTINUE"" program"
780 PAUSE
790 DISP "       WIDTH, RISE/FALL SKEW CALIBRATION IN PROGRESS"
800 !SINCE COUNTER INPUTS ARE COMMON, THIS MEANS ONLY THE START-CHANNEL IS
810 !BEING USED FOR MEASUREMENTS.  THE STOP-CHANNEL SERVES ONLY AS A 50-ohm
820 !TERMINATION FOR THE CALIBRATOR B-OUTPUT
830 !IF NOTHING ELSE IS CHANGED, CALIBRATOR SHOULD BE ON B4
840 OUTPUT Ctr;"AR1SA1SO2MR"
850 OUTPUT Ctr;"MR"
860 ENTER Ctr;W4                        ! + - WIDTH SWAPPED
870 OUTPUT Ctr;"SA2SO1MR"
880 OUTPUT Ctr;"MR"
890 ENTER Ctr;W3                        ! - + WIDTH SWAPPED
900 OUTPUT Cal;"B3"
910 WAIT .004
920 OUTPUT Ctr;"MR"
930 ENTER Ctr;W2                        ! - + WIDTH DIRECT
940 OUTPUT Ctr;"SA1SO2MR"
950 OUTPUT Ctr;"MR"
960 ENTER Ctr;W1                        ! + - WIDTH DIRECT
970 OUTPUT Cal;"B1"
980 WAIT .004
990 OUTPUT Ctr;"AR2SA1SO1MR"
1000 OUTPUT Ctr;"MR"
1010 ENTER Ctr;R                        ! + + RISE TIME SKEW
1020 OUTPUT Ctr;"SA2SO2MR"
1030 OUTPUT Ctr;"MR"
1040 ENTER Ctr;F                        ! - - FALL TIME SKEW
1050!
1060!              END WIDTH RISE/FALL SKEW CALIBRATION
1070!_____
1080 OUTPUT Ctr;"MD1"                   ! RETURN COUNTER TO CYCLING MODE
1090!            BEGIN CALCULATE CALIBRATION CONSTANTS
1100 Cpp=.5*(T1+T4)
1110 Cnn=.5*(T2+T3)
1120 Cpn=.5*(T5+T8)
1130 Cnp=.5*(T6+T7)
1140 IF W1>Per THEN W1=W1-Per
1150 IF W2>Per THEN W2=W2-Per
1160 IF W3>Per THEN W3=W3-Per
1170 IF W4>Per THEN W4=W4-Per
1180 Wpn=.5*(W1+W4-Per)
1190 Wnp=.5*(W2+W3-Per)
1200 !            END CALCULATE CALIBRATION CONSTANTS
1210 !_____
1220 !
1230 !            BEGIN CALCULATE CONSISTENCY PARAMETERS
1240 Pp=.5*(T1-T4)
1250 Nn=.5*(T2-T3)
1260 Pn1=.5*(T5-T8)
1270 Pn2=.5*(T6-T7)
1280 Wpn1=W1-.5*Per-.25*(W1-W2+W3-W4)
1290 Wpn2=W4-.5*Per+.25*(W1-W2+W3-W4)
1300 Wnp1=W2-.5*Per+.25*(W1-W2+W3-W4)
1310 Wnp2=W3-.5*Per-.25*(W1-W2+W3-W4)
1320 !            END CALCULATE CONSISTENCY PARAMETERS
```

```
1330 Wnp1=W2-.5*Per+.25*(W1-W2+W3-W4)
1340 Wnp2=W3-.5*Per-.25*(W1-W2+W3-W4)
1350 !                  END CALCULATE CONSISTENCY PARAMETERS
1360 !
1370 !_____
1380 !
1390 PRINT "               CALIBRATION CONSTANTS:"
1400 PRINT "     (TO BE SUBTRACTED FROM COUNTER READINGS)"
1410 Ps=1.E+12
1420 PRINT USING """          TIME INTERVAL + TO +   "",  DDDDDD, "" ps""";Cpp*Ps
1430 PRINT USING """          TIME INTERVAL - TO -   "",  DDDDDD, "" ps""";Cnn*Ps
1440 PRINT USING """          TIME INTERVAL + TO -   "",  DDDDDD, "" ps""";Cpn*Ps
1450 PRINT USING """          TIME INTERVAL - TO +   "",  DDDDDD, "" ps""";Cnp*Ps
1460 PRINT USING """ PROBE-A      WIDTH  + TO -   "",  DDDDDD, "" ps""";Wpn*Ps
1470 PRINT USING """ PROBE-A      WIDTH  - TO +   "",  DDDDDD, "" ps""";Wnp*Ps
1480 PRINT USING """ PROBE-A     RISE-TIME SKEW  "",  DDDDDD, "" ps""";R*Ps
1490 PRINT USING """ PROBE-A     FALL-TIME SKEW  "",  DDDDDD, "" ps""";F*Ps
1500 Freq=INT(1.E-6/Per+.5)
1510 PRINT "CALIBRATION PERFORMED AT ";Freq;" MHz  @ OFFSET = ";V;" volts"
1520 PRINT "CONSISTENCY:"
1530 PRINT "TI ++,--: ";INT((Pp-Nn)*.5*Ps+.5);"ps"
1540 PRINT "TI +-,-+: ";INT((Pn1-Pn2)*.5*Ps+.5);"ps"
1550 PRINT "WIDTH    : ";INT((Wpn1-Wpn2)*Ps*.5+.5);"ps"
1560 ! "WIDTH -+: ";INT((Wnp1-Wnp2)*.5*Ps+.5);"ps"
1570 PRINT ""
1580 DISP "END CALIBRATION"
1590 END
1600 !_____
1610 !
1620 DEF FNTi(P,Ctr)                          !RETURNS T.I.
1630 ENTER Ctr;T
1640 IF ABS(T)<.5*P THEN 1670                 !WITH PROPER PERIOD COMPLEMENT
1650 OUTPUT Ctr;"PCMR"
1660 ENTER Ctr;T
1670 RETURN T
1680 FNEND
```

```
10!   RE-STORE "CAL5363"
20    PRINT "CAL5363    REV 19 JUL 85"
30    !ORIG 11 DEC 84
40    ! THIS PROGRAM EXECUTES THE CALIBRATION ALGORITHM DESCRIBED IN D. CHU'S
50    ! PAPER "CALIBRATION OF SYSTEMATIC ERRORS IN PRECISION TIME-INTERVAL
60    ! COUNTERS", INTERNATIONAL TEST CONFERENCE, PHILA, 1985, WITH HP5363B
70    !                     SET-UP PROCEDURE
80    ! 1) CONNECT A PULSE SOURCE TO THE INPUT OF CALIBRATOR, 3 DB LARGER
90    !     THAN THE DESIRED SIGNAL TO BE MEASURED AND APPROXIMATELY THE
100   !     SAME RISE/FALL TIMES, ~50% DUTY-CYCLE, STABLE 1 TO 100 MHz.
110   ! 2) CONNECT A PAIR OF CABLES FROM 5363B PROBE OUTPUTS TO
120   !     COUNTER START & STOP INPUTS
130   !     (NOTE:  THE SAME CABLES MUST BE USED LATER TO DO MEASUREMENTS
140   !             FOR CALIBRATION TO BE VALID)
150   ! 3) PROBES SHOULD BE PRE-CALIBRATED FOR TRIGGER-LEVEL ACCURACY
160   !     IN ACCORDANCE WITH HP5363B MANUAL (INSERT PROBES TO 5363 AND PUSH
170   !     SWITCH TO "LEVEL" MOMENTARILY)
180   ! 4) TERMINATE CALIBRATOR OUTPUTS A & B WITH 50 ohm AND INSERT PROBES
190   !     A AND B WITH TWO TEE'S; (MUST HAVE 50 ohm SOURCE IF NO 50 ohm LOAD)
200   ! 5) SET COUNTER TO SEPERATE;  DC/50 ohms/X1/PRESET to BOTH CHANNELS
210   ! 6) CONNECT 5363 TRIG LEVEL OUTPUT (A or B) TO CALIBRATOR OFFSET INPUT
220   ! 7) HPIB ADDRESSES:  COUNTER-707, CALIBRATOR-705, PROBE-704
230   !
240   !_____ INITIALIZATION _____
250   Ctr=707                             !HPIB ADDRESSES
260   Cal=705
270   Probe=704
280   Ps=1.E+12                           !CONSTANT
290   OUTPUT Ctr;"FN1"
300   INPUT "TYPE IN OFFSET (-9.99 TO 9.99 volts @ Hi Z; -2 TO +2 V @ 50 OHMS)",V
310   OUTPUT Ctr;"ST6"                    !CLEARS ANY PREVIOUS REFERENCE
320   Level$=VAL$(1000+INT(ABS(100*V)+.5)) !A TRICK TO GET LEADING 0
330   Level$="+"&Level$[2,4]              !TRADE LEADING "1" FOR "+"
340   IF V<0 THEN Level$="-"&Level$[2,4]  !TRADE "+" FOR "-"
350   OUTPUT Probe;"GA"&Level$&"USRB"&Level$&"US"!SET TRIG LEVEL (2-PROBE CAL)
360   OUTPUT Ctr;"FN2TRTA0.00"            !SET COUNTER TO SUIT PROBE OUTPUTS
370   OUTPUT Ctr;"TO0.00"
380   OUTPUT Ctr;"SRSA1SO1"
390   OUTPUT Ctr;"FN4GT2MR"               !MEASURE FREQUENCY (PERIOD)
400   ENTER Ctr;Per
410   OUTPUT Ctr;"FN1ST1SS3AR2EA0MD2MR"   !SET COUNTER FOR T.I.
420   ENTER Ctr;Pfff                      !DUMMY READ TO CLEAR PIPELINE
430   !
440   !_____
450   DISP "       TIME-INTERVAL CALIBRATION IN PROGRESS"
460   OUTPUT Cal;"B1"
470   OUTPUT Ctr;"MR"
480   T1=FNTi(Per,Ctr)                    ! + +  SLOPE DIRECT
490   OUTPUT Probe;"GADSRBDS"
500   OUTPUT Ctr;"MR"
510   T2=FNTi(Per,Ctr)                    ! - -  SLOPE DIRECT
520   OUTPUT Cal;"B2"
530   WAIT .004
540   OUTPUT Ctr;"MR"
550   T3=FNTi(Per,Ctr)                    ! - -  SLOPE SWAPPED
560   OUTPUT Probe;"GAUSRBUS"
570   OUTPUT Ctr;"MR"
580   T4=FNTi(Per,Ctr)                    ! + +  SLOPE SWAPPED
590   OUTPUT Cal;"B3"
600   WAIT .004
610   OUTPUT Probe;"GAUSRBDS"
620   OUTPUT Ctr;"MR"
630   T5=FNTi(Per,Ctr)                    ! + -  SLOPE DIRECT
640   OUTPUT Probe;"GADSRBUS"
650   OUTPUT Ctr;"MR"
660   T6=FNTi(Per,Ctr)                    ! - +  SLOPE DIRECT
```

```
670 OUTPUT Cal;"B4"
680 WAIT .004
690 OUTPUT Ctr;"MR"
700 T7=FNTi(Per,Ctr)                        ! -  +  SLOPE SWAPPED
710 OUTPUT Probe;"GAUSRBDS"
720 OUTPUT Ctr;"MR"
730 T8=FNTi(Per,Ctr)                        ! +  -  SLOPE SWAPPED
740 !                 END TIME-INTERVAL CALIBRATION
750 !
760 !_____
770 DISP "      WIDTH, RISE/FALL SKEW CALIBRATION IN PROGRESS"
780 !SINGLE PROBE MEASUREMENTS (PROBE-A)
790 !FOR PROBE-B CALIBRATION, REPLACE A BY B IN PROBE COMMANDS IN THIS SECTION
800 !FOR EXAMPLE,"GAUSRADS" IS CHANGED TO "GBUSRBDS"
810 !IF NOTHING ELSE IS CHANGED, CALIBRATOR SHOULD BE ON B4
820 OUTPUT Ctr;"AR1MR"
830 OUTPUT Probe;"GAUSRADS"
840 WAIT .004                               ! PROBE-A CAL (ONE-PROBE)
850 OUTPUT Ctr;"MR"
860 ENTER Ctr;W4                            ! +  -  WIDTH SWAPPED
870 OUTPUT Probe;"GADSRAUS"
880 OUTPUT Ctr;"MR"
890 ENTER Ctr;W3                            ! -  +  WIDTH SWAPPED
900 OUTPUT Cal;"B3"
910 WAIT .004
920 OUTPUT Ctr;"MR"
930 ENTER Ctr;W2                            ! -  +  WIDTH DIRECT
940 OUTPUT Probe;"GAUSRADS"
950 OUTPUT Ctr;"MR"
960 ENTER Ctr;W1                            ! +  -  WIDTH DIRECT
970 OUTPUT Cal;"B1"
980 WAIT .004
990 OUTPUT Ctr;"AR2MR"
1000 OUTPUT Probe;"GAUSRAUS"
1010 OUTPUT Ctr;"MR"
1020 R=FNTi(Per,Ctr)                        ! +  +  PROBE-A (RISE)
1030 OUTPUT Probe;"GADSRADS"
1040 OUTPUT Ctr;"MR"
1050 F=FNTi(Per,Ctr)                        ! -  -  PROBE-A (FALL)
1060!                 END WIDTH RISE/FALL CALIBRATION
1070!_____
1080!
1090 OUTPUT Probe;"GAUSRBUS"                !BACK TO 2-PROBES TO THERMO EQUILIZE
1100 OUTPUT Ctr;"MD1"                       !RETURN COUNTER TO CYCLING MODE
1110!
1120!          BEGIN CALCULATE CALIBRATION CONSTANTS
1130 Cpp=.5*(T1+T4)
1140 Cnn=.5*(T2+T3)
1150 Cpn=.5*(T5+T8)
1160 Cnp=.5*(T6+T7)
1170 IF W1>Per THEN W1=W1-Per
1180 IF W2>Per THEN W2=W2-Per
1190 IF W3>Per THEN W3=W3-Per
1200 IF W4>Per THEN W4=W4-Per
1210 Wpn=.5*(W1+W4-Per)
1220 Wnp=.5*(W2+W3-Per)
1230 !          END CALCULATE CALIBRATION CONSTANTS
1240 !_____
1250 !
1260 !          BEGIN CALCULATE CONSISTENCY PARAMETERS
1270 Pp=.5*(T1-T4)
1280 Nn=.5*(T2-T3)
1290 Pn1=.5*(T5-T8)
1300 Pn2=.5*(T6-T7)
1310 Wpn1=W1-.5*Per-.25*(W1-W2+W3-W4)
1320 Wpn2=W4-.5*Per+.25*(W1-W2+W3-W4)
```

```
1330 PRINT "              CALIBRATION CONSTANTS:"
1340 PRINT "     (TO BE SUBTRACTED FROM COUNTER READINGS)"
1350 PRINT USING """"        TIME INTERVAL + TO +   "",  DDDDDD, "" ps""";Cpp*Ps
1360 PRINT USING """"        TIME INTERVAL - TO -   "",  DDDDDD, "" ps""";Cnn*Ps
1370 PRINT USING """"        TIME INTERVAL + TO -   "",  DDDDDD, "" ps""";Cpn*Ps
1380 PRINT USING """"        TIME INTERVAL - TO +   "",  DDDDDD, "" ps""";Cnp*Ps
1390 PRINT USING """"        WIDTH  + TO -          "",  DDDDDD, "" ps""";Wpn*Ps
1400 PRINT USING """"        WIDTH  - TO +          "",  DDDDDD, "" ps""";Wnp*Ps
1410 PRINT USING """"        RISE-TIME SKEW         "",  DDDDDD, "" ps""";R*Ps
1420 PRINT USING """"        FALL-TIME SKEW         "",  DDDDDD, "" ps""";F*Ps
1430 PRINT "CALIBRATED AT ";INT(1.E-6/Per+.5);" MHz with OFFSET @ ";Ofs;" VOLTS"
1440 PRINT "CONSISTENCY:"
1450 PRINT "TI ++,--: ";INT(Ps*(Pp-Nn)*.5);"ps"
1455 PRINT "TI +-,+-: ";INT(Ps*(Pn1-Pn2)*.5);"ps"
1460 PRINT "WIDTH   : ";INT(Ps*(Wpn1-Wpn2)*.5);"ps"
1470 !PRINT "WIDTH -+: ";INT(Ps*(Wnp1-Wnp2)*.5);"ps"
1480 DISP "END CALIBRATION"
1490 END
1500 !
1510 !_____
1520 DEF FNTi(P,Ctr)                    !RETURNS T.I.
1530 ENTER Ctr;T
1540 IF ABS(T)<.5*P THEN 1570           !WITH PROPER PERIOD COMPLEMENT
1550 OUTPUT Ctr;"PCMR"
1560 ENTER Ctr;T
1570 RETURN T
1580 FNEND
```

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