HP 70820A Microwave Transition Analyzer: Picosecond Delta-Time Accuracy

Product Note 70820-3

HP 71500A/70820A Product Note Series

DC - 40 GHz frequency range
1 picosecond accuracy
0.1 % time span resolution

Device characterization and modeling
Switching times
Rise/fall times
Delay

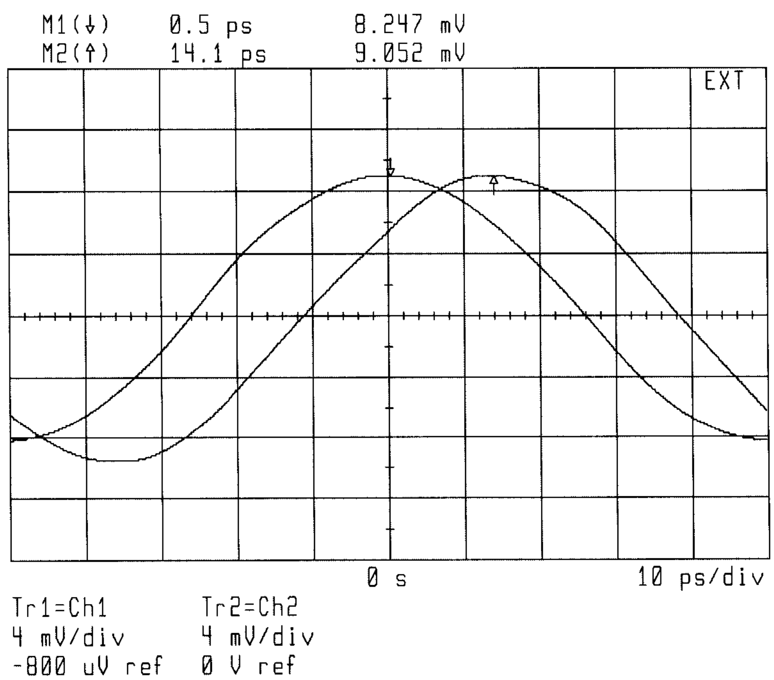


Figure 1. The HP 70820A controls a synthesized source for best ΔT accuracies. Here, the HP 70820A measures ΔT between two points to 1 picosecond accuracy

The HP 70820A microwave transition analyzer provides excellent ΔT accuracies. This product note demonstrates the proper measurement technique for achieving picosecond time-scale accuracies.

Product Note 70820-3

HP 70820A Microwave Transition Analyzer: Picosecond Delta-Time Accuracy

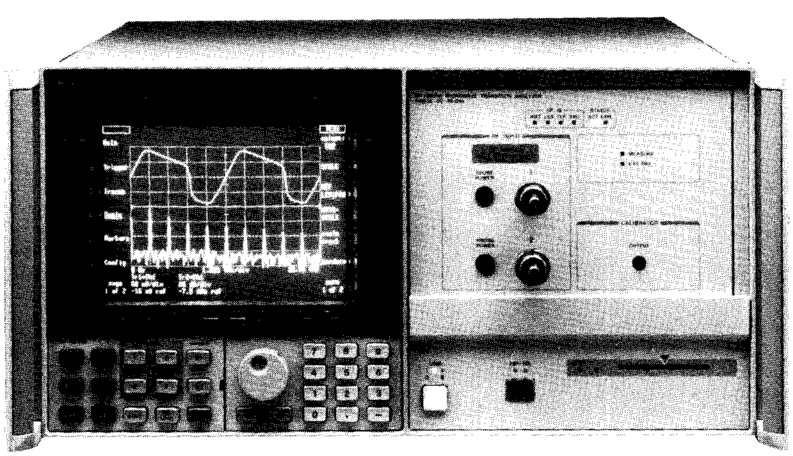
Accurate ΔT Measurements Using the HP 70820A Microwave Transition Analyzer

The HP 70820A microwave transition analyzer accurately measures the time between two events, either on a single signal or between two signals. Accuracies of 1 ps can be achieved using proper measurement techniques. These techniques rely on a stimulus/response environment, using a stable signal source to stimulate the device under test, a common frequency reference with the HP 70820A, and minimizing system noise.

The frequency of the RF input signal must be entered into the HP 70820A to set up the x-axis time scale. By configuring the HP 70820A with a source in a stimulus/response system, entering the source frequency is as easy as setting the RF input frequency. Using a stable source with a common frequency reference, the time-scale accuracy can be improved to the absolute accuracy of the frequency reference (approximately 0.1 ppm/year).

Other measurement methods can be used, but they result in a larger signal-frequency uncertainty. The HP 70820A multiplies this uncertainty, resulting in an inaccurate x-axis time scale. A later section, "Alternate Measurement Setup for Reduced ΔT Accuracy," provides more information regarding other measurement methods.

Markers can be used to measure rise time, fall time, delay, pulse widths and frequency. To perform marker frequency measurements of an unknown input signal, the HP 70820A provides a find-signal routine. This routine measures the signal frequency and improves the accuracy of the time scale.



The HP 70820A microwave transition analyzer is a two channel, dc-40 GHz measuring receiver module for the HP 70000 modular measurement system. It combines time-domain and frequency-domain measurement capabilities into one instrument.
The HP 71500A microwave transition analyzer system is configured by installing an HP 70820A in an HP 70004A color display and mainframe to form a complete measuring system.

The HP 70820A offers other advantages for ΔT measurements:

- Improved noise performance using noise-reduction filtering
- Improved ΔT resolution using fast Fourier transform (FFT) and phase measurement to improve signal-to-noise ratio
- Negative time; that is, the ability to see events prior to the trigger. Negative time simplifies measuring rise time on the trigger edge without using a delay line that could degrade the transition.
- User corrections for input cable losses

Additional information for using the HP 70820A to perform ΔT measurements can be found at the end of this note:

Table 1. -- Sample ΔT accuracies
Appendix A -- Reducing the effects of frequency estimation errors
Appendix B -- Sample time-scale accuracy calculations
Appendix C -- Supported sources
Appendix D -- Supported source compatibility
Appendix E -- Glossary of defined symbols

For more information on the HP 70820A, contact your local HP representative and ask for the following literature:

Technical Data Sheet
HP 71500A Microwave Transition Analyzer System
Literature number - 5091-0792E

Product Notes
Product Note 70820-1
The Microwave Transition Analyzer: A Versatile Measurement Set for Bench and Test
Literature Number - 5952-2543

Product Note 70820-2
The Microwave Transition Analyzer: Measure 25 ps Transitions on Switched and Pulsed Microwave Components
Literature Number - 5952-2546

ΔT Accuracy

The accuracy of time-interval, or ΔT, measurements made with the HP 70820A depends on the accuracy of the displayed time scale and the resolution of the time-interval markers. Equation 1 defines ΔT accuracy as the greater of:

$$\Delta T_a = (E_{TS} \times \Delta T) + T_S/N_P$$

or

$$= 1 \text{ ps} \qquad \text{eq. 1}$$

where:

E_{TS} = Time-scale accuracy, a ratio

ΔT = Delta-time marker reading

T_S = Time span

N_P = Number of trace points, and

T_S/N_P = Time-scale resolution = T_r

As an example, using the data shown in figure 1:

ΔT_a = (0.1 ppm x 14.1 ps)+100ps/1000

ΔT_a = 0.1 ps

or

ΔT_a = 0.1% of time span

Having an accurately calibrated HP 70820A time axis depends on using proper measurement techniques shown in figure 2 and discussed in this product note.

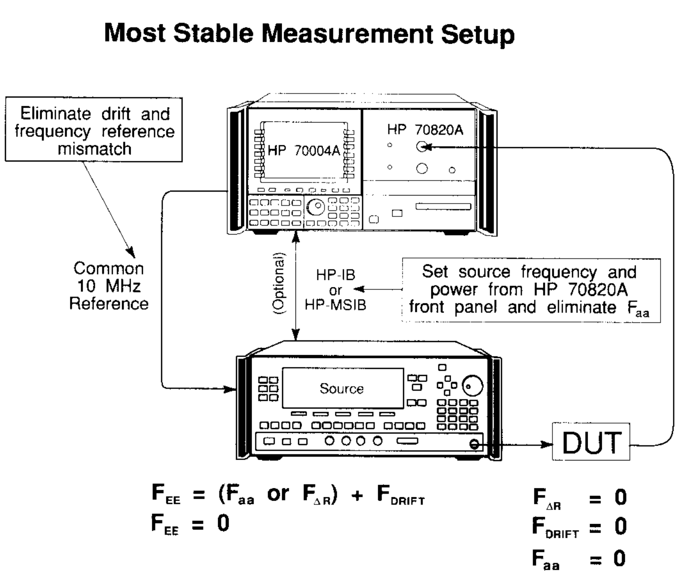


Figure 2. Recommended time-scale accuracy measurement setup

Time-scale Accuracy (E_{TS})

The accuracy of the time-scale is defined by equation 2:

$$E_{TS}=(F_{EE}/F_{IF})+E_R \qquad \text{eq. 2}$$

where :

F_{EE} = Frequency estimation error

F_{IF} = IF frequency

E_R = Frequency reference error, a ratio

The best way to improve the time-scale accuracy is to reduce the frequency estimation error to zero.

$$F_{EE} = (F_{aa} \text{ or } F_{\Delta R}) + F_{Drift} \qquad \text{eq. 3}$$

where:

F_{aa} = Accuracy of the find-signal routine.

$F_{\Delta R}$ = Difference in frequency between the source and the HP 70820A frequency reference.

F_{Drift} = Change in input signal frequency from estimation.

The first step in reducing the frequency error (F_{EE} in equation 3) to zero is to use a common time base between the HP 70820A and the synthesized source, as shown in figure 2. Here, the 10 MHz frequency reference of the synthesized source and the HP 70820A are connected. Sharing a common frequency reference eliminates $F_{\Delta R}$ and $F_{Drift.}$

To set F_{aa} to zero, the HP 70820A can be used to control the source over either HP-IB or HP-MSIB. The frequency and power level of the source are set from the HP 70820A front panel, and the signal frequency is known exactly.

If the source cannot be controlled by the HP 70820A, F_{aa} can be eliminated by entering the value of the source signal frequency into the HP 70820A. Knowing the exact input signal frequency of the source eliminates the need to use the find-signal routine in the HP 70820A to determine the signal frequency. Thus F_{aa} is set to zero.

Therefore, the frequency-estimation error is zero. From equation 1,

$$E_{TS} = 0 + E_R \approx 0.1 \text{ ppm}$$

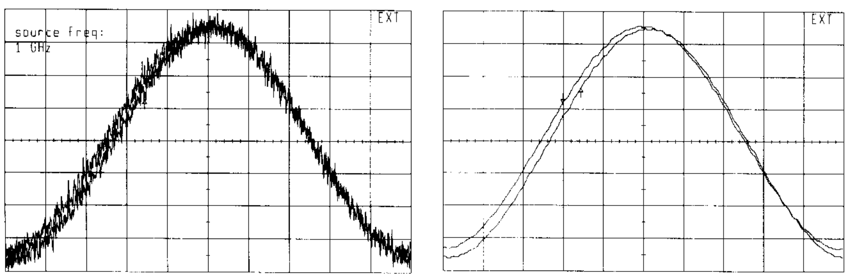
and from equation 2,

$$\Delta T_a = (E_R \times \Delta T) + T_r \approx T_r$$

The uncertainty of the ΔT measurement is therefore reduced to where it is dominated by the resolution of the measurement.

Noise Reduction Filtering Improves Measurement Resolution

Displayed noise on a signal affects the resolution of a ΔT measurement. Averaging the trace reduces the noise but slows the measurement time. The noise filter in the HP 70820A provides a 20 dB improvement in the signal-to-noise ratio on a single trace acquisition, improving resolution while reducing total measurement time when compared to averaging. Averaging of the trace may still be used with the noise filter for greater reduction in noise. Figure 3 illustrates the effects of using the noise filter on the resolution of a ΔT measurement.

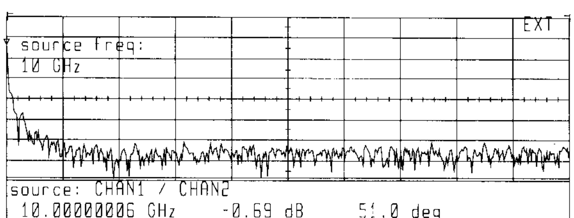


Without Noise Filter **With Noise Filter**

Figure 3. Effects of adding a noise filter

Using the Fast Fourier Transform to Improve ΔT Resolution

Using the fast Fourier transform (FFT) provides another method of improving the signal-to-noise ratio. When measuring the ΔT between two sinusoid waveforms, the FFT can improve resolution by lowering the noise level. The FFT improves the signal-to-noise ratio by $10 \times \log(N_p)$. Figure 4 demonstrates the results of using the FFT in tabular form using table mode. The phase readout from the table has a 0.1 degree readout resolution between the two signal fundamentals. The phase reading is then converted to ΔT using the formula shown in figure 4.

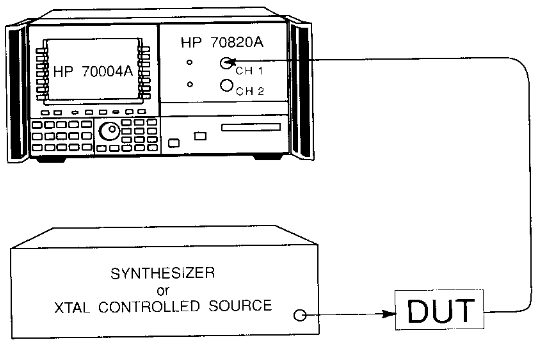


$$\Delta T = \frac{\text{Phase}}{360} \times \frac{1}{\text{freq}}$$

$$\frac{51.0}{360} \times \frac{1}{10.0\ \text{GHz}} = 14.1\ \text{ps}$$

Figure 4. Using the FFT to perform a delta-time measurement

Alternate Measurement Setup for Reduced ΔT Accuracy. An alternate method for making ΔT measurements using the HP 70820A is shown in the measurement setup of figure 5. Table 1 presents information on the ΔT accuracies that can be expected using this setup.



$F_{EE} = (F_{aa} \text{ or } F_{\Delta R}) + F_{DRIFT}$

$F_{EE} \approx F_{aa}$

$F_{\Delta R} = 0.2\text{ppm}$

$F_{DRIFT} = 0.1\text{ppm}$

$F_{aa} = 0.01$ Hz; CW = 500 Hz to 10 MHz

$F_{aa} = 15$ Hz + (0.035ppm x CW); CW = 10 MHz to 40 GHz

Figure 5. Alternate time scale measurement setup

When sharing a common frequency reference with the synthesized source is not possible, the find-signal routine of the HP 70820A should be used to determine the input signal frequency (F_{IN}). The routine determines signal frequencies to an accuracy of approximately 15 Hz +[0.035 ppm x F_{IN}] for input signals > 10 MHz, and 0.01 Hz for input signals < 10 MHz. This signal frequency accuracy does not include the frequency reference uncertainty. The reference uncertainty is added later (see equation 2).

In the setup shown in figure 5, the source uses a crystal-controlled oscillator as a frequency reference but cannot be locked to the 10 MHz reference of the HP 70820A. In this case, the frequency source is stable, but F_{EE} is not zero; even so, it is still acceptable in many cases. As an alternative to using the find-signal routine to estimate the input signal frequency, the signal frequency can be entered into the HP 70820A. Entering the signal frequency replaces F_{aa} with $F_{\Delta R}$. Typically, F_{aa} is less than $F_{\Delta R}$, so using the find signal routine is recommended for this type of setup.

With the frequency estimation error not zero:

$E_{TS} = F_{EE}/F_{IF} + E_R$, and
$\Delta T_a = (E_{TS}$ x reading$) + T_r$

The uncertainty of the ΔT measurement is no longer dominated by the resolution of the measurement. Appendix A discusses means of improving the time-scale accuracy for this alternate case.

Performing ΔT measurements with a source that is not crystal controlled or that drifts is not recommended. Unstable sources produce the highest inaccuracies in the time scale. Table 1 provides an example of these inaccuracies.

Pulse and Function Generators as a Source (Baseband)
Care should be taken when using pulse generators as sources with the HP 70820A. Pulse generators typically use a resistance-capacitance oscillator as a time base, and the relative instability of the oscillator directly affects the stability of the pulse generator. For pulse repetition frequencies (PRFs) between 153 Hz and 5 MHz (pulse repetition interval is set in 100 ns steps), the internal pulse generator of the HP 70820A should be connected to the external-trigger input of the pulse generator. This configuration, shown in figure 6, provides the best possible time-scale accuracies by locking the pulse repetition frequency of the pulse generator to the 10 MHz frequency reference of the HP 70820A. This configuration also provides the flexibility to change the pulse amplitude, which is not available when using the internal pulse generator of the HP 70820A. For repetition rates faster than 5 MHz, the external trigger input of the pulse generator must be driven with a synthesized source set to the desired repetition rate. The frequency reference of the synthesized source and the HP 70820A must be connected to eliminate the frequency-estimation error, F_{EE}.

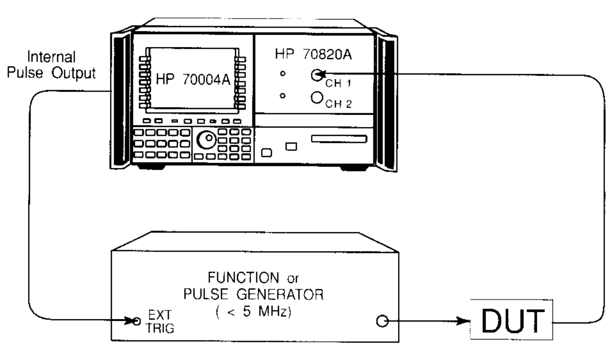


Figure 6. Setup for pulse function generators

Pulsed-RF Source

When measuring a repetitive pulsed-RF signal, it is important to note that the signal frequency is the PRF; the signal frequency is not the RF carrier frequency. As a result, F_{IF} typically is less than 500 Hz. The time-scale accuracy, E_{TS}, is now very dependent on F_{EE} being small, i.e., zero. Therefore, it is essential for these measurements that the pulse source be frequency stable and known. Connecting the HP 70820A to the same frequency reference as the source is the easiest way to ensure a stable, known pulse source. The internal pulse generator of the HP 70820A can also be used to trigger the pulse and achieve this same stability. Non-repetitive or unstable pulses can be measured with the single-shot mode, but the time-scale resolution is limited to 50 ns, at best.

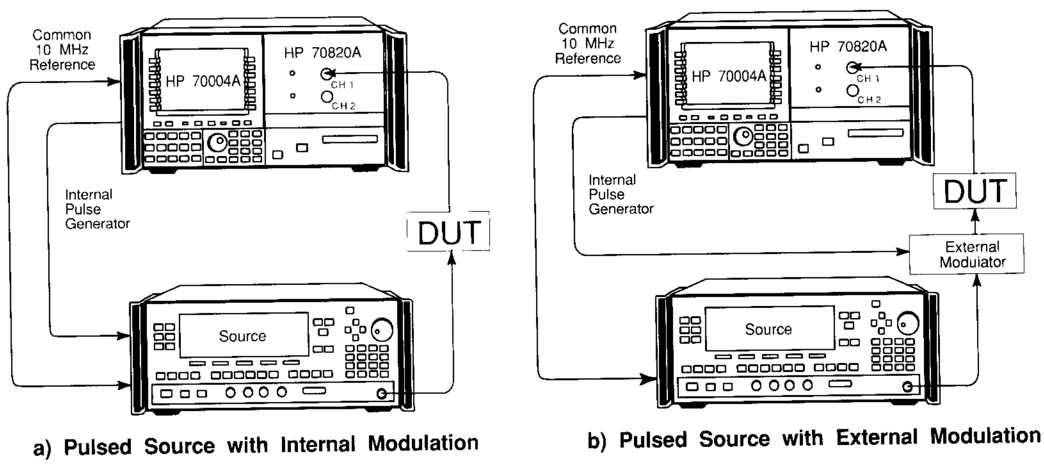


Figure 7. Pulsed-RF source set up, showing internal and external pulse modulation connections

Table 1

Sample calculations of ΔT accuracy using the setups shown in figure 2 and 5. A 1,000 point (N_P) trace length is used in each example, and the frequency reference error (E_R) is 0.1 ppm. Using the setup shown in figure 2 yields the smallest errors in ΔT measurements.

Time span[1] (T_S)	Frequency Estimation Error (F_{EE})	Time Scale Accuracy (E_{TS})	ΔT Accuracy (ΔT=time span) (time)	ΔT Accuracy (ΔT=time span) (%)
Common frequency reference, frequency entered. $F_{EE} = 0$.				
50 ps	0 Hz	0.1 ppm	± 50 fs	0.1 %
1 ns	0 Hz	0.1 ppm	± 1 ps	0.1 %
1 µs	0 Hz	0.1 ppm	± 1 ns	0.1 %
The following information illustrates the effect on time-scale accuracy when the find-signal routine is used. Common frequency reference, frequency determined by find-signal routine. $F_{EE} = F_{aa}$.				
50 ps	1,415 Hz	3.5 %	± 1.8 ps	3.6 %
1 ns	50 Hz	0.25 %	± 3.5 ps	0.35 %
1 µs	0.01 Hz	0.1 %	± 2.0 ns	0.20 %
No common frequency reference, determined by find-signal routine. $F_{EE} = F_{aa} + F_{Drift}$, assume drift = 0.1 ppm.				
50 ps	5,415 Hz	13.5 %	± 6.8 ps	13.6 %
1 ns	150 Hz	0.75 %	± 8.5 ps	0.85 %
1 µs	0.11 Hz	1.1 %	± 12.0 ns	1.2 %
No common frequency reference, frequencies entered ($F_{aa} = 0$). $F_{EE} = F_{\Delta R} + F_{Drift}$, assume drift = 0.1 ppm.				
50 ps	12,000 Hz	30 %	± 15.0 ps	30 %
1 ns	300 Hz	1.5 %	± 16.0 ps	1.6 %
1 µs	0.3 Hz	3 %	± 31.0 ns	3.1 %

The best accuracy and easiest-to-use configuration results when a common frequency reference is used between the source and HP 70820A. Appendix D lists the HP sources that are supported with a driver in the HP 70820A. ΔT measurements using a drifting source are not recommended, although frequency and power measurements may be made in these configurations. Shown below are the effects on ΔT when using a drifting source for the measurement.

Frequency determined by auto-acquire routine, frequency drifting. $F_{EE} = F_{aa} + F_{Drift}$, assume drift = 1 ppm.				
50 ps	41,415 Hz[2]	104 %	± 52. ps	104 %
1 ns	1,050 Hz[2]	5.3 %	± 54. ps	5.4 %
1 µs	1.01 Hz[2]	10.1%	± 102 ns	10.2 %

[1] Input frequency (FIN), sampling frequency (FS) and IF frequency (FIF) for the time scale settings are shown below:

Time span	Input Frequency (F_{IN})	Sampling Frequency (F_S)	IF Frequency (F_{IF})
50 ps	40 GHz	20 MHz	40 kHz
1 ns	1 GHz	20 MHz	20 kHz
1 us	1 MHz	10 kHz	10 Hz

[2] Assuming a drift of 1 ppm from the time the frequency estimate was made.

APPENDIX A: Improving Time-Scale Accuracy

The accuracy of the time-scale depends on two factors:

1) The frequency of the time-scaled replica of the RF input in the IF (F_{IF}). This is determined by the time-scale setting of the HP 70820A.

2) The accuracy with which the HP 70820A knows the RF input frequency.

An error in estimating the RF frequency, or a drift of the RF signal from the estimation, results in a time-scale accuracy error. Knowing the RF input frequency exactly reduces the time-scale accuracy error to the frequency-reference accuracy. The following equation describes the time-scale accuracy uncertainty (E_{TS}) of the HP 70820A as a ratio:

$$\mathbf{E_{TS}=(F_{EE}/F_{IF})+E_R} \qquad \text{eq. 4}$$

where:

F_{EE} = Frequency estimation error; that is, the difference between the HP 70820A signal frequency and the actual signal frequency.

F_{IF} = Frequency of the signal in the IF.

E_R = Frequency reference accuracy, a ratio.

Connecting the frequency reference of the source and the HP 70820A reduces the frequency-estimation error (F_{EE}) to zero. The uncertainties are then dominated by the ΔT resolution.

An understanding of how to achieve the most accurate time-scale with the HP 70820A can be gained by examining how the system acquires data. The HP 70820A uses a sampling technique called "harmonic repetitive sampling," which is described below.

Overview of the HP 70820A Data Acquisition Process
Figure 8 shows a simplified block diagram of the HP 70820A. As a measurement begins, the HP 70820A sets the frequency of its local oscillator to a value very close to a sub-harmonic of the input frequency (either the fundamental or the PRF of a pulsed-RF signal). The frequency is set between 10 MHz and 20 MHz; typically the frequency will be very close to 20 MHz. The HP 70820A samples the waveform, incrementing forward through the input signal, as shown in figure 9. Each time the sampler is enabled, the HP 70820A samples a different point on the input signal.

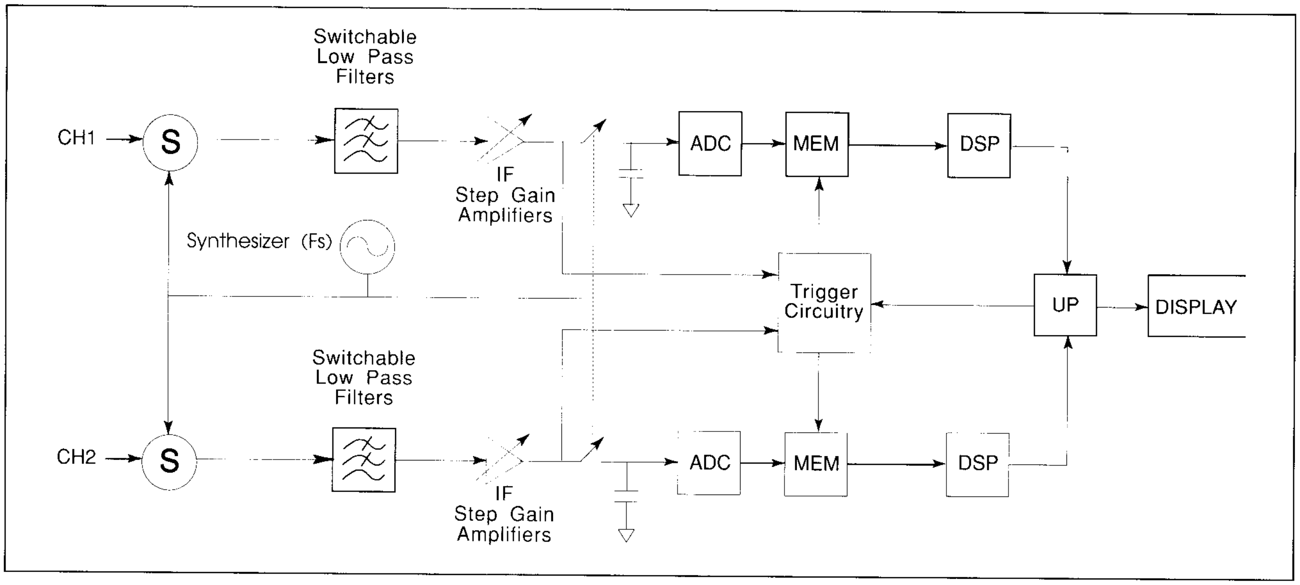


Figure 8. HP 70820A Simplified Block Diagram

Figure 9 shows an example of this sampling process. The input signal frequency is 100 MHz. The sampler frequency chosen is slightly less than 20 MHz. Choosing a sampling frequency of slightly less than 20 MHz (period slightly greater than 50 ns) causes the sampler to sample successive points on the waveform, and the sampling point moves forward through the input signal.

The sampling process creates a time-scaled replica of the RF signal in the IF. The HP 70820A digitizes and analyzes this IF signal.

If the sampling frequency chosen had been exactly 20 MHz, the same point on the input waveform would have been sampled each time. The resulting sampled signal would correspond to the dc value of the input waveform at the sample point.

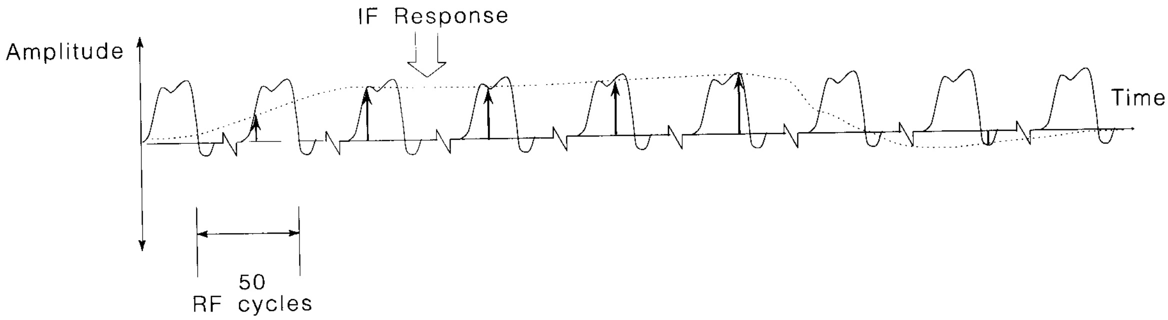
Reducing the Frequency Estimation Error

For the setup in figure 2, the frequency-estimation error is zero and, for this reason, is the recommended setup. The setup in figure 5, however, has a frequency-estimation error. The effect of this error can be minimized in some cases.

If the frequency-estimation error is not zero, the time-scale accuracy can be improved by increasing the frequency of the signal in the IF (F_{IF}). This signal is a scaled replica of the RF input and is the waveform that actually is displayed on the CRT screen. Increasing F_{IF} is most easily accomplished by reducing the number of trace points across the screen, though this also reduces time-scale resolution (T_r).

The time-scale accuracy error (ratio) is:

$$\mathbf{E_{TS} = (F_{EE} / F_{IF}) + E_R} \qquad \text{eq. 5}$$



Input:

F_{signal} = 100 MHz square wave
T_{signal} = 10 ns

Instrument State:

Time Span = 10 ns
# Trace Points = 100
N = 5

$$T_S = \frac{1}{F_S} = (N \times T_{signal}) + T_R$$

$$T_R = \frac{\text{time span}}{\text{\# trace points}} = \frac{10\text{ ns}}{100} = 0.1\text{ ns}$$

Therefore: T_S = 50.1 ns

Figure 9. Harmonic Repetitive Sampling, an example

If the measurement is dominated by the time-scale accuracy error, E_{TS}, rather than the resolution, T_R, then several tactics can be used to increase F_{IF} and thus reduce E_{TS}.

Increasing F_{IF} can be accomplished by:

1. Decreasing the number of trace points (N_P).
2. Increasing the number of cycles shown on the screen (N_C).
3. Increasing the sampling frequency (F_S).

An examination of how F_{IF} is calculated is useful. The equation that describes the F_{IF} and its relationship between the number of cycles on the screen, trace points, and sampling frequency is:

$$\mathbf{F_{IF} = (N_C / N_P) \times F_S} \qquad \text{eq. 6}$$

where:

N_C = Number of cycles of the signal shown across screen

N_P = Number of trace points across screen

F_S = Sampling frequency

Sample calculation of F_{IF}

Equation 6 shows how sampling frequency, number of cycles on screen, and number of trace points affect the IF frequency. In the following example, the display of the instrument shows one cycle of the waveform using a trace length of 1,000 points. For this single cycle, the HP 70820A must acquire 1,000 sample points.
The sampling frequency is approximately 20 MHz (50.1 ns/point). Therefore, F_{IF} for this display equals 1/1,000 x 20 MHz = 20 kHz.

The example can be changed slightly so that two cycles of a waveform are displayed, and the trace length is kept equal to 1,000 points. Now, 500 data points represent one cycle of the waveform. A simple calculation shows that F_{IF} now equals 2/1,000 x 20 MHz = 40 kHz.

Substituting for F_{IF} in equation 1:

$$\mathbf{E_{TS}} = \frac{(\mathbf{F_{EE}} \times \mathbf{N_P})}{(\mathbf{F_S} \times \mathbf{N_C})} + \mathbf{E_R} \qquad \text{eq. 7}$$

For RF input frequencies greater than 10 MHz, the sampling frequency, F_S, may be assumed to equal 20 MHz. F_{IF} is limited to values between 25 Hz and 1 MHz. While harmonics may mix into the IF above 1 MHz, the fundamental of the input signal will be mixed to less than 1 MHz in time-domain applications.

Equation 7 shows that the time-scale accuracy error is inversely proportional to the sample rate, F_S. For RF input frequencies greater than 10 MHz, F_S has been given as 20 MHz.

F_S is effectively reduced in other cases:

Rep freq > 10 MHz, noise filter off	F_S = 20 MHz	
Rep freq > 10 MHz, noise filter on	F_S = 1 MHz	
Rep freq < 10 MHz and > 10 kHz	F_S = 10 kHz	pulsed-RF measurements
Rep freq < 10 kHz	F_S = PRF	pulsed-RF measurements
Rep freq < 10 MHz, noise filter on	F_S = 1 Hz	pulsed-RF measurements

As can be seen, some modes significantly reduce F_S, which can significantly increase the time-scale accuracy error. Therefore, for these cases, HP recommends using the setup in figure 2 to reduce the relative frequency reference error to zero and totally remove this error.

In summary, more cycles onscreen, fewer trace points, and a higher sample rate F_S give a higher F_{IF} and, thus, better time-scale accuracies. However, these factors reduce the time-scale resolution, which from equation 1, may reduce the overall ΔT accuracy. A trade-off must be made depending on how large the frequency-estimation error is expected to be.

APPENDIX B: Sample Time-scale Accuracy Calculations

Examining a typical uncertainty scenario shows how time-scale accuracy may be calculated. The instrumentation setup includes a synthesized source that shares a common frequency reference with the HP 70820A. Therefore, the drift has been eliminated. However, in this example, the source is not coupled over HP-IB to the HP 70820A, and the find-signal routine is used to determine the input frequency.

The following assumptions apply to the calculation:

1. RF input frequency = 1 GHz = 1×10^9 Hz
2. Frequency estimation error (F_{EE}) = 50 Hz + (0.035 ppm x 1×10^9) = 85 Hz
3. Number of trace points (N_p) = 1,000
4. Display 1 cycle on the screen (N_C), this implies time span (T_S) = 1 ns.
5. Sampling frequency (F_S) = 20 MHz

The frequency in the IF is determined

$$\begin{aligned} F_{IF} &= (N_C / N_P) \times F_S \\ &= (1 / 1000) \times 20 \times 10^6 \text{ Hz} \\ &= 20 \text{ kHz} \end{aligned}$$

The time-scale accuracy error is determined:

$$\begin{aligned} E_{TS} &= (F_{EE} / F_{IF}) + E_R \\ &= (85 \text{ Hz} / 20 \times 10^3 \text{ Hz}) + 0.1 \text{ ppm} \\ &= 4250.1 \text{ ppm or } 0.425\% \text{ of time span} \end{aligned}$$

where E_R is determined by the drift term, which is 0.1 ppm/year.

The time-scale resolution is determined:

$$\begin{aligned} T_r &= T_S/N_P \\ &= 1 \text{ ns}/1000 \\ &= 1 \text{ ps} \end{aligned}$$

Let reading = ΔT = 1 ns

The ΔT accuracy is determined:

$$\begin{aligned} \Delta T_a &= (E_{TS} \times \Delta T) + T_r \\ &= (0.00425 \times \Delta T) + 1 \text{ ps} \\ &= 4.25 \text{ ps} + 1 \text{ ps} \\ &= 5.25 \text{ ps} \end{aligned}$$

As cycles on the screen are reduced to less than one, the error begins to increase. When 1/10[1] of a cycle is displayed on the screen, the time-scale accuracy error can be calculated as follows:

$$F_{IF} = (0.1 / 1000) \times 20 \times 10^6 \text{ Hz} = 2 \text{ kHz}$$

The time-scale accuracy error is determined:

$$E_{TS} = 85 \text{ Hz} / 2 \times 10^3 \text{ Hz} = 0.0425 \text{ or } 4.25\%$$

This error is fairly large. For measurements with fractions of a cycle onscreen, the accuracy can be improved by using the setup shown in figure 2.

If the input signal frequency is entered so that the $F_{EE} = 0$; the time-scale accuracy error (E_{TS}) is reduced to 0.1 ppm.

$$\Delta T_a = (0.1 \text{ ppm} \times \Delta T) + T_r \approx T_r = 1 \text{ ps.}$$

[1]1/10 of a cycle of a 1 GHz input signal is 100 ps across the screen (time span). This provides a screen resolution of 10 ps/div.

Appendix C: Supported Sources

Synthesized Sources Supported With HP 70820A Drivers						
	Frequency Range (GHz)	Frequency Resolution Controls	Frequency & Power Control	RF Out ON/OFF Adjustment	Pulsed-RF Carrier Freq Control	Pulse Mod ON/OFF
HP 3325B[1,2]	1 μHz[2] to 21 MHz	1 μHz	Yes	No	Yes	No
HP 3335A[1,2]	200 Hz to 81 MHz	1 mHz	Yes	No	Yes	No
HP 8340	0.01 to 26.5	1 Hz	Yes	Yes	Yes	Yes
HP 8341	0.01 to 20	1 Hz	Yes	Yes	Yes	Yes
HP 83620A Opt 008	0.01 to 20	1 Hz	Yes	Yes	Yes	Yes
HP 83622A Opt 008	2 to 20	1 Hz	Yes	Yes	Yes	Yes
HP 83623A Opt 008 (hi pwr)	0.01 to 20	1 Hz	Yes	Yes	Yes	Yes
HP 83624A Opt 008 (hi pwr)	2 to 20	1 Hz	Yes	Yes	Yes	Yes
HP 83640A Opt 008	0.01 to 40	1 Hz	Yes	Yes	Yes	Yes
HP 83642A Opt 008	2 to 40	1 Hz	Yes	Yes	Yes	Yes
HP 836xx W/O Opt 008		1 kHz	Yes	Yes	No[3]	Yes
HP 8672A	2 to 18	1-3 kHz	Yes	Yes	No[3]	Yes
HP 8673B	2 to 26	1-4 kHz	Yes	Yes	No[3]	Yes
HP 8673C	0.05 to 18.6	1-4 kHz	Yes	Yes	No[3]	Yes
HP 8673D	0.05 to 26	1-4 kHz	Yes	Yes	No[3]	Yes
HP 8673E	2 to 18	1-3 kHz	Yes	Yes	No[3]	Yes
HP 8673G	2 to 26	1-4 kHz	Yes	Yes	No[3]	No
HP 8673H	2 to 12 or 5 to 18	1-3 kHz	Yes	Yes	No[3]	Yes
HP 70320A (HP 8644A)[1]	0.000252 to 2.06	0.01 Hz	Yes	Yes	Yes	Yes
HP 70325A (HP 8645A)[1]	0.000252 to 2.06	0.01 Hz	Yes	Yes	Yes	Yes
HP 70322A (HP 8665A)[1]	0.000100 to 4.20	0.01 Hz	Yes	Yes	Yes	Yes

Use of a synthesizer under HP-IB or HP-MSIB control and sharing a common 10 MHz time base, while not absolutely required, is highly recommended to simplify the use of the instrument. Drivers for synthesizers consist of HP-IB/HP-MSIB drivers in the HP 70820A to control the source frequency, power level, RF output on/off, and pulse modulation on/off from the HP 70820A. Custom drivers for other HP-IB synthesized sources may be defined over HP-IB.

[1]The HP 3325, HP 3335, and HP 7032x synthesizers do not support a "signal settled" bit. To be safe, the user should include a dwell time sufficient to let the signal settle in frequency sweeps. The dwell time required depends on the noise filter BW used and accuracy desired.

[2]The HP 3325B and HP 3335A work well for frequency and power sweeps or any case where approximately one cycle is onscreen. But these instruments have jitter that is inversely proportional to the repetition frequency. When observing fast events at low repetition frequencies, this jitter may make the HP 3325B and HP 3335A unsuitable for ΔT measurements with the HP 70820A. HP recommends using the internal pulse generator (as a time base for low repetition frequencies) to trigger an external signal source reducing the jitter problem. The HP 3325B is supported only down to 0.1 Hz.

[3]For pulsed-RF component characterization, the HP 70820A may adjust the carrier frequency slightly from what was chosen to allow the AM/PM demodulation routines to operate properly. Because of this adjustment, synthesizers with at least 1 Hz frequency resolution are recommended for pulsed-RF component characterization.

Appendix D: Table of HP signal sources and compatibility with HP 70820A

Following is a list of HP signal sources and their compatibility rating with the HP 70820A.
See Appendix C for synthesizers specifically supported with an HP-IB/HP-MSIB driver in the HP 70820A.

Synthesized signal sources compatible with HP 70820A:				
Model #	Frequency Range	10 MHz in	10 MHz out	HP-IB
HP 3325B	1 µHz to 21 MHz	yes	yes	yes[1]
HP 3335A	200 Hz to 81 MHz	yes	yes	yes[1]
HP 8642A/B	100 kHz - 1,057.5 / 2,115 MHz	yes	yes	yes
HP 8644A	dc - 2.060 GHz	yes	yes	yes[1]
HP 8645A	252 kHz - 2.060 GHz	yes	yes	yes[1]
HP 8656B	100 kHz - 990 MHz	yes	yes	yes
HP 8657A	100 kHz - 1.040 GHz	yes[2]	yes	yes
HP 8660D	10 kHz - 2.600 GHz	yes	yes	yes
HP 8662A	10 kHz - 1.280 GHz	yes[2]	yes	yes
HP 8663A	100 kHz - 2.560 GHz	yes[2]	yes	yes
HP 8665A	100 kHz - 4.200 GHz	yes	yes	yes
HP 8671B	2 GHz - 18 GHz	yes	yes	yes
HP 8672A	2 GHz - 18 GHz	yes	yes	yes[1]
HP 8672S	10 MHz - 18 GHz	yes	yes	yes[1]
HP 8673B	2 GHz - 26.5 GHz	yes	yes	yes[1]
HP 8673C/D	50 MHz - 18.6/26.5 GHz	yes	yes	yes[1]
HP 8673E	2 GHz - 18 GHz	yes	yes	yes[1]
HP 8780A	10 MHz - 3 GHz	yes	yes	yes

Synthesized sweep generators compatible with HP 70820A:				
Model #	Frequency Range	10 MHz in	10 MHz out	HP-IB
HP 8340B	0.01 GHz - 26.5 GHz	yes	yes	yes[1]
HP 8341B	0.01 GHz - 20 GHz	yes	yes	yes[1]
HP 83620A	0.01 GHz - 20 GHz	yes	yes	yes[1]
HP 83622A	2 GHz - 20 GHz	yes	yes	yes[1]
HP 83623A	0.01 GHz - 20 GHz	yes	yes	yes[1]
HP 83624A	2 GHz - 20 GHz	yes	yes	yes[1]
HP 83640A	0.01 GHz - 40 GHz	yes	yes	yes[1]
HP 83642A	2 GHz - 40 GHz	yes	yes	yes[1]

Not Compatible with HP 70820A Non-synthesized signal sources and sweep generators:				
Model #	Frequeny Range	10 MHz in	10 MHz out	HP-IB
HP 8350B	depends on plug-in	no	no	yes
HP 8640B	0.5 MHz - 1,024 MHz	no	no	no
HP 8683/4 B	2.3 GHz - 12.5 GHz	no	no	no
HP 8683/4 D	2.3 GHz - 18 GHz	no	no	no

[1] HP-IB driver available
[2] The external reference input level required is greater than the HP 70820A reference output level. Use the source frequency reference output as the system frequency reference.

Appendix E. Glossary of defined symbols

E_{TS} = Time scale accuracy, a ratio

E_R = Frequency reference accuracy for the HP 70820A. The drift term of the internal reference is 0.1 ppm/year.

F_{AA} = Frequency error due to the accuracy of the find-signal and auto-acquire measurement routines. This error is introduced by a frequency measurement of the signal undertest.

Signal Frequency	F_{AA}
500 Hz ≤ CW signals ≤ 10 MHz	0.01 Hz + (E_R x F_{IN})
10 MHz < CW signals ≤ 40 GHz	15 Hz +[(0.035ppm +E_R) x F_{IN}]

F_{aa} = F_{AA} - (E_R x F_{IN})

F_{Drift} = Change in frequency of the input signal from the frequency measurement.

F_{EE} = Frequency estimation error. This is the difference be tween the actual input frequency and what the HP 70820A thinks the input frequency is (F_{aa}+ $F_{\Delta R}$+ F_{Drift}).

F_{IF} = Frequency of the signal in the IF

F_{IN} = Input signal frequency (this is the PRF for a pulsed RF signal)

F_S = Sampler Frequency

$F_{\Delta R}$ = Frequency error due to the difference between the two frequency references of the source and the receiver. We approximate the frequency reference difference as 2 x ER = 0.2ppm. This assumes that the error of the source is the same as the error of the HP 70820A, which represents worst case.

N_C = Number of displayed cycles, carrier or pulses

N_P = Number of trace points

ΔT = Delta time marker reading

ΔT_a = Delta time accuracy

T_r = Time-scale resolution = T_S/N_P

T_S = Time span

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