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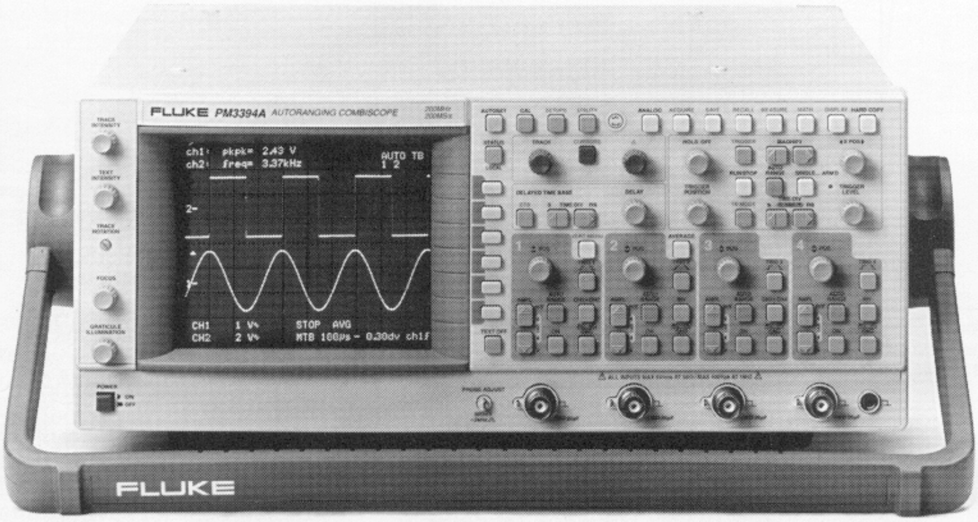
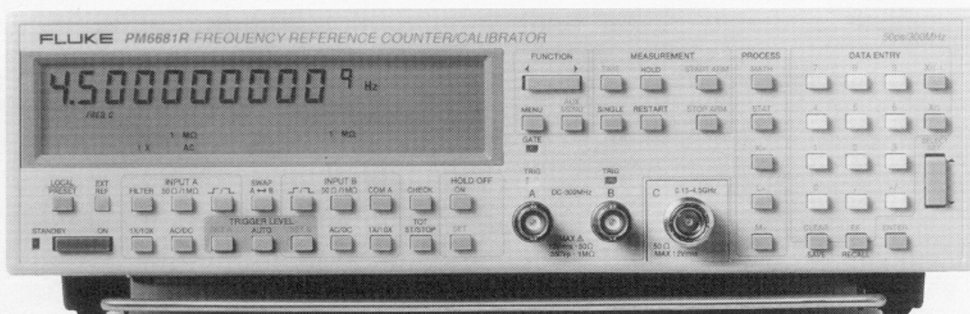
How to Measure Signal Jitter

Application Note

Measurement methods include use of oscilloscopes and electronic counters, as well as modulation-domain techniques.





Jitter is a primary cause of errors in digital communication circuits, system clocks, and signal sources. Excessive jitter can cause high bit-error rates, resulting in degradation of system performance. Just about every pulse or waveform exhibits jitter to some degree. It is often necessary to measure and quantify jitter so that it can be specified or dealt with.

Jitter is specified in a number of ways. The two most common are peak jitter, which is the maximum total excursion of the jittered signal in relation to the ideal clock, and root-mean-square (rms) jitter, which is a statistical measure, most commonly equal to the standard deviation of 1,000 waveform periods. RMS measurements are usually preferred over peak measurements because they reveal much more about the actual distribution of the jitter. The best way to measure jitter is to view the actual jitter function (see What is Jitter). From this, peak and rms values can be determined.

Specialized testers for measuring jitter are available–for example, many telecommunications test sets can measure jitter. Unfortunately though, these testers are expensive and consequently not usually found on designers' benches. Furthermore, they cannot display the jitter function. Jitter can also be measured using either an oscilloscope or an electronic counter. Another way to measure jitter that also displays the jitter function, involves a PC and special modulation analysis software.

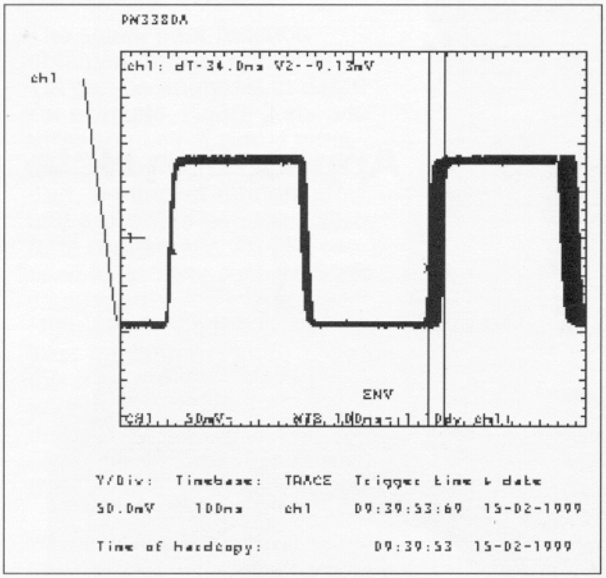


Figure 1. Envelope mode on a digital storage scope shows peak jitter value measured with cursors and displayed in the upper left corner (39.0 ns).

Measuring Jitter With a Scope

Oscilloscopes are the traditional tools for analyzing clock jitter. By watching the trace on a scope and using cursors, a user can obtain a general idea of the peak jitter. Digital storage oscilloscopes (DSOs) with an envelope mode provide an easier and more accurate method of measuring jitter. In this mode the DSO remembers the maximum and minimum excursions of the signal. This makes it easy for the user to visualize and measure the peak jitter value (see Figure 1).

Eye patterns apply a similar technique to the actual data stream. Multiple bit combinations are united into a single eye pattern. Specifications for system performance are often written around eye patterns. Color may be used in high-performance oscilloscopes to indicate bit density, giving a rough idea of the jitter distribution. Unfortunately, eye patterns and color are found only on the highest-priced DSOs. Since any analog scope is capable of displaying eye patterns, combination analog/digital scopes can be very useful.

Using a Counter

Oscilloscopes have their limitations in characterizing jitter. The jitter function cannot be reconstructed and the vast majority of oscilloscopes can measure only peak jitter.

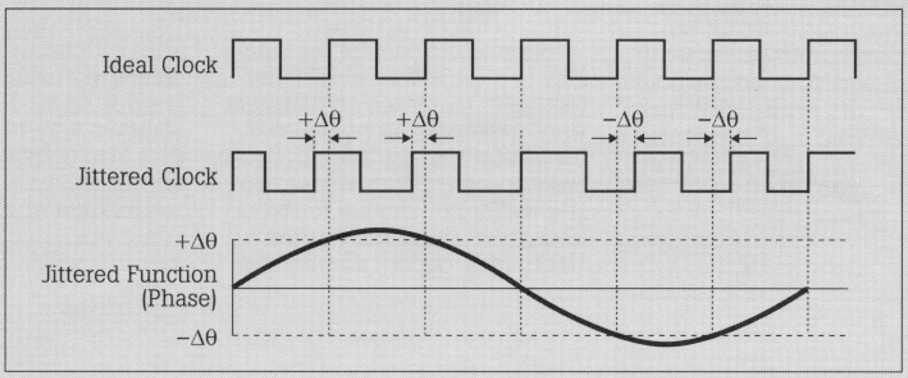
High-performance timer/counters–those offering a resolution of better than 1 ns, built-in memory, and statistics functions–can measure both peak and rms jitter faster and at lower cost than an oscilloscope. While oscilloscopes sample the voltage at precise intervals and then derive the time information, timer/counters directly measure and store the actual time information required to make the jitter measurement.

What is Jitter?

If a signal deviates in phase or frequency when compared to an ideal clock, it may be exhibiting jitter. Figure 1 shows a changing phase relationship between the ideal clock and the phase modulated clock. The jitter function shows the change of phase of the clock over time. Note that the jitter function has both amplitude (phase) and frequency components. The jitter function is equivalent to the modulating waveform of the phase modulated signal. The term jitter is actually defined as modulation where the frequency of the jitter function is greater than 10 Hz. Lower frequency modulation is called wander.

Jitter may be measured as phase, in units of degrees, but is more commonly measured in terms of unit intervals (UI), where one UI is equal to the period of the ideal clock (or 360°). Another method of measurement is in terms of frequency, where jitter is characterized by the deviation of the jittered clock from the ideal frequency. A measurement of jitter function expressed in frequency is equal to the derivative of the jitter function expressed in phase.

Jitter may be measured on either the clock signal, or on the actual data stream. It's easier to measure the jitter on the clock signal, but that may not always be available. The clock may be recovered from the data stream or eye patterns may be used.



For example, the Fluke PM 6680B Timer/Counter can measure the period of 1,000 samples and display either the standard deviation (rms jitter) or maximum and minimum deviation (peak jitter) in under three seconds. A PM 6680B sells for about one third the price of an oscilloscope capable of making measurements with equivalent resolution (500 ps).

Thus, with a counter, peak as well as rms jitter can be measured. The sample size may also be precisely set. Another advantage is that the data may easily be transferred to a computer for further analysis or for use in an automated system. And a counter can make these measurements much faster than an oscilloscope. As with most oscilloscopes, though, counters can measure jitter on a data stream only if a derived clock signal is available.

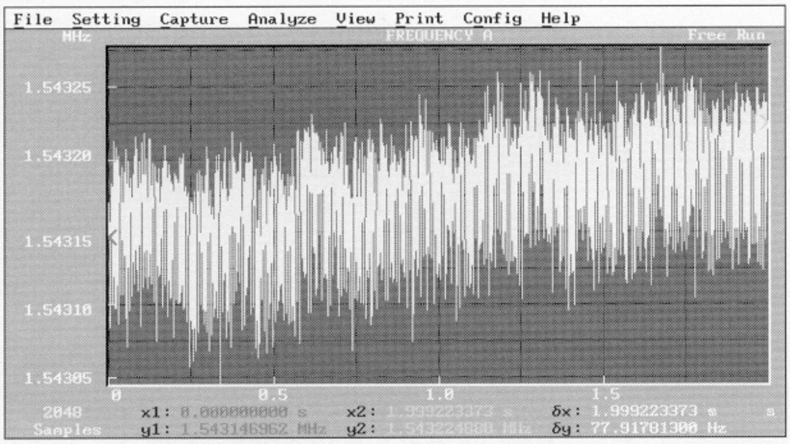


Figure 2. Modulation Domain Analysis yields this jitter function over two seconds expressed in terms of frequency.

Modulation-Domain Techniques

A fairly recent type of instrument, the time-interval analyzer (TIA), provides an even more complete method of measuring jitter. These analyzers can measure clock periods at very high speed (some beyond 10 million per second). From these measurements, the jitter function can be reconstructed (see Figure 2). Plots like these, where frequency is plotted as a function of time, are often called modulation-domain plots. As with scopes and counters, the TIA can measure jitter only on clocks or derived clocks.

Unfortunately, with prices usually ranging from $10,000 to over $30,000 (U.S.), TIAs are often too expensive for most engineers to consider. Recently, though, a number of vendors have introduced lower-cost alternatives for modulation-domain analysis that use personal computers for analysis and the user interface. One such example is the TimeView™ software package from Fluke, which teams a high-performance, relatively low-priced timer/counter with a personal computer. Even with the PC, a complete TimeView system costs much less than the lowest-priced dedicated TIA.

Although this approach yields slower measuring speeds (thousands per second), it is important to note that the high speed of a TIA exacts a severe penalty in measurement resolution. At one million readings per second, for example, no TIA can achieve a frequency resolution of four digits. TIAs and high-performance counters offer almost the same speed for high-resolution measurements. However, the high sampling rates found in TIAs are useful only in applications that require up to one million samples for a very high degree of statistical confidence.

The capabilities of the various measurement methods are compared in the table below. The typical price range for each is also given.

Capabilities of Various Jitter Measurement Methods

	Measurement Capabilities						
Measurement Method	**Peak**	**RMS**	**Eye Patterns**	**Jitter Function**	**Histogram**	**FFT**	**Typical Price (in U.S.)**
Digital Storage Oscilloscope	•		•			•	$3,500 to $10,000
Electronic Counter	•	•					$2,000 to $5,000
Dedicated Modulation Domain Analyzer	•	•		•	•	•	$10,000 to $30,000
Counter/Timer and PC Combination	•	•		•	•	•	$3,000 to $7,000

Analyzing Jitter

The actual jitter function obtained from a counter or a TIA can be analyzed in detail. For example, Figure 2 shows three sources of signal variation: a longer-term upward drift, significant random jitter, and a possible periodic short-term component. An FFT can be used to uncover such periodic components. For example, Figure 3 shows the FFT of the jitter function in Figure 2. Note the cursor at the 120 Hz peak, which may indicate poor filtering, allowing the first harmonic of the power line to modulate the clock.

For TIAs, FFT analysis is either unavailable or an expensive option. Using the power of the PC, packages like TimeView provide the FFT function easily and at no extra charge.

A histogram of the jitter (see Figure 4) shows not only the range of measurements, but the distribution of the measurements as well. The histogram clearly indicates the number of measurements that fall outside a required limit. Minimum, maximum, mean, standard deviation (rms jitter), and root Allan variance are also displayed.

Fluke timer/counters suitable for jitter analysis are PM 6680B, PM 6681 and PM 6681R.

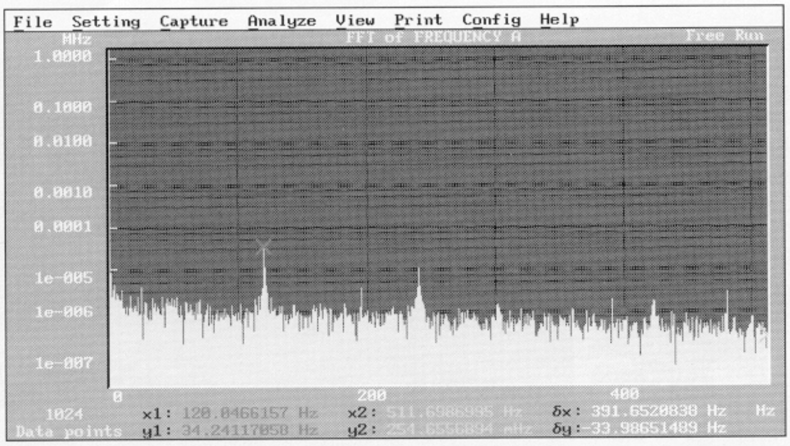


Figure 3. The FFT of the jitter function shown in Figure 2 shows peaks that indicate the frequencies of modulation sources. Note the peak at 120 Hz which may indicate modulation from a harmonic of the powerline.

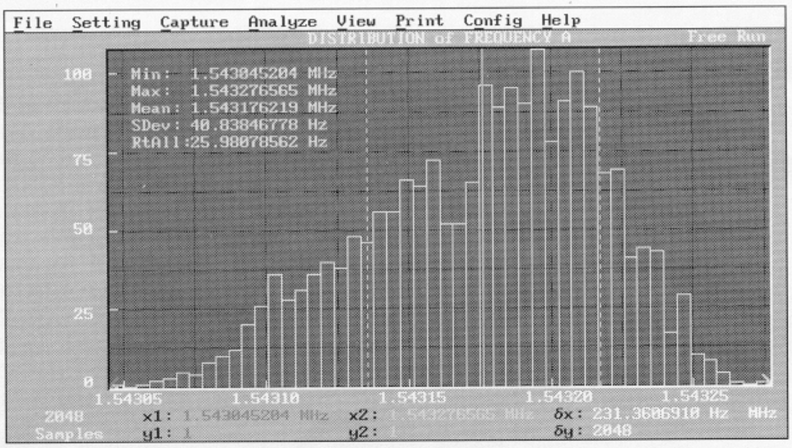


Figure 4. A histogram of the jitter function shows how the measurements are distributed. Peak, rms, and root Allan variance are shown in the upper left corner.

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