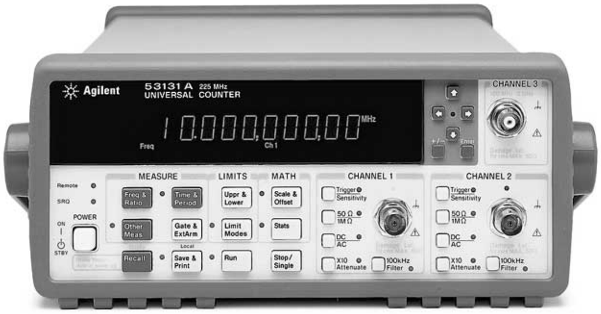
More Hints for Making Better Frequency Counter Measurements

Application Note 1499



The hints in this application note are intended to show you how you can make more accurate measurements with your frequency counter and how you can make these measurements faster and more easily.

No matter which frequency counter you use, you should be able to apply the hints in this application note to your measurement application. To illustrate the concepts, we have used Agilent 53131A, 53132A and 53181A frequency counters.

Contents

Agilent Technologies

Hint 1

Tips for making more accurate measurements with a frequency counter

A modern frequency counter reduces the complexity of making accurate measurements, but there are still some pitfalls you need to avoid when you are measuring frequencies. Following are six tips that will help you make better frequency measurements with your frequency counter.

Tip 1: Select the best arming mode.

If you want to make quick measurements, using a frequency counter's automatic arming mode is a simple way to configure it. However, of the four typical arming modes (automatic, external, time, and digits), automatic mode is the least accurate. You can improve RMS resolution and systematic uncertainty—both components of measurement error, as shown in the formula below—by increasing gate time with either the external, time, or digits arming modes.

Measurement error = Systematic uncertainty ± $\sigma \times$ (RMS resolution)

σ = Confidence factor (i.e. 2-sigma, 3-sigma, etc.)

Tip 2: For better accuracy, keep your frequency counter's timebase warm.

Most precision frequency counters rely on a temperature-compensated frequency oscillator (TCXO) or an oven-controlled frequency oscillator (OCXO). Keeping the frequency oscillator continuously powered up will avoid a couple timing errors: retrace and a shift in the output frequency. Removing the power to an oscillator, even for a short length of time, means that the oscillator has to be allowed to "retrace," or go through its entire power-on cycle of fluctuation before it comes to rest at a stable frequency. Agilent's 53100 Series counters do not

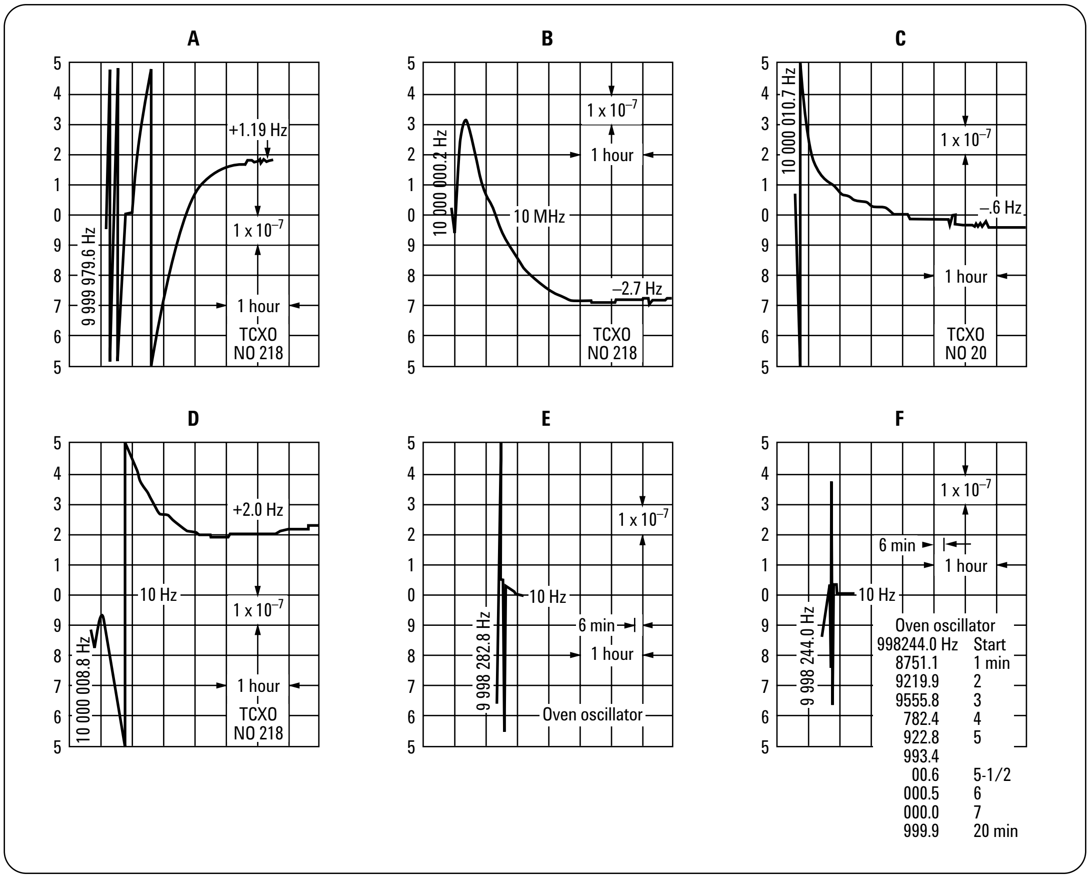


Figure 1. Graphs A, B, and C show how three similar crystals have very different turn-on characteristics. Graphs A and D show how the same crystal will exhibit different turn-on (retrace) characteristics. Finally, graphs E and F show the improved turn-on stability of an OCXO.

actually turn off unless you unplug them; they remain in “standby” mode to prevent the oscillations that happen every time the instrument power is cycled. To ensure the most stable operation of the crystal, keep your counter in a spot where you don’t have to unplug it, so it can alternate between on and standby mode. When you calibrate the timebase, bring the calibration equipment to the counter, rather than the other way around, so you don’t have to unplug the instrument. When you remove power from the counter, however briefly, the aging rate must start over from the daily aging rate.

The aging rate of an Agilent Option 012 ultra-high-stability oven in the first 90 days is:

1E-10×(30 days) + 3E-9×(2 months) = 9E-9

In the first year, the aging rate is:

1E-10×(30 days) + 3E-9×(11 months) = 36E-8

The second year (without adjustments) the aging rate is:

1E-10×(30 days) + 3E-9×(11 months) + 2E-8×(1 year) = 56E-8

If you made an adjustment at the end of the first year without removing the timebase from the power source, then the first per-day and per-month specs would not apply. In the first 90 days, the timebase aging rate would be 2E-8×(.25 year) = 5E-9. The first year aging rate would be 2E-8×(1 year) = 2E-8. Leaving the timebase powered improves the 1-year specs by an order of magnitude.

In Agilent counters, the optional timebases have improved performance over the standard timebase, in part because they have internal ovens. Keeping your frequency counter out of drafts and protecting it from changes in temperatures will also improve its stability.

Tip 3: For the greatest precision, use the best timebase available and calibrate it frequently.

The quality of the timebase and how often you calibration it will affect your measurement accuracy. For most applications, you can make a tradeoff between accuracy, timebase quality, and calibration period. If you purchase a higher-quality timebase, you can lengthen the time between calibrations. If you calibrate more frequently, you may be able to meet your accuracy requirements with a less-costly timebase. In the example above, a calibration period of 90 days will ensure the aging factor is never more than 5E-9 (after the first year).

The timebase does not need to be housed within the frequency counter. You can use a precision source or a house standard external to the counter to improve measurement accuracy.

	After initial turn on, no adjustments	Left on for 1 year and re-adjusted. Aging rate after re-adjustment
+ 90 days	9E-9	5E-9 (1.8X improvement)
+ 1 year	36E-8	2E-8 (18X improvement)
+ 2 year	56E-8	4E-8 (14X improvement)

Table 1. After 1 year of continuous operation, timebases tend to become very stable. Re-adjusting the frequency counter after 1 year without removing power allows you to take advantage of the additional stability.

Tip 4: For noisy signals, pay attention to trigger error.

When making rough accuracy calculations, engineers often ignore the effects of trigger error. Trigger error is the RMS noise of the instrument’s input amplifier and the RMS noise of the input signal over the bandwidth of the instrument. For example, a 225-MHz counter may offer a 100-kHz low-pass filter. When you measure a low-frequency signal, limiting the bandwidth will eliminate high-frequency noise. A noisy signal can increase the effects of trigger error so it can no longer be considered negligible.

How do you determine the noise contributed by the signal source over the counter’s bandwidth? One possible approach is to use a spectrum analyzer to measure the signal of interest plus any noise. A spectrum analyzer has an IF bandwidth much smaller than a frequency counter. The noise measured by the spectrum analyzer has to be scaled to match the counter’s bandwidth.

Consider measuring a 10-MHz signal with a counter having a 225-MHz bandwidth. Let's say that you look at your 10-MHz signal on a spectrum analyzer with a IF bandwidth of 10 kHz and it shows the noise from the 10-MHz source to be flat and 60 dB below the fundamental, or at –70 dBm. –70 dBm into 50 ohms is approximately 70 μVrms. Obviously, you say, noise is no problem. You hook up the 10-MHz source to your counter and the counter displays noisy readings. Why? Since the frequency counter is a time-domain measuring instrument, and the spectrum analyzer measures the frequency domain, the counter input sees the integral of all the spectral components over its bandwidth.

If the spectrum analyzer's 3–dB IF bandwidth is 10 kHz, the equivalent random noise bandwidth is 12 kHz (1.2 x 10 kHz). Correcting the –70 dBm by 2.5 dB because of detector characteristic and logarithmic scaling, we can say that we have –67.5 dBm/ 12 kHz. To find the noise in a 225-MHz bandwidth, add

10 log (225 MHz/12 kHz) = 42.73 dB

So, the noise in 225 MHz is –67.5 + 42.73 = –24.8 dBm, which is equivalent to 12.9 mV rms. This noise causes a high level of trigger error and is responsible for the random readings. For high-sensitivity counters, this level of noise could cause erratic counting.

Tip 5: Pay attention to trigger level timing error.

When you make timing measurements (time interval, pulse width, rise time, fall time, phase, and duty cycle), you need to consider the effects of the trigger level timing error. There are several factors, primarily resolution and accuracy of the trigger level circuit, fidelity of the input amplifier, slew rate of the input signal at the trigger point, and width of the input hysteresis band.

To reduce these effects, trigger at the offset value of the sine wave or square wave signal. Doing so will give you the highest slew rate, and it also will minimize errors of the hysteresis band. If you measure from offset-to-offset (such as a complete period, 0 degrees phase between two signals) then the effects of the hysteresis window may actually cancel out.

Most counters are optimized for a 0V trigger level setting. For the 53131A and 53132A, if the trigger level setting is 0V and the start and stop trigger points have the same slew rate, the trigger level timing error simplifies to become 30 mV/slew rate.

Tip 6: When possible, lock all timebases to a single clock.

The skew and/or jitter that occurs between two independent timebases will add to error. Using independent timebases is like watching a movie with the video and the audio tracks on different systems. At the beginning of the movie, the audio and video may be synchronized, but as time passes, small differences between the two become more noticeable. In many applications using modern test and measurement equipment, this skew is negligible.

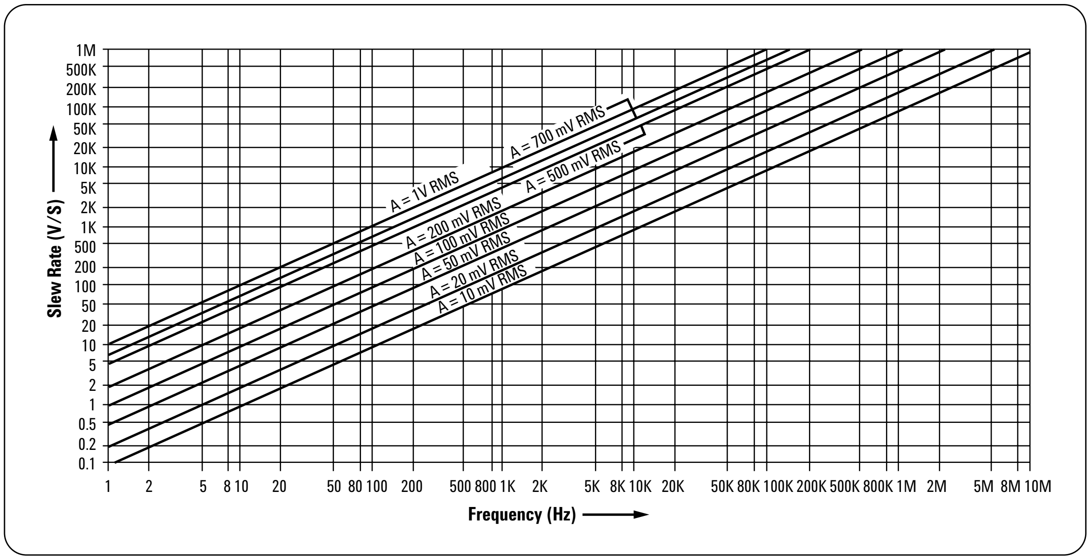


Figure 2. Slew rate vs. frequency

Limit-testing with a frequency counter

Hint 2

It is not uncommon for a frequency counter to produce a reading with 10 or 12 digits every second. Because of the quantity of numbers produced, many engineers prefer to use limit-testing to make it easier to interpret readings. You can configure and implement limit tests several different ways:

1. Frequency counters typically have a visual indicator on the display to indicate an out-of-limit reading when limit testing is enabled.
2. You can set the counter to stop taking readings when a limit is reached.
3. You can instruct the counter to send an SRQ over the GPIB interface to indicate a reading is out of limits
4. A hardware line is provided that indicates an out-of-limit reading has occurred.
5. You can set the counter to exclude out-of-limit readings from statistical measurements.

The 53100 series frequency counter have all of the features listed above, plus the ability to display readings numerically or graphically. Figure 3 shows the display of a 53100 series frequency counter with the asterisk between the colons to indicate an in-limits reading. The left colon represents the low limit and the right colon represents the high limit.

The external hardware line used to indicate an out-of-limit reading is part of the 53100 Series RS-232 port. To use the hardware line rather than the default “talk only” RS-232 mode, you must configure the port. Setup your measurement (including limits) first and save your setup. Next, enable the external hardware line. Press and hold the **Utility** key, press the power button, and press **Recall** until “DTR:” is displayed. Then press any of the arrow keys until “DTR: LIMIT” is displayed, press **RUN**, and press **RECALL** until “RECALL 1” is displayed. At this point, the counter will cycle power and will power up in a default state. After the counter has been re-powered, recall your measurement setup. Once enabled, the hardware line will be low (RS-232 levels ±12 V) while an out-of-limit reading is present.

You can combine limit testing with your counter’s statistics, scale and offset features. Scale and offset are often used to convert a frequency measurement to a physical measurement (for example, speed or rpm).

Measurement sequence for limit testing

Use the **Utility** menu to:

- choose the timebase source
- configure the GPIB interface if you intend to operate the counter remotely
- set the RS-232 serial port if you intend to print or use limit-detection

Use the **Measure** menu keys to select the measurement function.

Use **Channels 1** and **2** keys to set up input conditioning.

Use **Gate & ExtArm** key to:
- set the gate time and resolution
- set arming

Use **Scale & Offset** key to set up math operations.

Use **Uppr & Lower** key to set limits.

Use **Limit Modes** key to set up limit testing.

Use **Stats** key to set up statistics and limit filtering.

Use **Save & Print** key to enable or disable printing.

Use **Run and Stop/Single** keys to control measurements.

Lastly, you can configure the counter to continue or to stop taking readings after a limit has been exceeded. If your counter seems to stop triggering, it may be because it is configured to stop after an out-of-limit reading. Also, when you configure your counter to output an external signal, it will cycle power and come up in a default state, so make sure you save and recall the frequency counter setup.

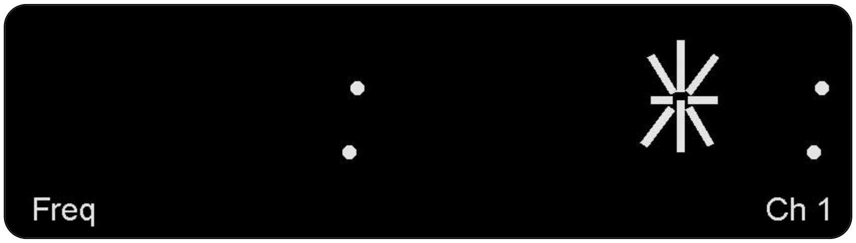


Figure 3: When the asterisk on the frequency counter display is between the colons, you know your reading is within the upper and lower limits you set.

3 *Hint*

Making fast measurements with a frequency counter

You can configure a modern frequency counter to make hundreds of reading per second, which can be useful for characterizing a signal that changes over time. Keep in mind that frequency counters are optimized for measuring a stable or slowly changing signal. Also remember, for making accurate readings, it is better to make a single good reading than trying to average lots of readings.

Following are the steps to set up a frequency counter for the fastest measurements. You can use the Agilent 53131A, 53132A and 53181A frequency counter SCPI commands as examples.

Tip 1: Set the counter to a known state.

After sending a reset command, it is a good practice not to send any additional commands until the instrument has come back to a ready state. Adding a wait or delay of 1 second to a program is enough for most instruments to return to a ready state. If the instrument receives a command while it is resetting, the command may be lost.

*RST	Reset the counter, Clear the counter and interface
*CLS	Clear errors and status registers
*SRE 0	Clear service request enable register
*ESE 0	Clear event status enable register
:STATus:PRESet	Preset enable registers and transition filters

Tip 2: Set the output format to match the data type used in the instrument.

This will prevent a delay as the instrument converts the data to a different format during post processing.

:FORMAT ASCII	Data in ASCII format

Tip 3: Make sure all post-processing and printing operations are disabled.

When you disable these functions, the processor dedicates it resources to making the readings and sending them to the computer, rather than responding to extra interrupts, such as updating the display.

:CALC:MATH:STATE OFF	
:CALC2:LIM:STATE OFF	
:CALC3:AVER:STATE OFF	
:HCOPY:CONT OFF	
:ROSC:SOUR INT	
:ROSC:EXT:CHECK OFF	
:DIAG:CAL:INT:AUTO OFF	Disable automatic interpolator calibration
:DISP:ENABLE OFF	Turn off display

Tip 4: Tell the counter the expected frequency.

The 53131A, 53132A, and 53181A have the ability to optimize their configuration based on the frequency you are measuring. For faster measurements, use the command "FREQ:EXP1.<value>" to tell the counter the expected frequency. The actual signal being measured must be within 10% of the value you provide in the command.

:FUNC "FREQ 1"	Measure Frequency
:FREQ:EXP1 10000000	Set Expected Frequency

Tip 5: Set the trigger level.

The input signal will create a trigger condition as it passes through the level set in the command. Set the trigger level so that it intersects the signal at its maximum slew rate. The input signal will be is changing at its fastest rate and will minimize the amount of time it takes to satisfy the trigger condition. A sine or a square wave has the maximum slew rate at the zero crossing (assuming a 0V offset).

:EVENT1:LEVEL 0	Set trigger level to 0V

Tip 6: Set up triggering to make immediate readings.

When instruments use dual-level triggering, both triggering conditions must be met before a reading can be made. For the 53131A, 53132A, and 53181A, setting the trigger arm condition to immediate will satisfy the first level of triggering. You can set the trigger event to a request for reading with the "*DDT #15FETC?" command. Using this trigger condition eliminates the need to send a bus trigger or a FETCH? command for each reading.

*DDT #15FETC?	Decrease number of bytes transferred over bus
:FREQ:ARM:STAR:SOUR IMM	Immediate Arming
:FREQ:ARM:STOP:SOUR TIM	

You can also download a Visual Basic program to set up triggering. The Visual Basic program allows several different types of triggering, and it configures the counter to operate in the fastest mode possible for each triggering mode. For the fastest possible readings, select the option that sets both the start and stop trigger to IMMEDIATE.

4 Hint

Making low-frequency measurements with a frequency counter

Measuring low-frequency signals can be a bit tricky, but with a few tips you can begin making better measurements. The first step is to use DC coupling. DC coupling removes a blocking capacitor, which is normally in series with the input signal. Generally a frequency counter would be AC coupled, which limits the amplitude of low-frequency signals.

Low-frequency measurements are particularly susceptible to false triggers caused by spurious noise. A modern frequency counter has a built-in high-frequency filter to help eliminate high-frequency noise, and it should be enabled for low-frequency measurements. For example, the Agilent 53131A, 53132A, and the 53181A frequency counters have a 100-kHz low-pass filter that you can switch into the signal path. This reduces the chance of triggering on harmonics and high-frequency noise.

A low-frequency signal may have a low slew rate—meaning the signal is slow to change states. The lower the slew rate, the harder it is to create a repeatable trigger. Decreasing the counters sensitivity will help. In order for a counter to successfully trigger, the signal will need to pass through a lower and an upper threshold. The trigger band, the delta between the upper and lower threshold, is determined by the counter’s sensitivity. Decreasing the counter sensitivity will increase the difference between the upper and lower threshold, widening the trigger band.

When a counter is set to auto triggering, it estimates the peak to-peak level of the signal and computes the midpoint to establish a trigger level. While this approach generally leads to good results, it can cause trouble with low-frequency signals. The problem occurs when the auto-trigger algorithm completes before the signal transition between its minimum and maximum values. The trigger will be set based upon a portion of the waveform, rather than a trigger level based on an approximate average of the minimum and maximum values of multiple cycles. The solution is to turn off auto trigger and set the trigger level manually.

Be patient. A low-frequency measurement can take time to complete. If you are controlling the counter from a computer, you may want to check the status register before requesting a reading. The counter will continue to make a measurement until it receives a second valid trigger condition, indicating the end of the measurement. If the input signal becomes disconnected, the counter will wait indefinitely for the measurement to complete. If you request a measurement (MEAS?), the computer will be stuck waiting until the counter measurement finishes before responding to the query. To avoid this, start the measurement (INIT) and then check the status register to be certain a measurement has completed before requesting the reading (FETCH?).

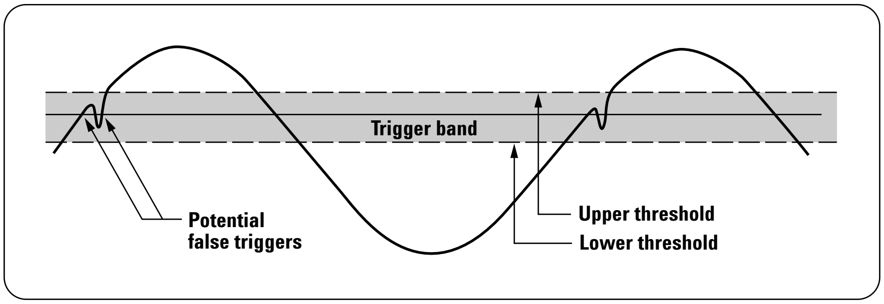


Figure 4. Potential false triggers can occur when spurious signals or noise on a waveform generate unwanted counts or triggers.

Glossary

Dual-level triggering — used when two triggers are required to take a measurement. One trigger condition, when met, instructs the instrument to move from “idle state” to “wait-for-trigger” state. A second trigger condition is configured to begin making measurements.

False triggers — triggers generated by spurious signals or noise on a waveform

Hardware line — a wire over which a device transmits a signal, such as a pass-fail indication or an IRQ (interrupt request)

Hysteresis — the “dead zone” of a voltage comparator or a Schmitt trigger that prevents triggering on noise. In a frequency counter, the input must pass through both the high and low hysteresis limits to generate a count.

Offset voltage — a DC bias voltage that raises or lowers a signal by a consistent amount

Slew rate — the amount of change in voltage over an amount of time (dV/dt). In many systems, the point of maximum rate of change of a signal, or max slew rate, is helpful for knowing ideal triggering points or system bandwidth requirements.

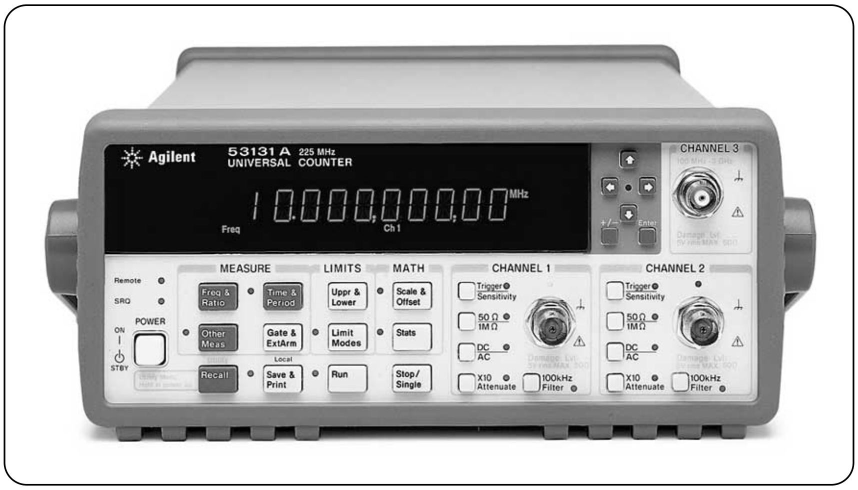
Threshold — the boundary marking the regions between two different states. Trigger band thresholds mark the maximum and minimum limits of the trigger band. A maximum voltage threshold is the region where clipping or damage may occur.

Trigger band — the gap between the two threshold levels a signal must pass through before a count is generated. The wider the trigger band, the less likely spurious noise will generate a count.

Zero crossing — the point at which the voltage of a signal changes from positive to negative, or from negative to positive, that is, at zero volts.

Appendix: Agilent frequency counters

Count on precision, speed and versatility



- **2 channels, 10 and 12 digits/ second frequency resolution and up to 150-ps time interval resolution**
- **Frequency ranges up to 12.4 GHz**
- **Pipelined architecture for higher measurement throughput**

The Agilent 53131A/32A universal counters perform a wide variety of time and frequency measurements at speeds up to 200 measurements per second via GPIB. Automated limit tests and extensive analysis features help you find detailed answers quickly. The 53131A offers 10 digits/sec frequency resolution and 500 ps time interval resolution up to 225 MHz on 2 channels (with optional 3, 5 or 12.4 GHz third channel). The 53132A offers the same measurement set and frequency coverage options with up to 12 digits/sec frequency resolution and 150 ps time interval resolution.

The value-priced Agilent 53181A RF frequency counter provides 10 digits/ second frequency resolution up to 225 MHz on one channel with an optional 1.5, 3, 5 or 12.4 GHz second channel.

Agilent frequency counter specifications

	53131A	53132A	53181A
Type	Universal (2 channel) [1]	Universal (2 channel) [1]	RF (1 channel)
Measurements	Frequency, frequency ratio, time interval, period, rise/fall time, positive/negative pulse width, duty cycle, phase, totalize, peak voltage, time interval average, time interval delay		Frequency, frequency ratio (with optional ch. 2), period, peak voltage
Analysis	Automatic limit testing, math (scale and offset), statistics (minimum, maximum, mean, standard deviation)		
Frequency range (optional)	dc to 225 MHz (3, 5 or 12.4 GHz)	dc to 225 MHz (3, 5 or 12.4 GHz)	dc to 225 MHz (1.5, 3, 5 or 12.4 GHz)
Resolution (frequency, time interval)	10 digits/s, 500 ps	12 digits/s, 150 ps	10 digits/s, N/A
Software	Includes IntuiLink connectivity software		

[1] Channel 2 can only be used to make frequency, period, ratio, and voltage measurements—measurements on channel 1 and channel 2 are made sequentially.

Related Agilent literature

Agilent 53131A/132A/181A Counters
Product overview
Pub. No. 5967-6039EN

8 Hints for Making Better Frequency Counter Measurements
Application note
Pub. No. 5967-6038E

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(tel) 0800 047 866
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(fax) (65) 6755 0042
(e-mail) tm_ap@agilent.com

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