Tips for making more accurate measurements with a frequency counter

A modern frequency counter reduces the complexity of making accurate measurements but some care is necessary to avoid the many pitfalls of 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

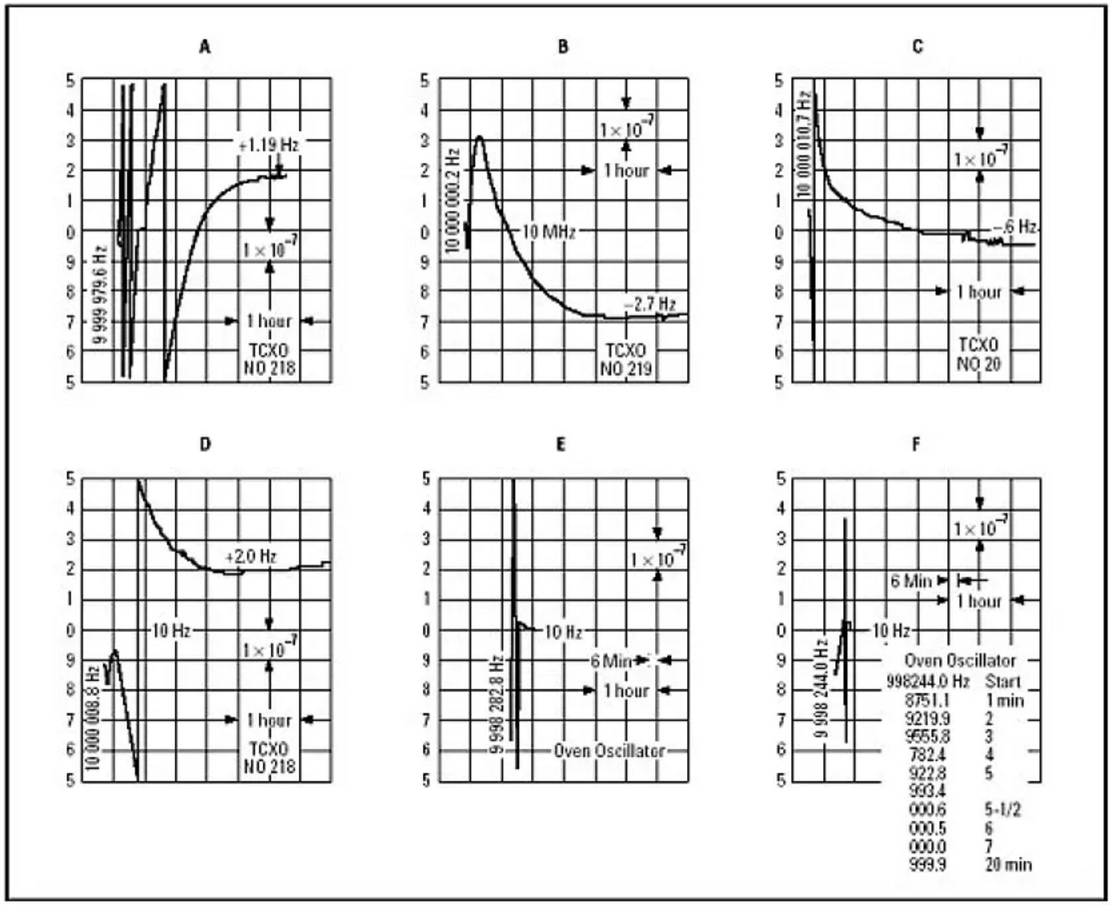
If you want to make quick measurements, using a frequency counter's automatic arming mode is a simple way to configure it. However, of the four typical arming modes (automatic, external, time, and digits), automatic mode is the least accurate. You can improve RMS resolution and systematic uncertainty - 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 * RMS resolution
sigma = 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 will go through its power on cycle of fluctuation (retrace) before coming to rest at a stable frequency. Keysight's 53100-Series counters do not 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.

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 have different turn on (retrace) characteristics. Finally, Graphs E & F. Show the improved turn-on stability of a OCXO

The aging rate of a Keysight 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 = 3.6E-8

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

1E-10 *30 days + 3E-9 * 11 months + 2E-8*1 year = 5.6E-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.

	After initial turn on, no adjustments	Left on for 1 yr and re-adjusted. Aging rate after re-adjustment
+ 90 days	9E-9	5E-9 (1.8X improvement)
+ 1 Yr	3.6E-8	2E-8 (18X improvement)
+ 2 Yr	5.6E-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 yr. without removing power allows you to take advantage of the additional stability.

In Keysight counters, the optional timebases have improved performance over the standard timbase, in part because they have an internal oven. 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.

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. As an example a 225 MHz counter may offer a 100 kHz low-pass filter. When measuring 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.

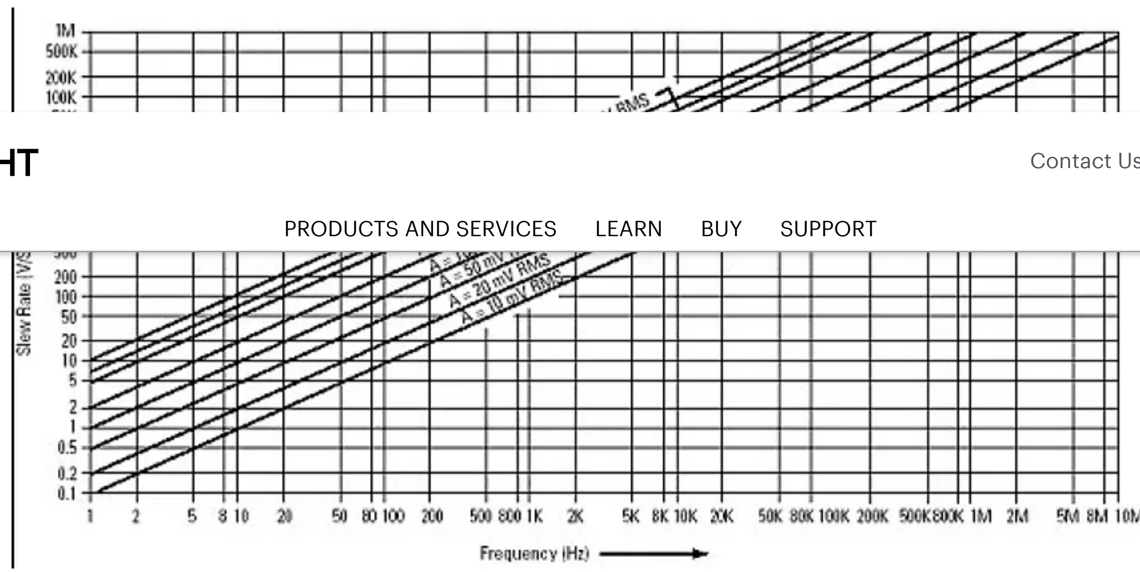
How do you determine the noise contributed by the signal source over the counter's bandwidth? One possible approach is to use a spectrum analyzer to measure the signal of interest plus any noise. A spectrum analyzer has an IF bandwidth much smaller than a frequency counter. The noise measured by the spectrum analyzer has to be scaled to match the counters 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 50Ω 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 while the spectrum analyzer is frequency domain, the counter input sees the integral of all the spectral components over its bandwidth.

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 mVrms. This 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 0 V trigger level setting. For the 53131A and 53132A, if the trigger level setting is 0 V and the start and stop trigger points have the same slew rate, the trigger level timing error simplifies to become 30 mV/slew rate.

Figure 2. Shows that for a given amplitude, the slew rate of a sine wave increases with frequency. Or, for a given frequency the slew rate increases with amplitude.

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.

Related Links

- 53131A 225 MHz Universal Frequency Counter/Timer
- 53132A Universal Frequency Counter, 12 digits/s
- 53181A RF Frequency Counter, 10 digits/s