10 Hints for Getting the Most from Your Frequency Counter

Application Note

Counters can be a plug and play instrument and seem fairly simple from the outside. You connect a signal to the input, and a digital readout tells you the frequency or some other parameter. However, to achieve the best results, whether that means speed or quality, attention to how you set up the counter measurement is important.

Choosing the Best Counter

Selecting which counter will best meet your needs is the first step. There are several related products that perform a variety of tasks at various frequencies:

- **Universal counters**
  Both frequency and time interval measurements, as well as a number of related parameters.
- **RF frequency counters**
  Precise frequency measurements, up to 3 GHz and beyond.
- **Microwave frequency counters**
  Precise frequency measurements, up to 40 GHz and beyond.
- **Time interval analyzers**
  Optimized for precision time interval measurements.
- **Modulation domain analyzers**
  Designed to show modulation quantities, such as frequency versus time, phase versus time, and time interval versus time.

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Hint 1

Recognize the difference between resolution and accuracy

Assuming a large number of digits equates to a very accurate measurement may not be correct. It is a common mistake to equate resolution and accuracy. They are related, but different concepts.

The resolution of a counter is the smallest change it can detect in closely spaced frequencies. All other things being equal (such as measurement time and product cost), more digits are better—but the digits you see on the display need to be supported by accuracy. Digits can be deceptive when other errors push the counter's resolving ability away from the actual frequency. In other words, it's possible for a counter to give you a very accurate reading of an incorrect frequency.

Random and systematic errors both determine a counter's accuracy. Random errors are the source of resolution uncertainties and include:

- **Quantization error**
  When a counter makes a measurement, a ±1 count ambiguity can exist in the least significant digit. This can occur because of the non-coherence between the internal clock frequency and the input signal.
- **Trigger error**
  Noise spikes can be triggered by noise on the input signal or noise from the input channels of the counter.
- **Timebase error**
  Any error resulting from the difference between the actual time base oscillator frequency and its nominal frequency is directly translated into measurement error.

Systematic errors are biases in the measurement system that push its readings away from the actual frequency of the signal. This group includes effects on the time base crystal such as aging, temperature and line voltage variations.

Compare the two counters in Figure 1. Counter A has good resolution but a serious systematic error, so its displayed result in most cases will be less accurate than those of Counter B, which has poorer resolution but a smaller systematic bias error.

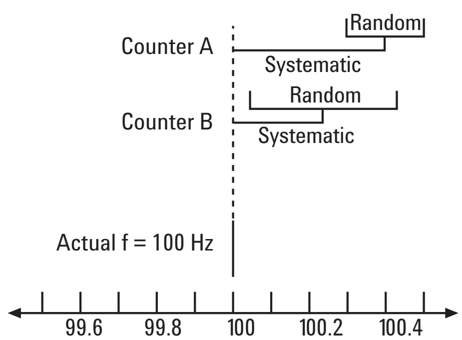

Figure 1. Simplified view of resolution vs. accuracy. Systematic errors related to the timebase "push" the displayed frequency away from the actual frequency. The random errors create a range of frequencies inside of which the counter can't distinguish different signals.

Hint 2

Understand counter measurement methods

Frequency counters fall into two basic types: direct counting and reciprocal counting. Understanding the effects of the two different approaches will help you choose the best counter for your needs and use it correctly.

Direct counters simply count cycles of the signal for a known period – the gate time. The resulting count is sent directly to the counter's readout for display.

This method is simple and inexpensive, but it means that the direct counter's resolution is fixed in Hertz. For example, with a 1 second gate time, the lowest frequency the counter can detect is 1 Hz (since 1 cycle of the signal in 1 second is 1 Hz, by definition). Thus, if you are measuring a 10 Hz signal, the best resolution you can expect for a 1 second gate time is 1 Hz, or 2 digits in the display. For a 1 kHz signal and a 1 second gate, you get 4 digits. For a 100 kHz signal, 6 digits, and so on. Figure 2 illustrates this relationship. Also note that a direct counter's gate times are selectable only as multiples and sub-multiples of 1 second, which could limit your measurement flexibility.

Reciprocal counters, in contrast, measure the input signal's period, then reciprocate it to get frequency. Given the measurement architecture involved, the resulting resolution is fixed in the number of digits displayed (not Hertz) for a given gate time.

In other words, a reciprocal counter will always display the same number of digits of resolution regardless of the input frequency. Note that you'll see the resolution of a reciprocal counter specified in terms of the number of digits for a particular gate time, such as "10 digits per second."

You can determine whether a counter is direct or reciprocal by looking at the frequency resolution specification. If it specifies resolution in Hertz, it's a direct counter. If it specifies resolution in digits-per-second, it's a reciprocal counter.

The counter industry has standardized on measuring relative to a 1 second gate time. Figure 3 compares the resolution of direct and reciprocal counters. In the lower frequency spectrum, reciprocal counters have a substantial advantage over direct counters. As an example, at 1 kHz, a direct counter gives a resolution of 1 Hz (4 digits). A 10 digit/second reciprocal counter gives a resolution of 1 μHz (10 digits).

If precision resolution is not a priority, the reciprocal counter still offers a significant speed advantage: the reciprocal counter will give 1 mHz resolution in 1 ms, while a direct counter needs a full second to give you just 1 Hz resolution (Figure 4). Reciprocal counters also offer continuously adjustable gate times (not just decade steps), so you can get the resolution you need in the minimum amount of time.

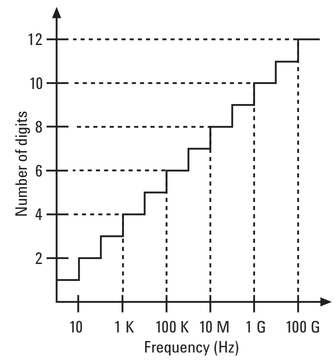

Figure 2. The number of digits displayed by a direct counter versus frequency (for a 1 second gate time).

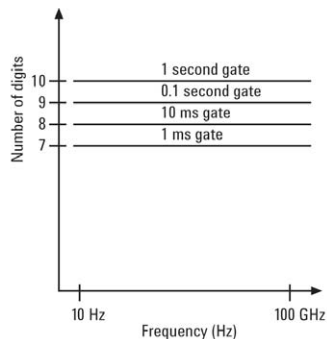

Figure 3. Comparing resolution for direct and reciprocal counters (for a 1 second gate time).

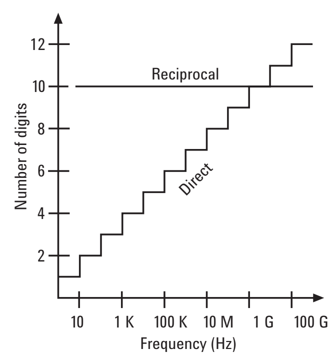

Figure 4. Here are the gate times needed to yield various resolutions with a 10 digits/second reciprocal counter.

The choice comes down to cost versus performance. If your resolution requirements are flexible and you aren't too concerned with speed, a direct counter can be an economical choice. A reciprocal counter is required for the fastest, highest resolution measurements.

Hint 3

Choose the appropriate timebase

The measurement accuracy of a frequency counter is strongly dependent on the stability of its timebase. The timebase establishes the reference against which the input signal is measured. The better the timebase, the better your measurements can be. The frequency at which quartz crystals vibrate is heavily influenced by ambient temperature, and timebase technologies fall into three categories based on the way they address this thermal behavior:

- **Room Temperature Crystal Oscillator (RTXO)**
  This type of timebase does not utilize any temperature compensation or control. These types of oscillators have been manufactured for minimum frequency change over a range of temperature– typically between 0°C and 50°C. This is accomplished through the proper choice of the crystal cut during the manufacturing process. A high quality RTXO would vary by about 2.5 parts per million (ppm) over that temperature range. This works out to ±2.5 Hz on a 1 MHz signal, so it can be a significant factor in your measurements. It carries the advantage of being inexpensive, but results in large frequency errors.

- **Temperature Compensated Crystal Oscillator (TCXO)**
  One method of compensating for frequency changes due to temperature variation is through externally added components that have complementary thermal responses to obtain a more stable frequency. This approach can stabilize the thermal behavior enough to reduce timebase errors by an order of magnitude relative to RTXO (approximately 1 ppm (±1 Hz on a 1 MHz signal)).

- **Oven Controlled Crystal Oscillator (OCXO)**
  In this technique, the crystal oscillator is housed in an oven which holds its temperature at a specific point in the thermal response curve. The result is much better timebase stability, with typical errors as small as 0.0025 ppm (±0.0025 Hz on a 1 MHz signal). Additionally, oven-controlled timebases also help with the effects of crystal aging, which means you don't have to take your counter out of service for calibration as often.

Hint 4

Schedule calibration to match performance demands

The frequency at which you calibrate your counter depends on several factors:

- The type of timebase
- The conditions the counter is subjected to during measurement
- How much accuracy you need from the measurement

Calibration can be a complex issue and is directly related to counter accuracy in general. The quality of the measurement you see on the display depends on four factors:

1. Time-invariant counter performance factors (such as the temperature stability of the timebase as discussed in Hint #3)
2. Time-variant counter performance factors (such as the aging rate of the timebase)
3. The input signal clarity and level of noise
4. Counter set-up and configuration

Item #2 is where calibration plays a role. Although counters are electronic instruments measuring electrical signals, the quartz crystal that is the heart of every counter's time-base is a mechanical device. Since it is a mechanical device, the crystal is susceptible to physical disturbances that can change the frequency at which it vibrates which ultimately affects the counter's accuracy. The cumulative effect of these various disturbances is known as *crystal aging*, and it is this aging that you are compensating for when you calibrate the counter.

Aging is a factor that is fairly easy to predict and easy to compensate for through calibration. You can determine if calibration is required by looking at the aging rate specification in your counter's data sheet.

For example: If the aging rate is 4×10^{-8} per day and it has been 300 days since calibration, aging will add a timebase error of 1.2×10^{-5} into the overall accuracy calculation. If this uncertainty (±12 Hz on a 1 MHz signal), in addition to the other inherent errors reviewed earlier is acceptable for your measurements, calibration is not required. Otherwise, calibrate.

Hint 5

Make the most accurate measurements

- **Select the best arming mode**
  If you want to make quick measurements, using your frequency counter s automatic arming mode is a simple way. However, of the four typical arming modes (automatic, external, time, and digits), automatic mode is the least accurate. You can improve resolution and systematic uncertainty (both elements of measurement error, as discussed in Hint #2) by increasing gate time with either the external, time, or digits arming modes.

- **Use the best timebase available and calibrate frequently**
  The quality of the timebase and how often you calibrate 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. 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.

- **Keep your counter's timebase warm**
  As discussed in Hint #3, 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 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. 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.
  - Keeping your frequency counter out of drafts and protecting it from changes in temperatures will also improve its stability.

    When you remove power from the counter, however briefly, the aging rate must start over from the daily aging rate.

- **Monitor 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 to consider: 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. Note that most counters are optimized for a 0 V trigger level setting.

- **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.

Hint 6

Make the fastest measurements

You can configure a modern frequency counter to make hundreds of readings 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.

- **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.

- **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.

- **Disable all post processing and printing operations**
  When you disable these functions, the processor dedicates its resources to making the readings and sending them to the computer, rather than responding to extra interrupts, such as updating the display.

- **Configure the expected frequency**
  The Agilent 53100 series of counters has the ability to optimize their configuration based on the frequency you are measuring. The actual signal being measured must be within 10% of the value you provide in the command.

- **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, this 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 0 V offset).

- **Set triggering to make immediate readings**
  When instruments use dual-level triggering, both triggering conditions must be met before a reading can be made. Setting the trigger arm condition to immediate will satisfy the first level of triggering.

Hint 7

Adjust sensitivity to avoid noise triggering

Modern counters are broadband instruments with sensitive input circuits. However, to a counter, all signals look the same. Sine waves, square waves, harmonics, random noise all look like a series of zero crossings. A counter measures the signal's frequency by triggering on these zero crossings. If your signal is clean, the process is relatively straightforward. Noisy signals, however, result in the counter triggering on spurious zero crossings. When this happens, you will not get the measurements you expect.

Fortunately, there are approaches around this issue.

- Counters require the signal to pass through both lower and upper hysteresis thresholds before they register a zero crossing. The gap between these two levels is referred to as *trigger sensitivity*, the *hysteresis band*, or the *trigger band*.
- High quality counters let you adjust this band to minimize unwanted triggering. Figure 5 shows a signal with some noise that are causing problems with the measurement. The trigger band is fairly narrow, so both the unwanted noise (at points 1 and 3) and the real signal (at points 2 and 4) cause the counter to trigger. What is really just two cycles of the signal get counted as four.

By adjusting the trigger band to make the counter less sensitive, you can avoid these spurious triggers. In Figure 6, the trigger band is wide enough (the sensitivity is low enough) that the spurs don't get counted as zero crossings. The counter registers two valid zero crossings and goes on to compute the appropriate frequency. If you think your signal might have some noise problems, try switching your counter into low sensitivity mode. If the displayed frequency changes, chances are you were triggering on noise.

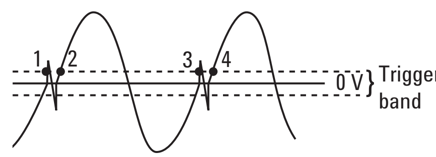

Figure 5. The two small peaks (spurious signals in this case) generate unwanted triggers at point 1 and point 3 because the trigger band is set too narrow.

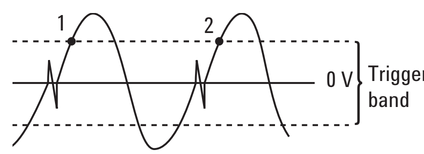

Figure 6. Lowering the trigger sensitivity by expanding the trigger band produces the desired count.

Hint 8

Reduce jumpy displays

A jumpy display, where the last several digits fluctuate rapidly, can be a challenge if you're trying to adjust a circuit in real time or perform some other task based on the counter's display. Depending on your counter's capabilities, you have several options:

- **Reduce the number of displayed digits**
  Most counters have a "Fewer Digits" function. While this can quiet the display, it might hide information you need to make decisions about circuit behavior. Note this is strictly a display function that does not have any effect on the actual measurement.

- **Use limit testing**
  If you only need to know whether a signal is within a certain band of frequencies, use limit testing with a visual indicator if your counter has this capability.

- **Use signal averaging**
  Averaging (also labeled as "Mean" on many counters) is a good option to consider any time your signal is jumping. Unlike simply reducing the number of displayed digits, averaging actually improves the quality of your measurements. By reducing the effects of random variations in the signal, it reduces the number of display changes.

Hint 9

Improve low frequency measurements

Hint #7 discussed the problem of triggering on noise in your signal. This problem can be even more acute with low frequency signals (roughly 100 Hz and below), since the chance of spurious triggering on irrelevant high-frequency components is increased. In addition, the signal's slew rate affects trigger accuracy – the lower the slew rate, the more chance there is for error.

Some steps you can take to help improve the quality of counter measurements on low-frequency signals:

- **Utilize the low-pass filter**
  If the option is available, this can reduce the chance of triggering on harmonics and high-frequency noise.

- **Use manual triggering**
  When a counter is set to use auto triggering, it estimates the peak-to-peak level of the signal and computes the midpoint to establish a trigger level. This approach generally leads to good results but can cause trouble on low-frequency signals. The problem is that the auto trigger algorithm can take less time than the signal takes to transition between its minimum and maximum values. As a result, the auto trigger can wind up following the signal level up and down, rather than setting a single trigger level based on a consistent estimate of the minimum and maximum values. The solution is to turn off auto trigger and set the trigger level manually.

- **Use DC coupling**
  Many counters offer a choice between DC and AC coupling on their primary input channel. AC coupling removes any DC offset from the signal, whereas DC coupling admits the entire signal, offset and all. The issue with AC coupling is that it also attenuates lower frequencies. Some counter's performance is not specified below a certain frequency with AC coupling due to this fact.

- **Decrease the counter's sensitivity**
  A low frequency signal may have a low slew rate – meaning the signal is slow to change states. The slower 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.

- **Monitor the status register**
  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 the computer will be stuck waiting until the counter measurement finishes before responding to the query. To avoid this, start the measurement and then check the status register to be certain a measurement has completed before requesting the reading.

Hint 10

Utilize limit testing capability

It is not uncommon for a counter to produce a reading with 10-12 digits every second. Limit testing can enable you to interpret the readings easier. You can configure and implement limit tests several different ways:

- A visual indication can be lit on the display to indicate an out-of-limit reading.
- You can set the counter to stop taking readings when a limit is reached.
- You can instruct the counter to send an SRQ over the GPIB interface to indicate a reading is out of limits.
- A hardware line is provided that indicates an out-of-limit reading has occurred.
- You can set the counter to omit out-of-limit readings from statistical measurements.

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).

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.

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