EIP Microwave, Inc. Application Note 101A

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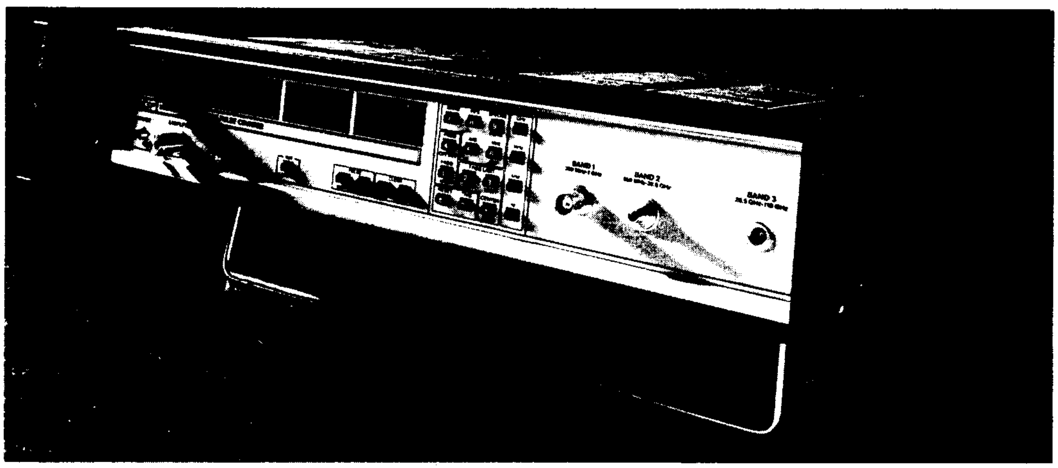
a new approach to frequency measurement in the time domain

THE AUTOMATIC MICROWAVE PULSE COUNTER



in the beginning . . .

pulsed microwave frequencies were measured
exclusively by manual techniques
using such instruments as a wavemeter
or a manual transfer oscillator

but then . . . .

EIP introduced the first

...automatic microwave pulse counter in 1976. This counter, the Model 451, provided automatic measurement of pulsed and time varying signals from 300 MHz to 18 GHz, obsoleting previous methods such as wave meters and transfer oscillators. In 1980, EIP introduced a line of superior CW counters. These counters, Models 545A and 548A, use a YIG preselector and millimeter wave technology to provide count capability to 110 GHz, multiple signal selectivity, and 10 watt burnout protection. The next logical step was to combine the CW and pulsed technologies and produce a superior pulsed counter. That is exactly what happened, and in May 1985, EIP introduced the 58X line of frequency counters. The 58X line consists of two models, 585 and 588. The Model 585 operates from 0.95 to 18 GHz with an option down to 300 MHz. The Model 588 operates from 0.95 to 26.5 GHz with options down to 300 MHz and up to 110 GHz. The 58X counters automatically count both pulsed and CW frequencies to 1 kHz resolution. With the addition of a delaying pulse generator, time domain profiling of time varying signals is made easy. The standard IEEE 488 (GPIB) interface makes the 58X suitable for ATE.

theory of operation

The 58X contains four functional sections: an RF converter, a microwave converter, a millimeter wave converter, and a counter (see Figure 1). The converters reduce the frequency of an incoming signal to a range that can be directly measured by the counter.

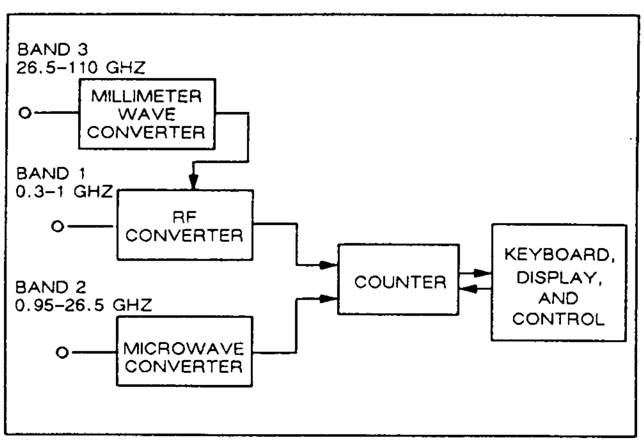


Figure 1

The microwave and millimeter wave converters operate on the heterodyne principle. The incoming signal is mixed with a known harmonic of a 400 to 500 MHz oscillator to produce a difference frequency that can be counted. The reference frequency is automatically selected by the converter circuitry. By adding the known reference frequency to the counted frequency, the instrument can produce a direct display of input frequency.

The RF converter is a prescaler that operates by dividing the input frequency by four. This frequency is then counted for four times the normal period to again produce a direct display of input frequency. Frequency counters operate by counting the number of cycles of an input signal for a known period of time – the gate interval. Usually, these intervals are available in decade steps and are selected by front panel controls – e.g., 1, 10, and 100 μs.

The counter portion of the 58X differs in three significant respects from a conventional frequency counter. First, it is possible to open and close the gate many times during a measurement cycle. Additional circuitry accumulates the amount of time during which the gate has been open until the total required gate time is obtained. This technique, frequency averaging, substantially improves measurement resolution on narrow pulses.

The second difference is the controlling signal for the gate. The converters detect the incoming signal and send a command to the counter when this signal exceeds a preset threshold. This command, known as SIGNAL THRESHOLD, must be present for the gate to open. This signal is then used to ensure that the counter gate is open only when an incoming signal is present.

The third difference is the "smarts" that enables the instrument to recognize a pulsed signal. In a CW counter, when the signal goes away, the counter can simply reset. In a pulsed counter, the instrument must decide if the signal is truly gone or just between pulses. To accomplish this, the instrument is provided with a user-selectable MIN PRF (minimum pulse repetition frequency) function. During signal acquisition and counting if the signal goes away for longer than the specified MIN PRF, the counter assumes the signal is gone and begins searching for another. This allows the user to optimize instrument performance for pulsed conditions.

Dynamic frequency measurements are made by combining the rear panel INHIBIT INPUT command with SIGNAL THRESHOLD. Under this condition, the gate can open only when both an input signal and an enable signal (low level at the INHIBIT input) are present. At all other times, the counter ignores any incoming signals.

applications

AUTOMATIC PULSE MEASUREMENTS

The simplest application of the 58X is measurement of microwave pulse signals. After selecting the proper band and MIN PRF, the signal is simply connected to the correct input and the frequency is displayed. Any pulse width from 50 ns to a CW signal can be measured.

PULSE PROFILE MEASUREMENTS

Automatic pulse measurements, as described above, determine the average frequency of a pulse. In some cases, however, additional information may be desired. For example, a pulsed magnetron may exhibit substantial frequency shift near the leading and trailing edges of the pulse or a pulsed Gunn diode oscillator may exhibit frequency shift during a pulse due to peak power thermal effects. Measurements of these characteristics are easily made with only the 58X and a delaying pulse generator as shown in Figure 2.

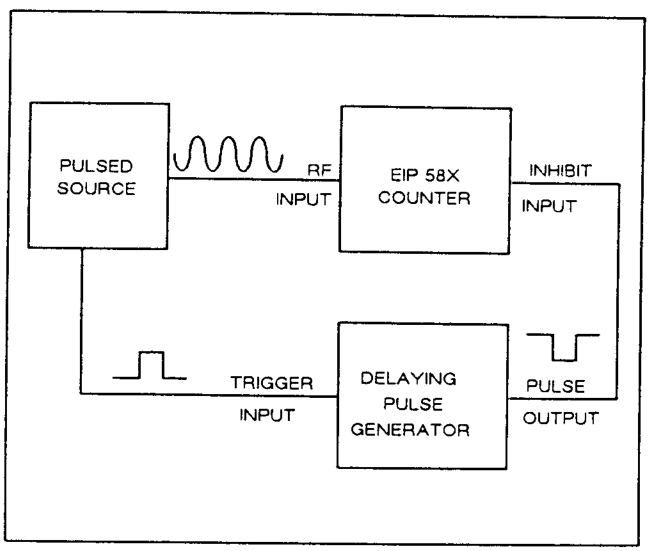


Figure 2

The pulsed source is used to trigger the pulse generator. The generator's output pulse is used as an enable input to the counter. As the pulse delay is varied, the measurement window can be "walked" through the pulse. A plot of frequency versus delay gives the frequency versus time profile of the pulse direct, as illustrated in Figure 3. The width of the measurement window is determined by the width of the pulse generator output. Measurement windows as narrow as 15 ns can be used, although wider windows yield higher accuracy.

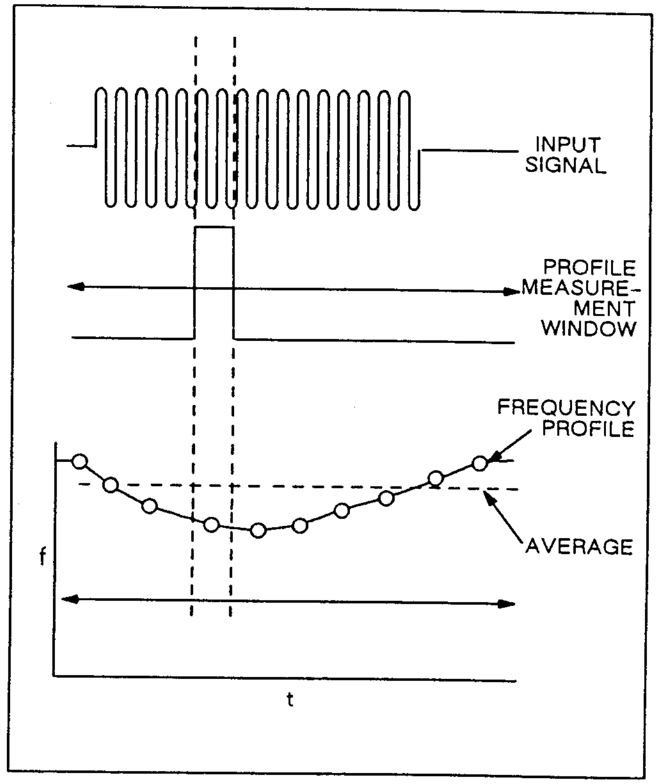


Figure 3

DYNAMIC CHARACTERISTICS OF TIME VARYING SIGNALS

Many complex signals are not pulses at all but simply continuous signals whose frequency varies repetitively with time. One example is in the measurement of the response of a device such as a voltage controlled oscillator (VCO). A square wave applied to the tuning voltage will produce a response curve of frequency versus time allowing measurement of settling time and post-tuning drift.

Another possible application is the measurement of linearity and amplitude for frequency modulated radar altimeter signals. Figure 4 shows a test setup designed to make measurements on time varying signals. It is similar to the previous test setup except the modulator is a frequency modulator, not pulse.

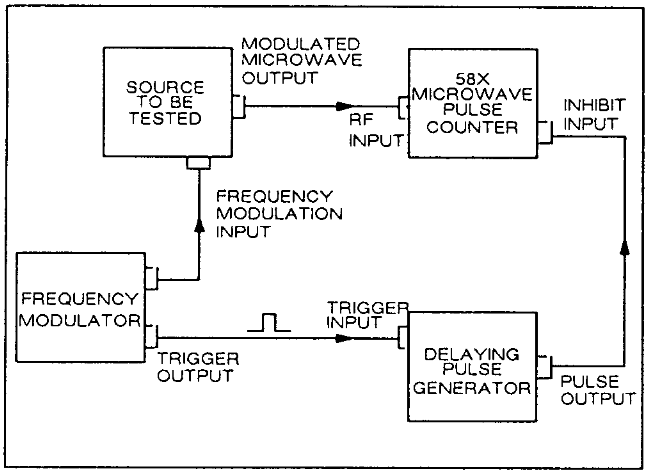


Figure 4

MULTIPLE PULSE SIGNAL MEASUREMENTS

Another application pertains to the measurement of a repetitive sequence of pulses differing in frequency. In this case, it is desirable to measure the frequency of each pulse in the sequence separately. There are two methods for measuring multiple pulse signals: time limited, using the delaying pulse generator, and frequency limited, using the built-in preselector. In the first, the same test set up as in Figure 4 is required. The trigger pulse must be synchronous with the sequence, and occur only once during the sequence.

In this example, the INHIBIT INPUT is used simply to discriminate between pulses. The enabling pulse can be slightly wider than the pulse to be measured. The 58X will automatically restrict the measurement window entirely within the pulse. By shifting the delay time of the enable pulse, each input pulse of the sequence can be separately measured.

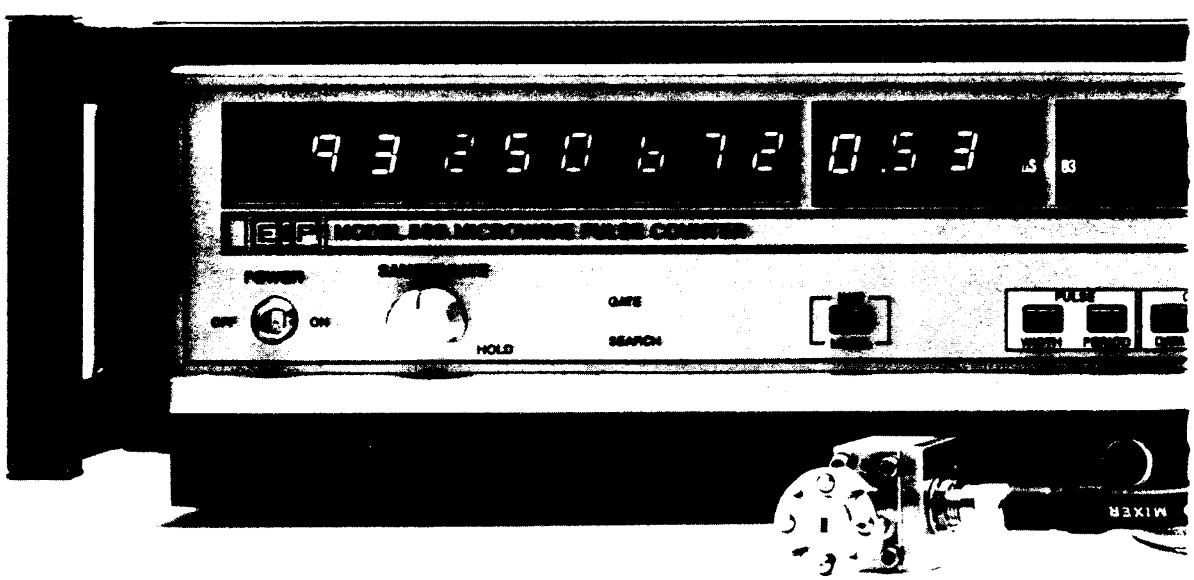
If the approximate frequencies of the pulses are known, the second method may be used. The second method uses the YIG preselector in the 58X counter to lock out all pulses but the desired one. Using the frequency limits on the 58X front panel, the operating window is narrowed until only the desired signal lies within the limits. The 58X then counts that signal. This method does not require a delaying pulse generator, but can only be used in the microwave range.

technical discussion

INHIBIT INPUT Level Requirement

The INHIBIT INPUT on the 58X is designed to be compatible with either a 50 ohm impedance pulse generator or emitter coupled logic (ECL) devices. An internal termination of 50 ohms returned to -2 volts makes this dual compatibility possible. An ECL high level signal (-.8 to -1.1 volts) will inhibit measurement, while an ECL low level signal (-1.5 to -2.0 volts) will enable measurement. ECL devices are designed to drive 50 ohm lines without reflections when the lines are terminated by 50 ohms returned to -2 volts.

The direct compatibility with a 50 ohm pulse generator results from the fact that 0 volts from a 50 ohm source will put -1 volt at the INHIBIT INPUT (which will inhibit the 58X) while a -1V signal into 50 ohms will produce -2 volts at the INHIBIT INPUT thus enabling the instrument.



TIMING CONSIDERATIONS

Under most circumstances, internal timing within the 58X would be of no concern to the user. However, in applications where a few nanoseconds are significant, some details of internal operation are important. These involve two areas: measurement window width and internal timing delays.

Measurement Window Width

The measurement window is the period during which the GATE is actually open to enable a signal to be counted. This GATE width will be typically 30 nanoseconds narrower than the pulse applied to the INHIBIT INPUT. The width of the GATE is always an integral number of clock periods (12.5 nanoseconds). For applications where the measurement window needs to be known to an accuracy better than 20 nanoseconds, it is recommended that the GATE output on the 58X rear panel be observed directly on a high speed oscilloscope. The desired GATE width may then be set by varying the INHIBIT INPUT pulse width. For accurate pulse representation, the oscilloscope input should be terminated in a 50-ohm load.

Internal Timing Delays

When it is necessary to measure the frequency of a signal at a precise point in time, the internal delays of the measuring instrument can be significant. In the 58X the total delay between the time a signal is applied to an input connector and the time it is available to be counted is nominally 90 nanoseconds. The SIGNAL THRESHOLD output at the rear panel typically occurs 70 nanoseconds after the signal is applied. The GATE signal at the rear panel occurs at the measurement time with virtually no delay.

In other words, when absolute time positioning of a signal is required, it is necessary to consider that the GATE signal, which represents the measurement period, is actually making a measurement of the signal that appeared at the input connector 90 nanoseconds earlier. If the SIGNAL THRESHOLD output is used as an indication of input signal, then it occurs 20 nanoseconds prior to measurement.

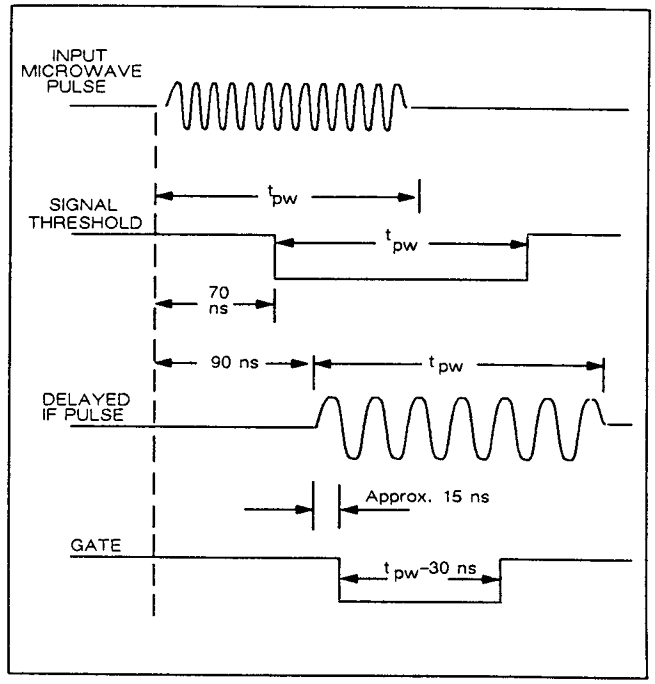
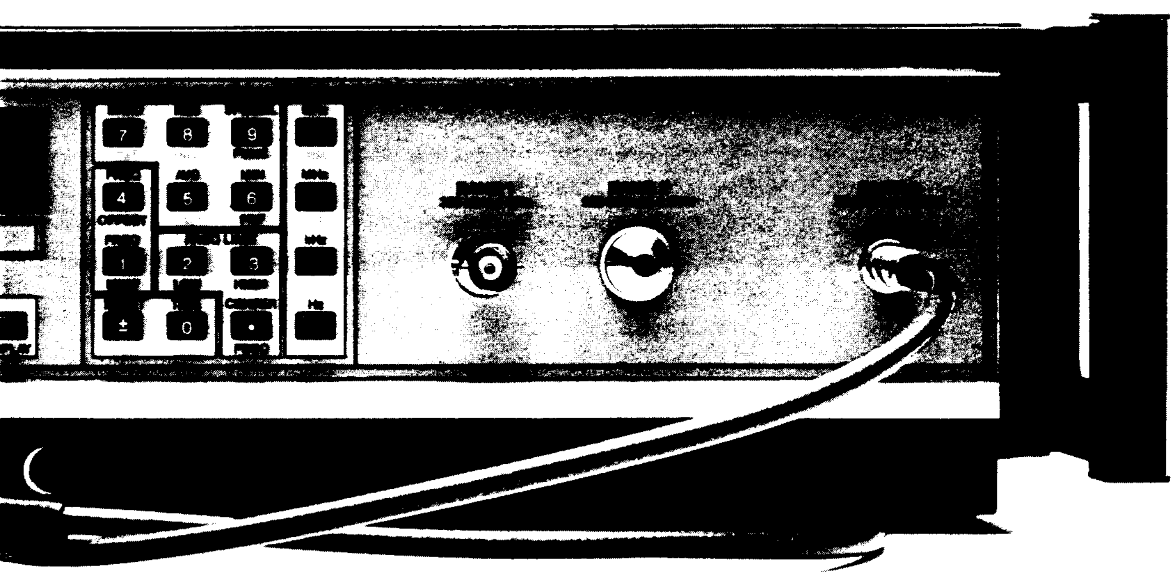


Figure 5

Figure 5 shows the relative timing of these signals for a pulsed input signal. Timing, however, is not a function of input signal characteristics.



ACCURACY

Measurement accuracy for the 58X Pulse Counters is subject to four main sources of error. The first two, time base error and ±1 count phasing error, are also sources of error for CW frequency counters. The other two, gate error and distortion error, are not significant for CW counters.

In a CW frequency counter, measurement accuracy is generally specified as "time base accuracy ±1 count." This means that frequency measurement is in error by the same percentage as the time base reference oscillator. The maximum error in the time base is the sum of various possible errors such as aging rate and temperature.

The second type error, "±1 count," is derived from the relative timing of gate and signal. Simply stated, if an event occurs every 400 ms (F = 2.5 Hz), a counter could measure either two or three events in a 1-second interval.

There are two other sources of error, which are not significant in a CW counter but may be in a pulsed counter. They are gate error and distortion error. Gate error is, as its name implies, the error in the measurement window, or gate, of the counter. For example, if the gate is supposed to be 1 ms, but is actually 1 ms + 1 ns, the gate error is 1 ns. Distortion error is a count error caused by transient effects when the signal changes amplitude.

Each of these four sources of error can contribute to the overall error in pulse frequency measurement. In fact, for narrow pulses, the last three sources of error, which are usually ignored in a CW counter, become the dominant sources of error.

Time Base Errors

A frequency error in the time base (reference oscillator) results in a proportional frequency measurement error. The two main sources of time base error are aging rate and temperature. Aging rates of $<|3 \times 10^{-7}|$/month and a temperature stability of $<|1 \times 10^{-6}|$ over the range of 0° C to 50° C are standard on the 58X. By calibration against a frequency standard or using an external reference, the user can make this error less than one count and thus insignificant.

Averaging Error

In a CW frequency counter, the ±1 count phasing error is due to the relative timing between the gate and the signal being counted. This causes an uncertainty of ±1 count in the least significant digit. For example, if an event occurs every 400 ms (F = 2.5 Hz), a counter could measure either two or three events in a 1-second interval depending on the phasing relationship between the gate and the signal.

In the pulse counter, the gate can be opened many times during one measurement cycle, because the pulse can be narrower than the total gate time. This causes an uncertainty of ±1 count each time the gate is opened and closed. If N measurements are made, then an uncertainty of ±N counts is possible, but very unlikely. The resultant averaged measurement follows the rules of statistics in that successive measurements varies randomly to a certain degree. In fact, most of the readings (63%) fall between $\pm\sqrt{N}$ counts, and this is called the RMS averaging error. N is the number of gates required to accumulate the necessary gate time. The gate is typically 30 nanoseconds narrower than the input pulse so that the RMS averaging error is:

Band 1: $AE = \pm 2 \times \sqrt{RES / ((GW)\ (AVE))}$

Band 2: $AE = \pm \sqrt{RES / ((GW)\ (AVE))}$

Band 3: $AE = \pm 2 \times \sqrt{RES / ((GW)\ (AVE))}$

AE is the RMS averaging error in Hz. RES is the specified instrument resolution in Hz. (This is true up to 1 MHz resolution. Above 1 MHz resolution RES is 10^6 Hz.) GW in seconds is the logical AND of inhibit and pulse width -3×10^{-8} seconds. AVE is the number of specified count averages.

Gate Error

When narrower pulses are counted, the gate is opened many times in order to obtain a higher resolution measurement. Each time the gate opens and closes, there will be a small but finite error. The total error is proportional to the number of times the gate is cycled during a measurement and is thus inversely proportional to the gate width. This error is also related to both temperature and input frequency. In the Model 58X the worst case error including all variables is specified as:

Band 1: $GE = (\pm 0.07) / (GW)$

Band 2: $GE = (\pm 0.01) / (GW)$

Band 3: $GE = (\pm 0.03) / (GW)$

GE is the gate error in Hz. GW in seconds is the logical AND of inhibit and pulse width -3×10^{-8} seconds.

Unlike averaging error, which is random, gate error is systematic and is not reduced by frequency averaging.

Distortion Error

When a pulsed signal comes and goes, it causes transient effects in the internal circuitry which cause changes in group delay during the pulse, resulting in an apparent frequency error called distortion error. Model 58X distortion error is specified as:

Band 1: DE = (+0.03) / (PW -3×10^{-8} seconds)

Band 2: DE = (+0.03) / (PW -3×10^{-8} seconds)

Band 3: DE = (+0.02) / (PW -3×10^{-8} seconds)

DE is distortion error in Hz. PW is pulsed width in seconds.

Like gate error, distortion error is systematic and is not reduced by frequency averaging. Unlike gate error, distortion error is not a function of gate width, but since it is caused by transient effects at the beginning and end of the pulse, is strictly a function of pulse width.

TECHNIQUES FOR IMPROVING ACCURACY

In most cases, the specified accuracy of the Model 58X will be more than sufficient to meet the measurement requirements. If greater accuracy is required, all four sources of error can be minimized by a combination of error calibration and long term averaging.

Time Base Calibration

A frequency error in the time base oscillator results in the same percentage error in the frequency reading for either CW or pulsed signals. By directly measuring the 10 MHz time base frequency at the rear panel using a standard of known accuracy, the user can determine and correct this error. As an example, suppose the measured time base output is 10.0001 MHz. The time base is thus 1×10^{-6} high in frequency. All readings will then be 1×10^{-6} low in frequency. Therefore, a reading at 10 GHz will be 10 kHz low. Instead of correcting the reading for this error, a better technique is to set the time base oscillator precisely on frequency by following the procedure in the Service Manual, or operating the counter from a known accurate external time base.

Long Term Averaging

Averaging error, as discussed previously, is simply the result of random statistical process. Like all such processes, taking a larger number of samples reduces the averaging error.

A function is provided on the 58X that can automatically average up to 99 readings before displaying the result. If more averaging is desired, a controller and the IEEE-488 interface may be used. In this manner averaging error can virtually be eliminated.

Gate Error

Gate error at any given frequency and pulse width can be virtually eliminated. This is accomplished by simulating a pulsed input and determining the gate error. This calibration factor can then be added to or subtracted from the indicated measurement to obtain the correct frequency.

First, determine the gate error using a CW source at approximately the same frequency (within 25 MHz) as the indicated measurement. A pulsed input is then simulated by applying an enable signal of the same width as the pulse to be measured to the INHIBIT INPUT. The gate error is the difference in reading between the pulsed and non-pulsed measurement of the same CW signal. This procedure provides the true gate error and avoids error associated with any possible pulling of the signal source. It should be noted that gate error can be calibrated out of the system for a given Pulse Width and Frequency. This calibration procedure however, may result in additional error at any other Pulse Width and Frequency.

Distortion Error

Since distortion error is a phenomenon associated with the leading and trailing edges of the pulse, moving the gate closer to the middle of the pulse will reduce distortion error. This is accomplished by using the time domain setup shown in Figure 4 and adjusting the inhibit so that the counter is enabled only in the middle of the pulse. It should be noted that this technique will reduce distortion error but increase gate error because the gate is being narrowed. Under many conditions, the reduction in distortion error will be greater than the increase in gate error.

summary

With the 58X family of superior pulsed counters, measurements on CW, pulsed, and time varying signals from 300 MHz to 110 GHz can now be made with unprecedented ease and accuracy.

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