Cardinal Components Inc. Applications Brief No. A.N. 1006

Clock Oscillator Stability

Measuring Clock Oscillator Frequency Stability

Oscillators exhibit a number of frequency/period instabilities. Manufacturers generally specify their oscillators in terms of short term, long term, and environmental frequency stability.

Environmental stability reflects the effects of temperature, vibration, power supply variations, and other environmental factors on an oscillator's output frequency or phase. Figure 1 is an example of the stability of a clock oscillator during warmup from a cold start. The actually oscillator output is shown in Trace 2. The lower trace (trace B) is the trend of mean internal temperature (1mV = 1° C). It shows that during startup the internal temperature increases by about 8° C over a period of 2000 seconds. During that time the average change in the oscillators period is about ±25 ps. This is read in trace C which contains the smoothed measurement of the trend of time interval error at level (tie@lv) . Time interval error at level measures the time difference of an oscillator's measured period from an ideal period. Trace A, the trend of tie @lv, is overlaid on the smoothed trace. It shows a peak to peak variation of slightly more than ±100 ps. Temperature variation has little effect on this oscillator.

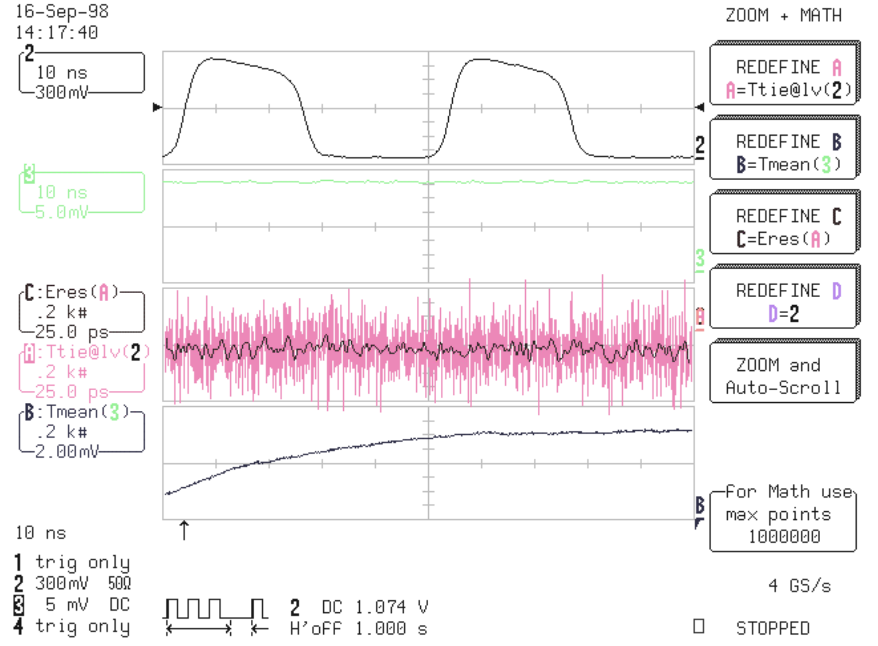


Figure 1 – Using Trend of Time Interval Error@Level to verify the temperature stability of a clock oscillator

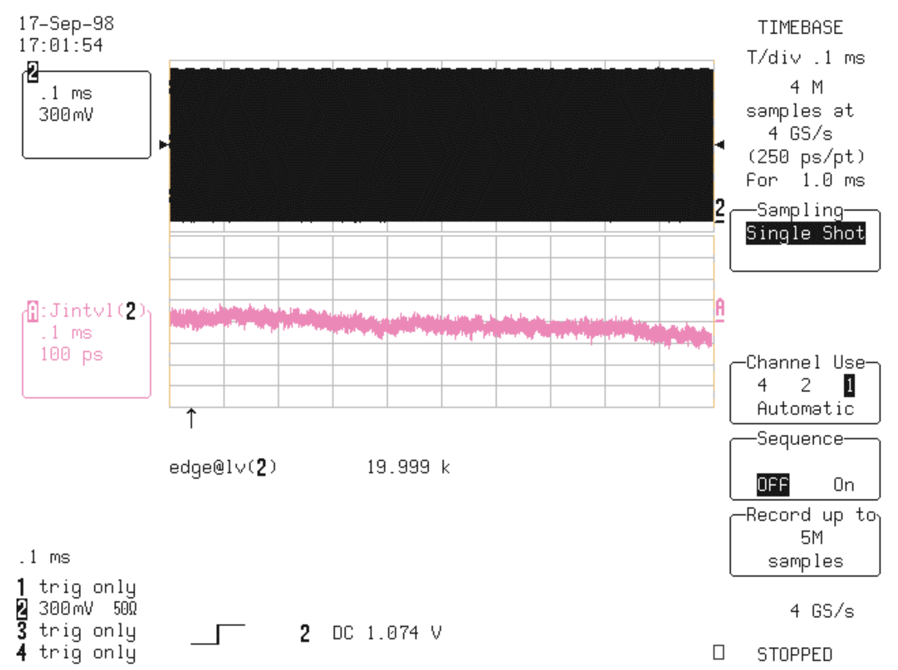


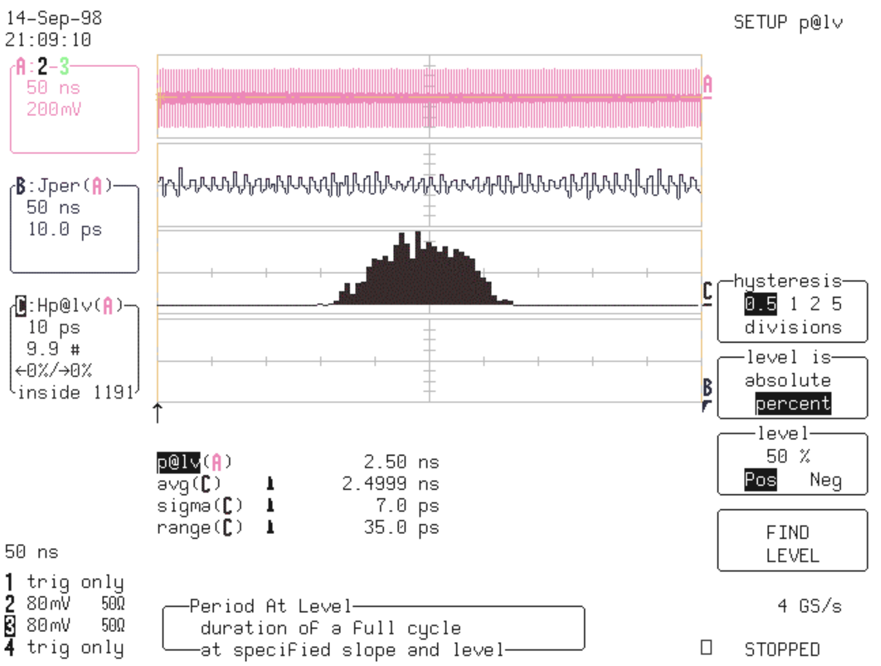
Figure 2 JitterTrack of Time Interval Error illustrates a long term change in oscillator period over a 1 ms acquisition time

Long term stability, illustrated in figure 2, involves a gradual drift in oscillator timing. Long term stability generally includes oscillator aging but excludes environmentally induced drift. Aging, in crystal oscillator is caused by a variety of electromechanical mechanisms. Long term stability is usually expressed in parts per million or ppm. A typical specification of 10 ppm means that over a 1 ms interval the clock period can change by 10 ns:

$\Delta t=1ms*(10/1,000,000)=10\ ns$

Short term stability is a function of noise signals within the oscillator and represents a phase modulation of the oscillator output. Short term stability can be specified in the time domain as jitter. The greatest drawback to this method of specifying short term stability is that it is dependent of the measurement interval. The longer the measurement observation time the greater the peak to peak jitter magnitude. Figure 3 shows a typical jitter measurement of a 400 MHz Surface Acoustic Wave (SAW) oscillator. The mean or average period is 2.4999 ns with an rms jitter (sigma) of 7 ps and a peak to peak jitter (range) of 35 ps. Note that the manufacturer of this oscillator specifies that peak to peak jitter for a measurement duration of 1000 cycles.

Many manufacturers minimize the observation time dependency by specifying the oscillator short term stability in terms of the Allan Variance. The Allan Variance uses the frequency difference between adjacent frequency measurements, usually made with a frequency counter, to compute the variance of oscillator output frequency.



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p@lv(A)          2.50 ns
avg(C)         2.4999 ns
sigma(C)          7.0 ps
range(C)         35.0 ps
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1 trig only
2 80mV   50Ω
3 80mV   50Ω
4 trig only
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Period At Level
 duration of a full cycle
 at specified slope and level
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Figure 3 – A jitter measurement of a 400 MHz oscillator taken over 1191cycles of the clock period with a LeCroy scope

Short term stability can also be specified in the frequency domain as phase noise. Phase noise characterizes the shape of the frequency spectrum of the oscillator. A typical phase noise specification is $-100\ db_C$ at 10 kHz offset from the carrier. Phase noise can be measured using a narrowband FFT spectrum analyzer (12-16 bit amplitude resolution) or a dedicated phase noise measurement system.

The greatest strength of the LeCroy jitter and timing analysis package is the ability to study both long term and short term variations in oscillator timing. Long memory and SmartTriggers make it easy to acquire and display this data Specialized jitter measurements combined with the capability to measure and correlate the effects of other parameters such as temperature or supply voltage are ideal for evaluating environmental stability.