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High Resolution Frequency Measurements using the SR620 Time Interval Counter.

A technique to measure frequencies with a factional resolution of 1:10^{-14} in 100s.

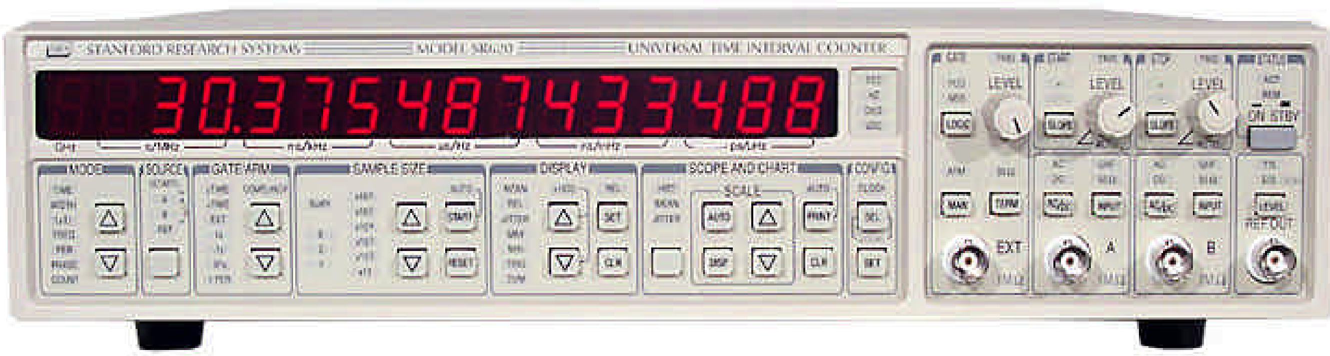
The SR620 time interval counter is a reciprocal interpolating counter which can directly measure frequencies to 1:10^{-10} in a one second interval. The resolution of these measurements increases in proportion to the duration of the measurement period, increasing to 1:10^{-11} in a ten second interval and 1:10^{-12} in a one-hundred second interval. While this is an impressive capability, many users require substantially higher resolution than can be directly measured by the SR620.

A time-honored technique to improve the resolution of a frequency measurement is to heterodyne the signal of interest to a lower "beat" frequency by mixing it with a precision reference. The mixer produces sum and difference frequency outputs. The sum frequency is eliminated by a low pass filter and the difference frequency is measured with a frequency counter. The measurement error is the counter's fractional frequency error times the difference frequency… a substantial improvement over the direct measurement.

The heterodyne technique has several drawbacks: the difficulty of building a precision reference (at a nearby frequency), a mixer, a low pass filter, base band amplifier and comparator. One must also be very careful to avoid signal interference with the (low frequency) base band signal. There is another approach which produces all the benefits of a heterodyne measurement while avoiding all of its pitfalls.

At SRS we use this alternate method to make frequency measurements with a resolution of 1:10^{-12} in a two second interval to 1:10^{-14} in a one-hundred second interval. The method has only one substantial restriction: the frequency to be measured must be an integral multiple of 1 kHz. This is a modest restriction as nearly all of the canonical frequencies of interest (5MHz, 10MHz, 10.23MHz… 622.08MHz…) satisfy this restriction. This alternate method computes the frequency offset by measuring the time rate of change of the phase between the frequency of interest and the SR620's 1 kHz reference: if the phase is changing by 1ps per second then the frequency offset is 1:10^{-12}.

The technique requires a 10MHz reference with stability characteristics that exceed the desired accuracy of the measurement, and an SR620 Time Interval Counter operated in the time interval measurement mode. The 10MHz reference is applied to the rear panel of the SR620 and the instrument's configuration menu is set to *use* the applied reference for its time base. The SR620 generates a low phase noise1 kHz square wave from the applied reference frequency; this 1 kHz square wave is available as an output on the front panel of the instrument and as a "START" source for the time interval measurement mode.



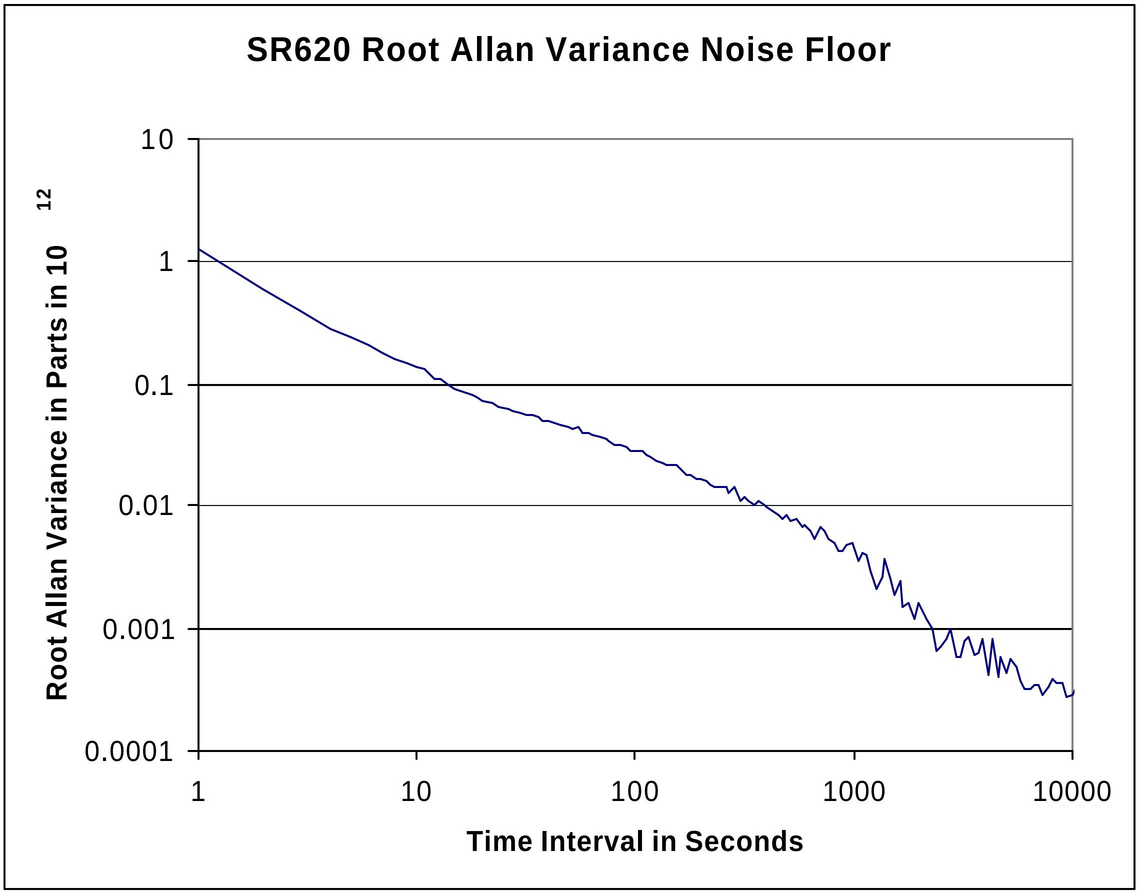
The frequency to be measured is applied to the "B-Input" and will serve as the "STOP" source. If the frequency to be measured is 5MHz then we would expect to measure a time interval between 0ns (in the case that the 5MHz zero-crossing is coincident with the 1kHz "START' and 200ns (in the case that the 1kHz "START" occurred just after a zero-crossing of the 5MHz input.)

The SR620 can measure a single time interval with a noise of about 25ps (rms). That noise is reduced to about 7ps (rms) in the case that the "START" in synchronous with the instrument's internal time base (as it is when the 1 kHz reference is used as the "START".) Averaging further reduces the noise of the measurement, decreasing with the square root of the number of measurements. By configuring the SR620 to use a SAMPLE SIZE of 1000 measurements, the noise is reduced to less than 1ps (rms). Hence we are able to measure the phase of the signal with sub-picosecond resolution in a 1 second interval, allowing fractional frequency measurements of $1:10^{-12}$ in a two second interval. It is the SR620 unique ability to make very high resolution time-interval measurements that makes the instrument an appropriate choice for this measurement.

The following check list may be helpful in making the measurement:

1. Apply a suitable 10MHz reference to the 10MHz input on the rear panel.
2. Use the CONFIG menu to set the "CLOCK SOURCE" to "rear"
3. Verify that the CLOCK LED is not glowing red.
4. Set MODE to TIME
5. Set SOURCE to REF
6. Set GATE/ARM to +TIME
7. Set SAMPLE SIZE to 1000
8. Set display to MEAN
9. Press the UP & DOWN buttons in the DISPLAY section simultaneously to increase the display resolution by 1000× (as indicated by the ×1000 LED)
10. Apply the signal of interest to the "B" input and set the threshold knob to AUTO.

Allan variance plots can be constructed by recording a long series of these measurements and computing the Allan variance vs. observation time. At SRS we typically record 8193 (2^{13}+1) time interval measurements to compute 8192 one-second frequency differences, 4096 two-second frequency differences… and 8 one-thousand and twenty-four second frequency differences to construct an Allan variance plot between 1s and 1024s.



(This data was collected by connecting one 10MHz out of an FS725 to the SR620 reference input. A second 10MHz output from the FS725 went to the input of an RF splitter (Minicircuits 15542 Splitter ZSCJ-2-1). The two splitter outputs were connected with identical 3 inch BNC cables to channel A and B of the SR620. The 1kHz REF out of the SR620 was connected to the EXT input of the SR620. The SR620 was set up for time interval measurements, starting on channel A using EXT +/-time gate/arm, with a sample size of 1000. 57600 1-second measurements were collected, starting on 3/2/04 4:15pm The modified root Allan variance was computed to give the graph shown above.)