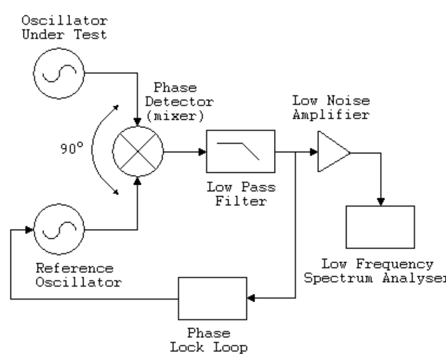
RELATIONSHIP BETWEEN PHASE NOISE AND JITTER

As stated in the article 'PHASE NOISE / JITTER IN CRYSTAL OSCILLATORS' Phase Noise and Jitter are both ways of describing the stability of an Oscillator. Phase Noise describes the stability in the Frequency Domain whilst Jitter describes the stability in the Time Domain. The choice of which Domain to consider the Oscillators stability is usually application dependant. RF (Radio Frequency) Engineers working in Radar, Base Station design etc. will be interested in Phase Noise as poor Phase Noise performance will affect Up/Down conversions and channel spacing. Digital Engineers working in Time Division multiplexing (the majority of modern Telecoms infrastructure) will be interested in Jitter as poor Jitter performance will result in Network slips and excessive re-send traffic.

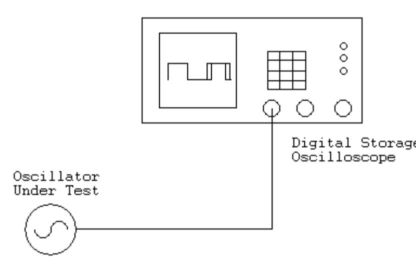
When specifying noise performance the test has to impose some 'boundaries' to the measurement. For Phase Noise this is the simple form of a 'from – to' figure (like Phase noise from 10Hz to 1MHz). For Jitter measurement it is a little more complex. To specify Jitter a sampling period needs to be specified and also a bandwidth. It is usually the bandwidth part of the 'boundaries' that is forgotten.

Fig.1



The next consideration is the test equipment used to make the measurement. Measurement of Phase Noise is achieved by quadrature locking the oscillator under test to a reference oscillator as shown in Fig.1. The effect of quadrature locking is to remove the Carrier frequency leaving only the non phase related noise components. The Low Pass Filter is not there to filter the Phase Noise but rather to remove the 2x frequency component.(The Phase Detector (mixer) generates the sum (2x) and difference of the two input frequencies, we are only interested in the difference, the part without the Carrier frequency). The Low Noise Amplifier can be switched in or out depending on the resolution of the Low Frequency Spectrum Analyser. Provided the Phase Noise performance of the Reference Oscillator is better than the Oscillator Under Test, and the other components in the test set up do not add measurable noise, then the Spectrum Analyser is measuring the Phase Noise performance of the Oscillator Under Test, not the test system.

Fig.2



Measurement of Jitter is often done using a fast Digital Storage Oscilloscope and triggering on one leading edge then looking at the position in time of the next edge (Fig. 2). This approach has several disadvantages as a measurement approach. The bandwidth of the measurement is unknown (is it DC to the bandwidth of the oscilloscope?), the number of samples and sample time is unknown, there is an uncertainty associated with the trigger point, and are you measuring the jitter of the oscillator under test or the jitter of the oscilloscopes internal time base oscillator.

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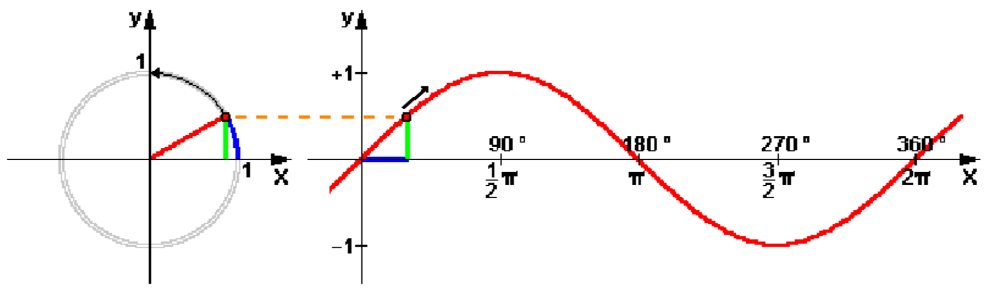
To describe a fixed frequency in the Time domain we use the classic theory of a ‘unit’ vector rotating around a ‘unit’ circle with constant angular velocity (Fig. 3).

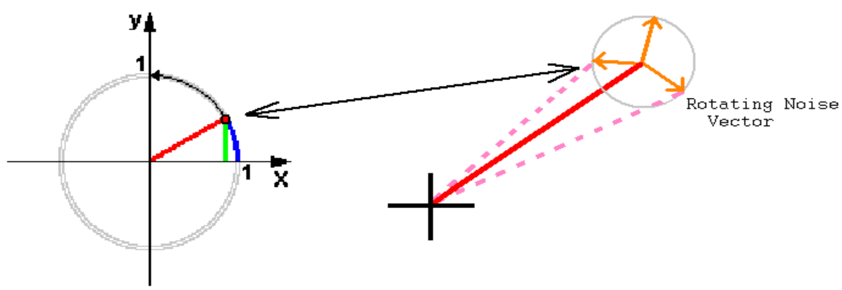
Fig. 3



For this waveform to exhibit Jitter the unit vector would have to complete its journey around the unit circle in slightly varying times, i.e. the angular velocity would have to be continually speeding up and slowing down. This is in effect frequency modulation which we know, for a stable crystal oscillator, is not the case so something else is happening.

The true cause of the unit vector crossing the X axis slightly early or slightly late is a little noise vector rotating around the end of the unit vector as shown in Fig. 4 (but greatly exaggerated for clarity).

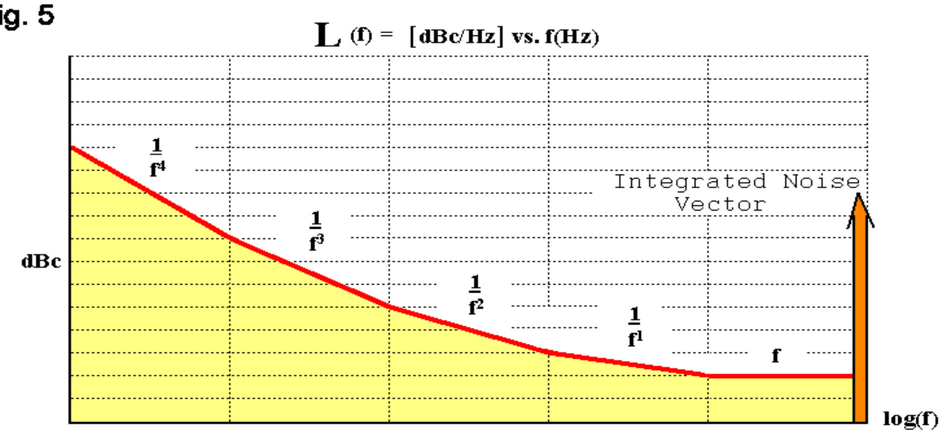
Fig. 4



The solid red line is the unit vector with the dotted pink lines showing how the rotating noise vector can displace the unit vector from its ideal position.

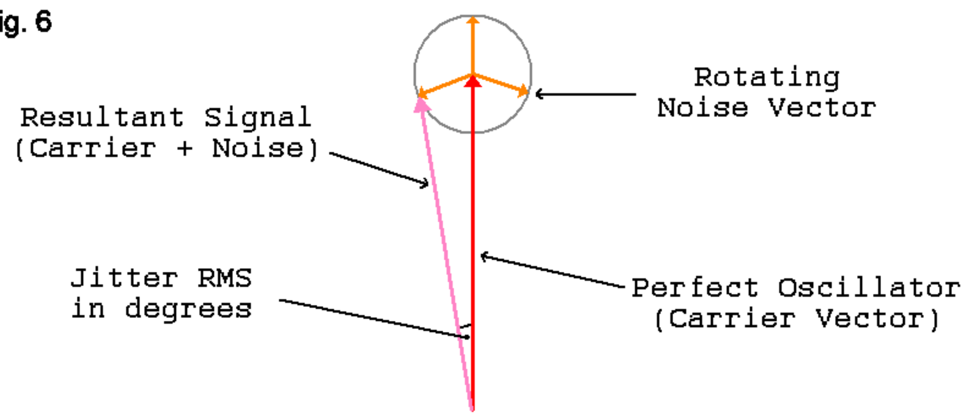
The magnitude of this noise vector is equivalent to integrating all the noise power under the phase noise plot (over the frequency range of interest) into a single figure as shown in Fig. 5.

Fig. 5



Now that the rotating noise vector has magnitude (in dBW, the vertical axis of a phase noise plot is Watts per Hz of Bandwidth) it is a simple trigonometrical identity to convert this to a figure for $Jitter_{rms}$ (Fig. 6).

Fig. 6



$Jitter_{rms}$ in degrees is then calculated as the maximum angle between the Resultant Signal vector (carrier + noise) and the Perfect Oscillator vector (carrier vector). To convert to time express as a fraction of 360 degrees and multiply by the period of the carrier frequency.

Jitter RMS in secs = angle/360 * T

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Since the noise sources in a Crystal Oscillator are Random (Stochastic) rather than Induced/Repetitive (Deterministic) then a 'ball park' figure for Peak - Peak jitter can be calculated based on the Standard Deviation (Fig. 7).

Fig. 7

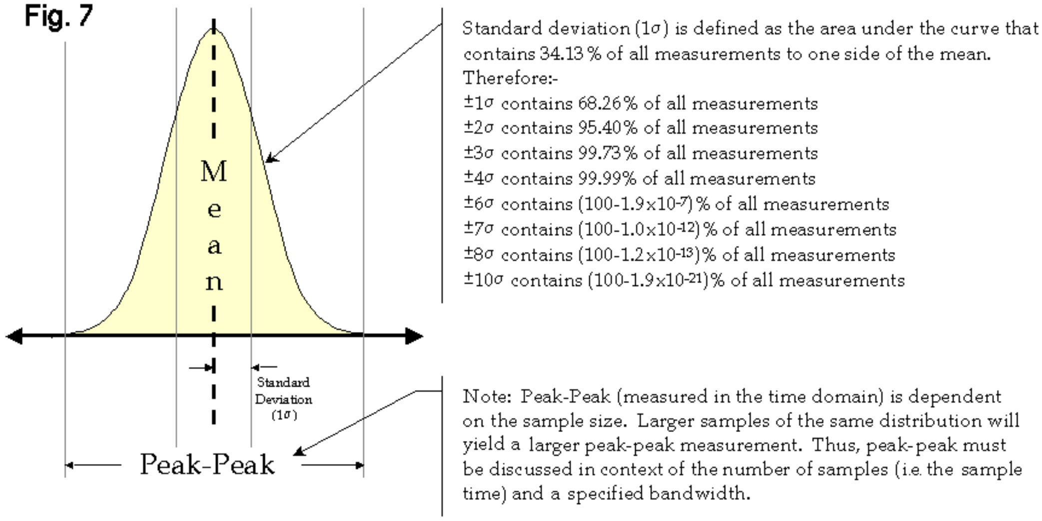

Fig. 8 shows the conversion of Phase Noise to Jitter for a real 13.0MHz Crystal Oscillator. The actual Phase Noise plot used is shown in Fig. 9.

Fig. 8

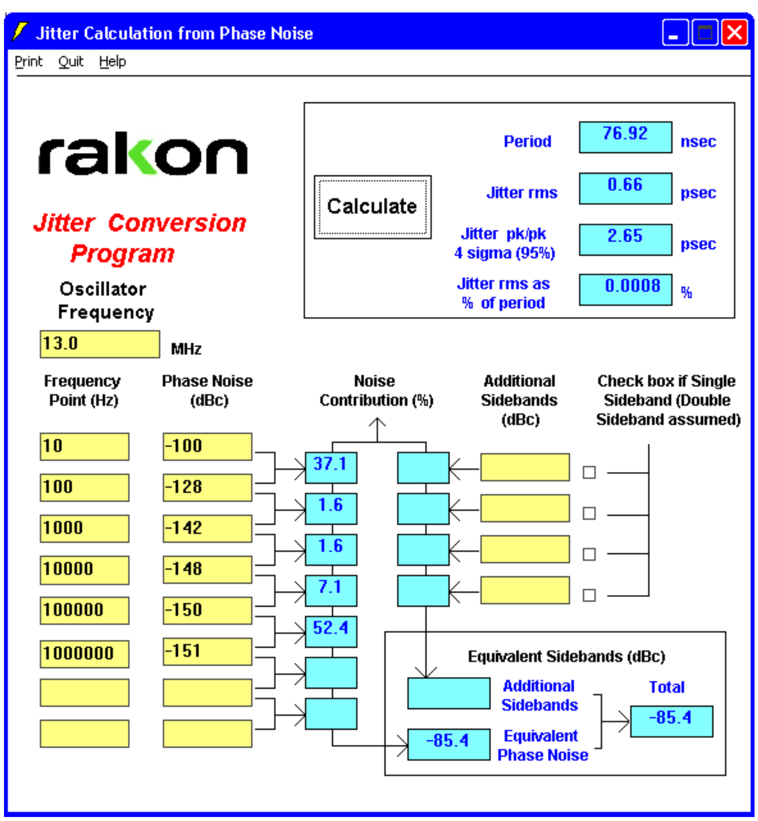

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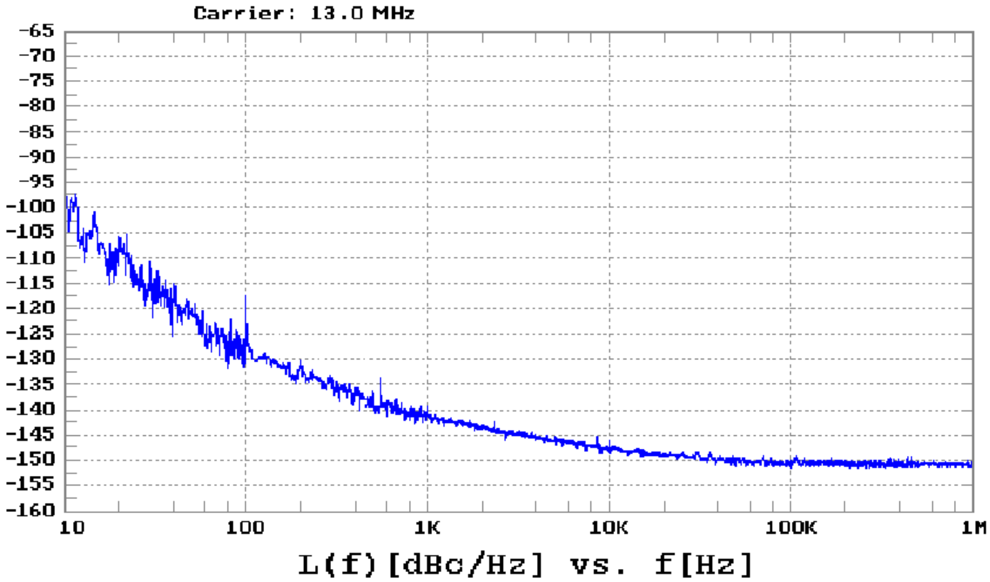
Fig. 9



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