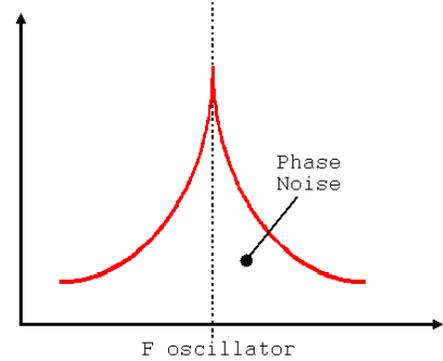


PHASE NOISE / JITTER IN CRYSTAL OSCILLATORS

Before we can cover the sources of Phase Noise / Jitter in Crystal Oscillators we need to de-mystify some of the wording associated with the measurement, so let's start with a simple description of Phase Noise and Jitter.

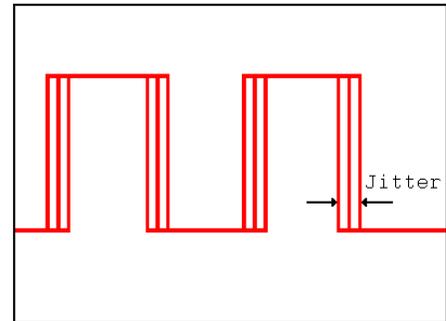
Phase Noise is a method of describing the stability of an oscillator in the Frequency Domain. It can differentiate between Random (Stochastic) noise and Induced/Repetitive (Deterministic) noise. The Frequency Domain shows you what the spectral (frequency) content of your oscillator output looks like over a given frequency range. In this domain we are using a Spectrum Analyser to look at the output of the oscillator (Fig. 1).

Fig. 1



Jitter is a method of describing the stability of an oscillator in the Time Domain. It lumps all the noise sources together and shows their effect with respect to time. The Time Domain shows you what the output of your oscillator looks like over a displayed time period. In this domain we are using an Oscilloscope to look at the output of the oscillator (Fig. 2).

Fig. 2

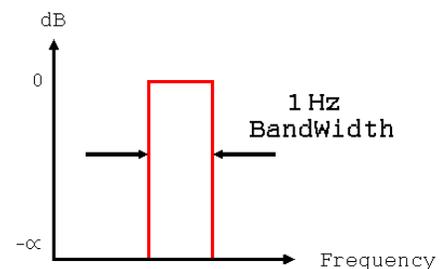


Understanding Phase Noise requires understanding the concept of Spectral Density.

Imagine an impossible to build band pass filter with the following properties (Fig. 3).

- 1) Pass band gain = 1
- 2) Stop band attenuation = infinite
- 3) Pass band width = 1 Hz
- 4) Vertical sides to the Stop band
- 5) Tuneable centre frequency in 1 Hz steps

Fig. 3



Apply this filter to the signal you are measuring, starting at a frequency f_{start} and finishing at f_{stop} in 1Hz steps. At each step measure the output power level from the filter using a power meter and plot on a graph (Fig. 4).

What you are plotting is:-

Signal Power Spectral Density in Watts per Hz of Bandwidth

Applying this filter to an oscillator where f_{start} is just above the oscillator frequency F_{osc} (Fig. 5) then we are measuring the **Single Side Band** (i.e. the Upper Side Band) **Signal Power Spectral Density** in Watts per Hertz of Bandwidth. Replace the word **Signal** with the word **Noise** (as anything above F_{osc} and not harmonically related can be considered as noise) and working in dBW ($10\log(\text{Watts})$ because of the large dynamic range) then, loosing some of the other words, means what we are measuring is:-

SSB Noise density in dBW/Hz

If the oscillator is a stable Crystal Oscillator then looking at the output on an Oscilloscope where we trigger on the rising edge and look at the next rising edge we will see a slightly 'jittery' waveform (Fig. 6). Providing this jitter is very much smaller than one complete period (as shown in Fig. 6), we can say it is caused by **Phase Fluctuations** (rather than frequency fluctuations). Replace the word **Fluctuations** with the word **Noise** and relating this back to the view on the Spectrum Analyser (Fig. 5) then

SSB Noise density is in fact **Phase Noise**

Fig. 4

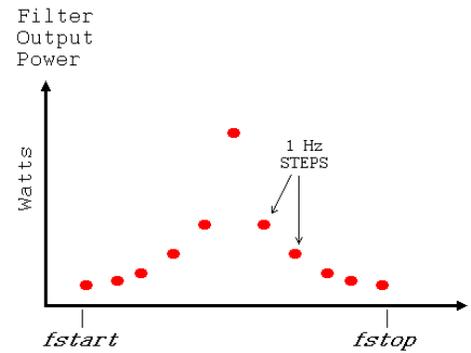


Fig. 5

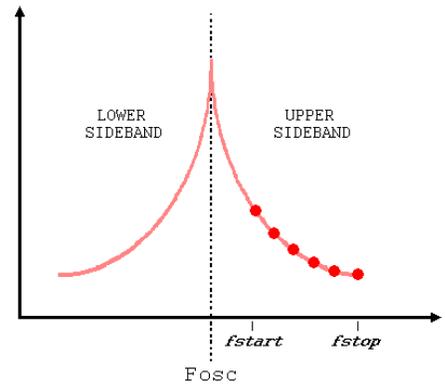
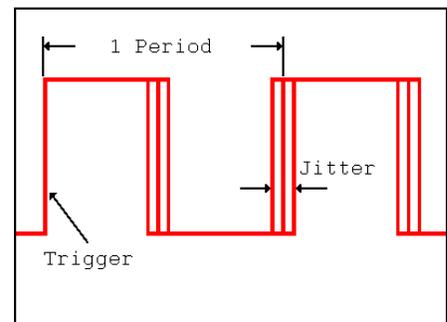


Fig. 6



As shown in Fig. 7, this leads to the classic definition of Phase Noise as a power ratio:-

$$L(f) = \frac{\text{Power density in a Single 1 Hz Side Band}}{\text{Total Signal Power}}$$

and is expressed in dBc (dB's down from the carrier)

Fig. 7

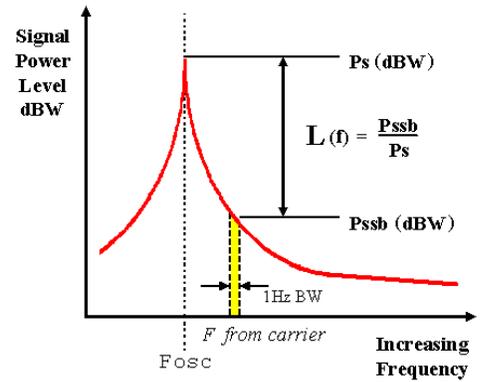
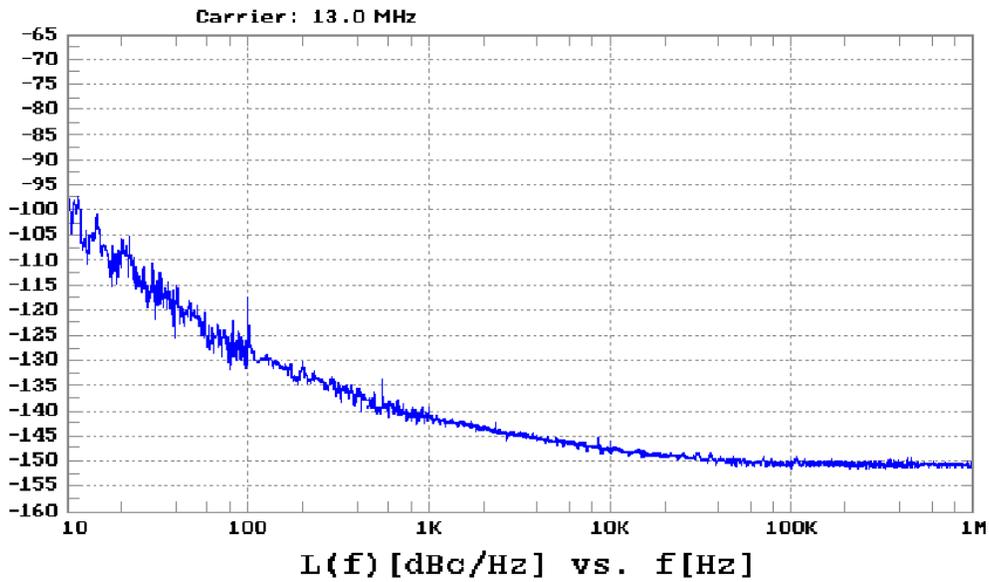


Fig.8 is a Phase Noise plot of a real 13.0MHz Crystal Oscillator.

Fig. 8

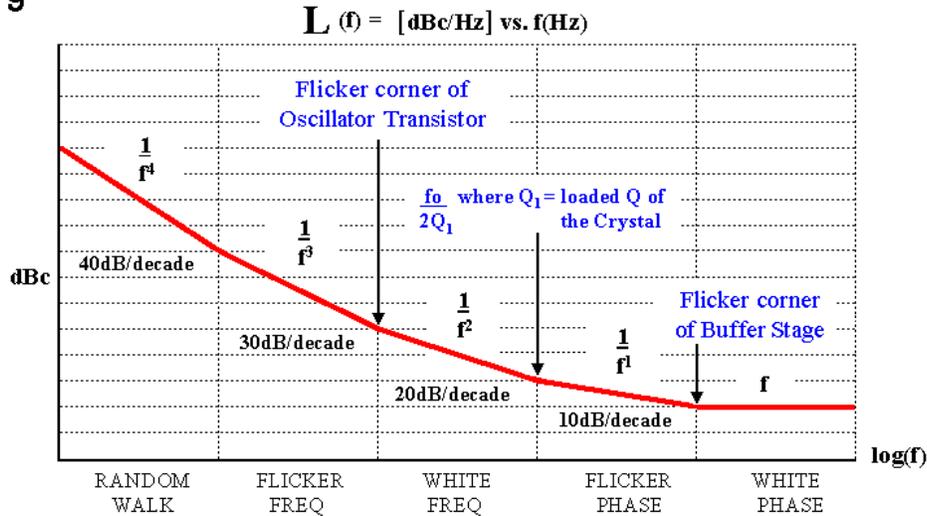


This can be analysed by matching the slopes of the real Phase Noise plot to those shown in the idealised Phase Noise plot of Fig. 9.

For this particular plot:-

Flicker corner of Buffer Stage	~ 5 kHz
Loaded Q of the Crystal	~ 170 Hz (Q ~ 38k)
Flicker corner of Oscillator Transistor	~ 12 Hz
Random Walk	~ 0.1 Hz (extrapolated)

Fig. 9



Where the cause of the Phase Noise can be described by:-

- WHITE PHASE** Thermal noise (Johnson noise)
i.e. kT buffer amplifier noise, resistor noise and Shott noise.
- FLICKER PHASE** Pink noise (equal power per decade frequency)
i.e. predominately buffer amplifier flicker noise.
- WHITE FREQ** Carrier noise
i.e. predominately the Crystal RLC noise.
- FLICKER FREQ** Intermodulation of WHITE FREQ (Carrier noise) and FLICKERPHASE (transistor noise) particularly within the oscillator loop.
- RANDOM WALK** Intrinsic noise sources within the Quartz and electrode structures. Possible external effects caused by environmental changes i.e. mechanical shock, vibration, temperature changes etc.

These are all sources of Phase Noise intrinsic to the Crystal Oscillator, there are other external influences which can affect the Oscillators Phase Noise performance. These include power supply noise, circulating ground currents, noise on the control voltage line, changing load conditions, mechanical vibration and electromagnetic interference to name a few.

In terms of voltages remember the Phase Noise plot is in dB's of power down from the carrier so for every -10 dBc divide the voltage by 0.316 ($\sqrt{10}$). This means for a 3.3V CMOS output Oscillator with a noise floor of -150dBc the noise floor voltage is only 104nV (nano Volts) pk/pk.