Ultra Low Phase Noise Techniques

ALARIS
LINWAVE

RF 2024
TECHNOLOGY EVENT

18 APRIL 2024
FHI Leusden

RF

Alaris Linwave Technology

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RF Design & Development Engineer

Daniel Lowbridge is a recent employee at Alaris Linwave joining the team in 2022, Daniel has been involved in a variety of projects ranging from a series of Ka-band BUCs to oscillator design, and more recently an internal case study launched to create a 5GHz ultra-low phase noise oscillator competing with the industry leaders. Daniel received his degree in Electronic Engineering from the University of York in 2022.

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Agenda:

This presentation will outline the following:

- Outline Phase Noise
- Discuss Phase Noise within RADAR systems
- Oscillator theory
- High Frequency Oscillators

Phase Noise

An ideal sinusoidal oscillator is mathematically represented as:

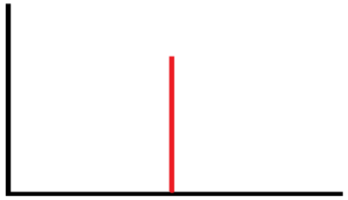
$$f_{out} = \mathrm{A} \cdot \sin(\omega t)$$

This would present as two symmetrical unity impulse functions scaled by amplitude ‘A’

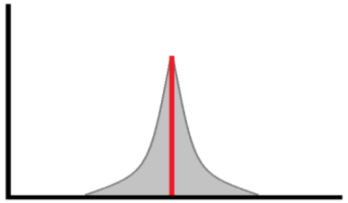
An oscillator with a phase noise component can be mathematically represented as:

$$f_{out} = \mathrm{A(t)} \cdot \sin(\omega t + \varphi(t))$$

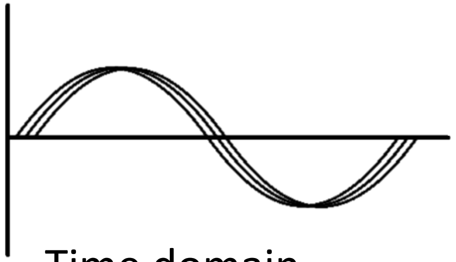
With $\mathrm{A(t)}$ & $\varphi(t)$ representing a time variant behaviour within both the amplitude and phase of the signal



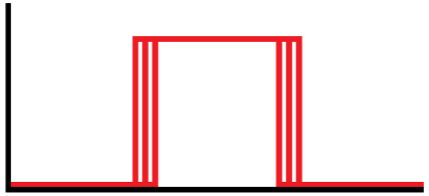
Ideal Oscillator



‘Real’ Oscillator



Time domain variation

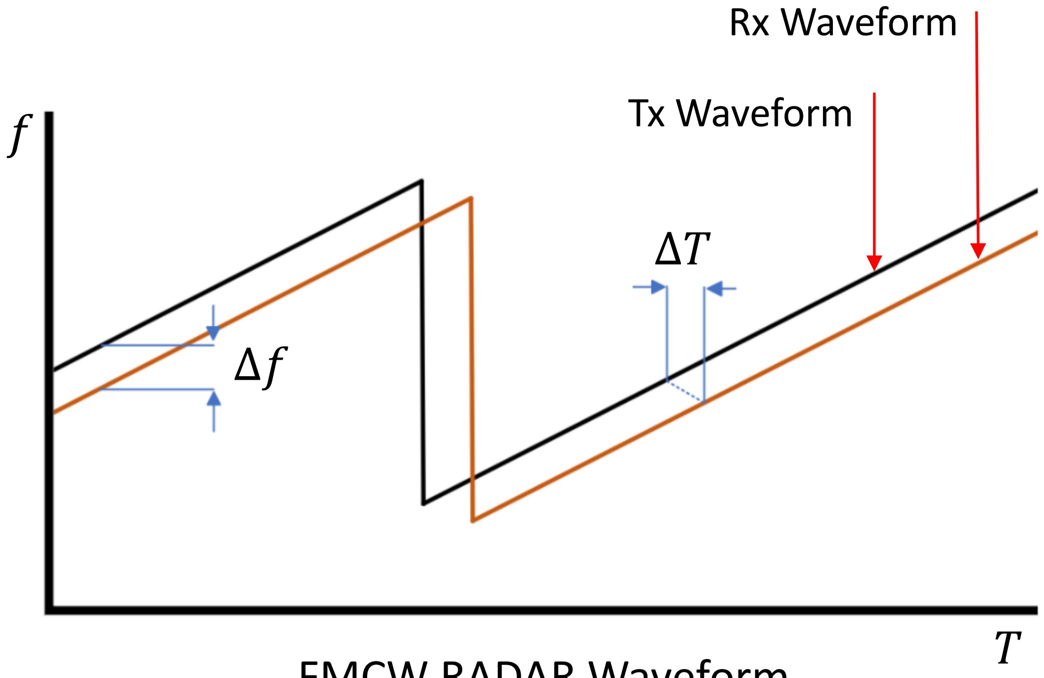


Oscillator Jitter

RADAR

RADAR works on principle by emitting a pulse of a known frequency & time and waiting for the echo to be received back. Using the deviation in time, calculations can dictate the distance of the object away from the RADAR transceiver.

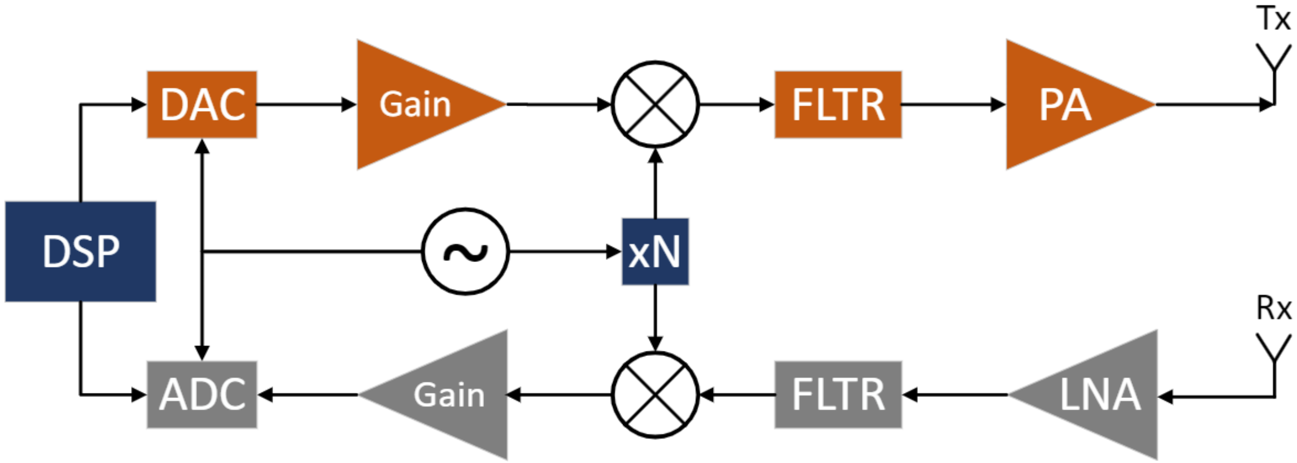
By performing DSP of the deviation in signal, a spectrum of objects detected will be displayed.



FMCW RADAR Waveform

RADAR

To achieve resolution in object detection, the time duration of the pulse wants to be small, and hence the equivalent frequency is high. This means that the signal needs to be upconverted for generation, and downconverter for DSP after being received. Both stages involve mixing with an LO, this is known as coherent RADAR providing both Tx & Rx share an LO.



Simplified block diagram of RADAR system

Phase Noise: Receiver Sensitivity

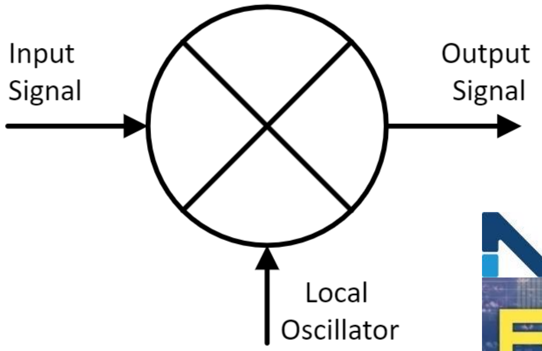
Receiver Sensitivity:

Receiver sensitivity is crucial in a RADAR system.

To allow for the RADAR pulse to be processed, and still collect data at a high enough resolution to distinguish the object, a process of frequency translation is often required.

The simplest form of RADAR frequency conversion is known as *heterodyne* conversion

This involves a single stage conversion as shown below:



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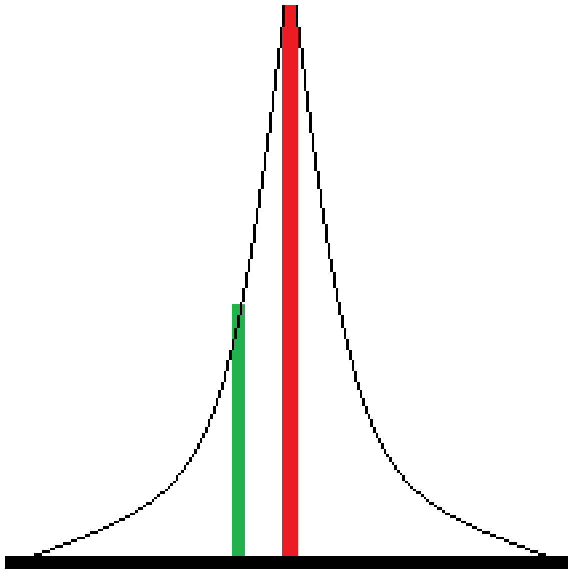
Phase Noise: Receiver Sensitivity

Given heterodyne systems only offer one stage of up/down conversion, the signal separation is limited to the bandwidth of the signal at baseband.

For example, a 50MHz BW baseband signal transmitted at 10GHz will require an LO of 9.95GHz.

If the LO phase noise is substantial in magnitude against the reflected signal of interest, it could be hidden under the noise profile.



Down-converted signal with ‘wanted’ (green) hidden by LO phase noise

Phase Noise: ADC Performance

Depending upon the frequency of sampling within the ADC, the clock reference phase noise can crucially affect the ability to sample accurately.

A decrease in SNR will increase the quantization error and reduce the effective number of sample bits

Clock jitter is given by:

$$\boldsymbol{T_{clk} = \frac{\sqrt{\int P(f)df}}{2\pi f_s}}$$

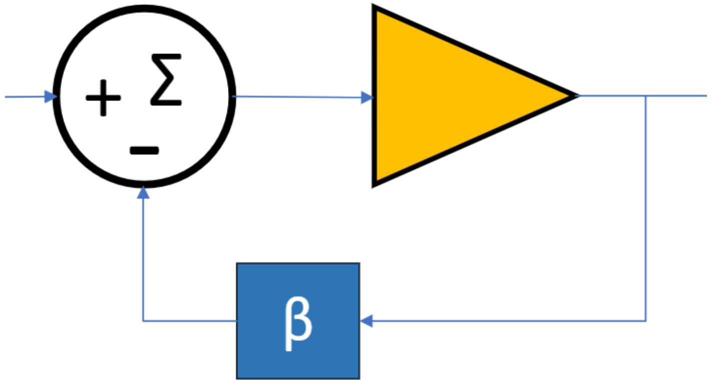
ADC SNR is given by:

$$\boldsymbol{SNR = 20\log_{10}\left(2\pi f_{in}\sqrt{(T_{clk})^2 + (T_{ap})^2}\right)}$$

Crystal Oscillators

Crystal oscillators are comprised of a sliced quartz plate between two electrodes.

They offer high levels of phase noise performance, at the cost of increased complexity.



Crystal oscillators need careful design considerations to achieve good phase noise performance.

Methods Of Characterising Oscillators

Oscillators can be characterised and compared in a variety of ways, most commonly:

Phase Noise: A metric of noise caused by random phase variations in the oscillator

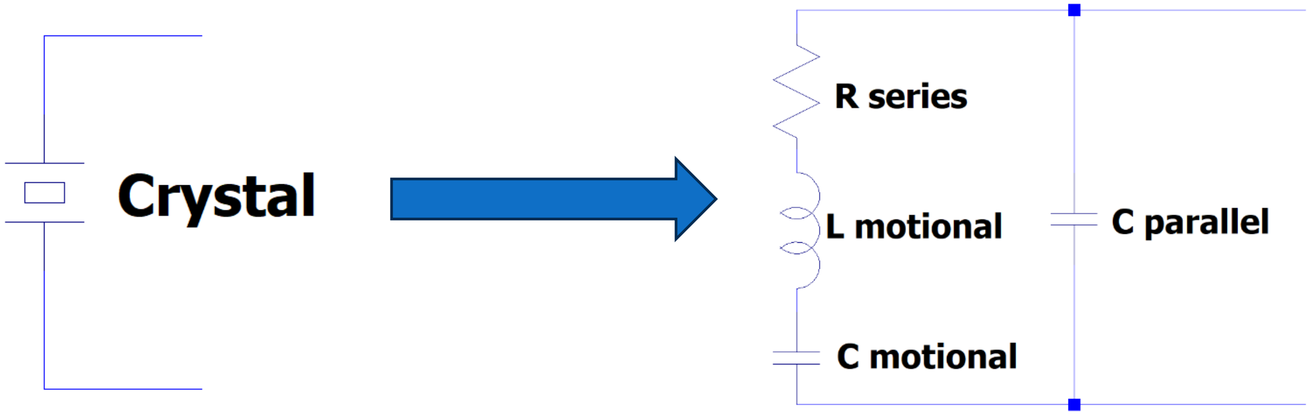
Aging: The frequency drift of an oscillator with respect to time

Temperature Stability: The frequency drift of an oscillator with respect to temperature

Vibration Sensitivity: The shift of frequency given a source of shock/vibration

Oscillators – Temperature Variation

AT CUT:	**SC CUT:**
▫ Most used crystal cut ▫ $500\text{kHz} \leq f_0 \leq 300\text{MHz}$ ▫ Temperature inflection point ≈ 25°C ▫ Average phase noise & aging	▫ ‘Stress Compensated’ crystal cut ▫ $500\text{kHz} \leq f_0 \leq 200\text{MHz}$ ▫ Temperature inflection point ≈ 85°C ▫ Improved phase noise & aging



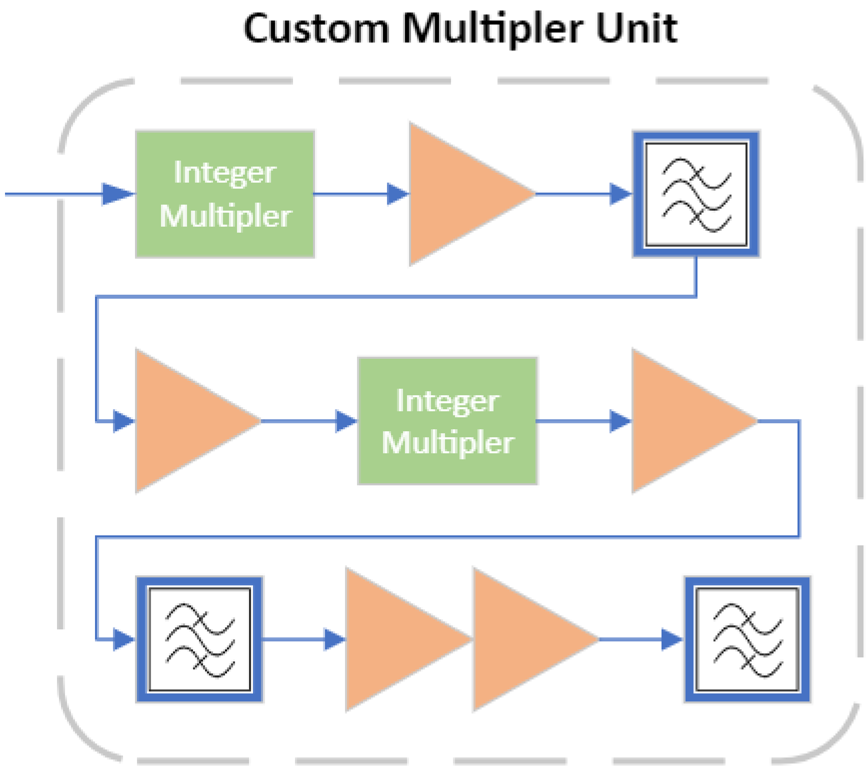
Oscillator Multiplication

Theoretical Phase Noise contribution from frequency multiplication:

$$P_N = 20 \cdot \log_{10}(N)$$

Where N represents the multiplication factor. For example, a 100MHz signal set for up conversion to 10GHz would report a phase noise degradation of:

$$P_N = 20 \cdot \log_{10}(100)$$ = **40d**B

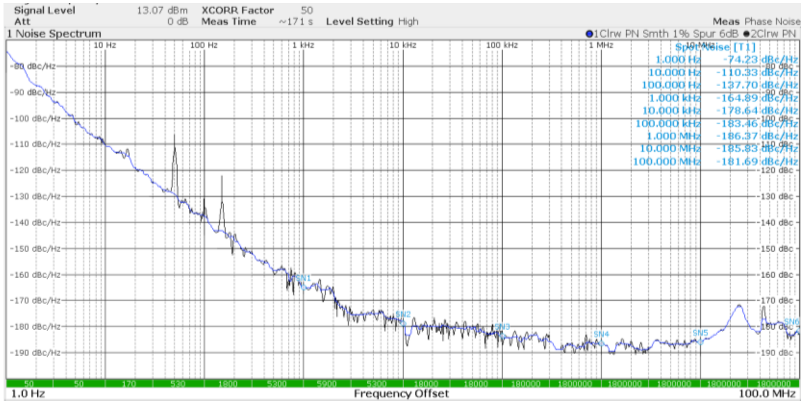

Custom Multpler Unit

How To Measure Phase Noise

Testing Process:

- Measures direct phase noise performance
- Can plot voltage against frequency for VCO
- Correlate the results

SOURCE: Rohde & Schwarz FSWP



Signal Level 13.07 dBm XCORR Factor 50
Att 0 dB Meas Time ~171 s Level Setting High
Meas Phase Noise
1 Noise Spectrum
●1Clrw PN Smth 1% Spur 6dB ●2Clrw PN

Spot Noise [T1]

1.000 Hz	-74.23 dBc/Hz
10.000 Hz	-110.33 dBc/Hz
100.000 Hz	-137.70 dBc/Hz
1.000 kHz	-164.89 dBc/Hz
10.000 kHz	-178.64 dBc/Hz
100.000 kHz	-183.46 dBc/Hz
1.000 MHz	-186.37 dBc/Hz
10.000 MHz	-185.83 dBc/Hz
100.000 MHz	-181.69 dBc/Hz

Cross-Correlation:

Cross correlation is a mathematical function comparing the similarities of two signals:

$$(f \ast g)(\tau) \triangleq \int_{-\infty}^{\infty} \overline{f(t-\tau)}\, g(t)\, dt$$

Phase Noise sensitivity is improved by:

$$Pn = 5\log_{10}(Corr)$$

Conclusion

To summarise, this presentation has included:

- Outline Phase Noise
- Discuss Phase Noise within RADAR systems
- Oscillator theory
- High Frequency Oscillators

Any Questions?

THANK YOU

Alaris Linwave: Ultra-Low Phase Noise Oscillators

Come see us at Booth 11

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