

CERN Timing Workshop #2

Some timing theory

The slide features several decorative circles. A light purple circle is positioned behind the word 'Timing' in the title. Two solid light purple circles are located below the title, one on the left and one in the middle. A light purple circle with a thin outline is positioned behind the word 'theory' in the title. Another light purple circle with a thin outline is located below the title on the right side.

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Outline

- Goals of a timing system.
- Time and frequency stability characterization.
 - Time domain.
 - Frequency domain.
- Basics of PLL design.
- Timing building blocks.



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Goals of a timing system

- Disseminate a common notion of time from a central node to n (~ 1000) distributed nodes.

- Master
 - Play tricks like delay PPS by $1-\delta$ seconds to simulate a time advance of δ seconds \rightarrow need for a highly stable frequency source feeding the master.
- Slaves
 - Regenerate high quality clocks in receivers (to feed counters, ADCs...) \rightarrow need for good quality PLLs to guarantee good spectral purity.
 - Phase aligned UTC time \rightarrow need for precise phase measurements and phase shifts for precise PTP.
 - Produce finely placed pulses \rightarrow need for precise delay generation.
 - Time tag external pulses \rightarrow need for precise delay measurement.



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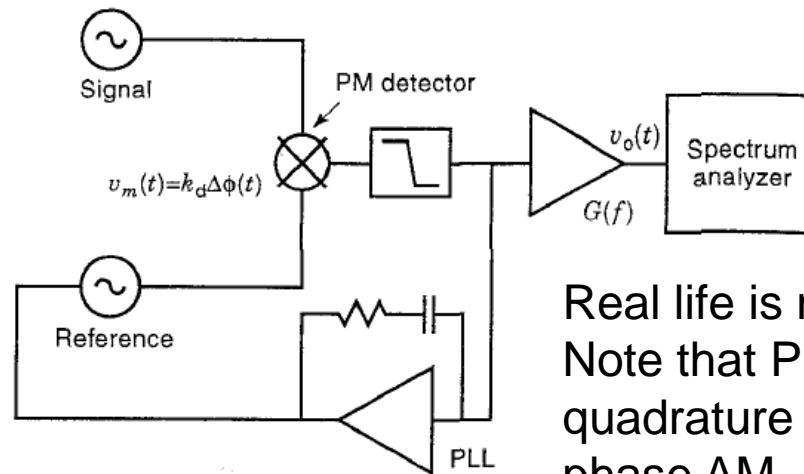
Frequency stability characterization

- Typically use time domain Allan Deviation (ADEV) or Modified Allan Deviation (MDEV) for $\tau > 1\text{s}$, and frequency domain phase noise for $\tau < 1\text{s}$.
- Both measurement techniques basically convey the same information: the departure of the phase of the output of an oscillator from its nominal value:

$$v(t) = A(1 + \varepsilon(t)) \sin(\omega t + \phi(t))$$

Oscillators and their imperfections

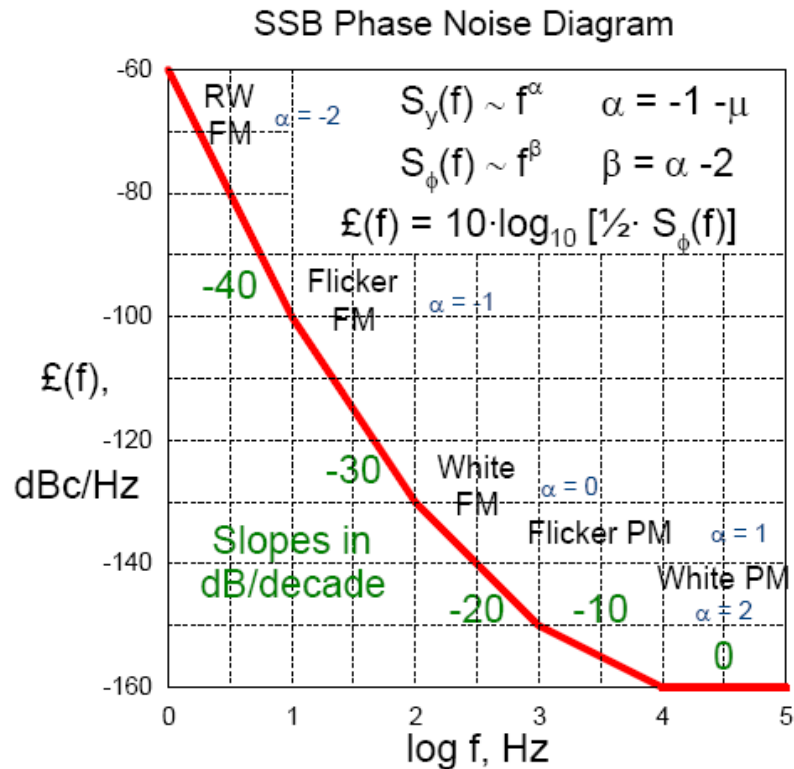
- $\varphi(t)$ is a wide-sense stationary random process (kind of), so it has an autocorrelation function $R_{\varphi\varphi}(\tau)$. Its Fourier transform is the double-sided Power Spectral Density (PSD) of $\varphi(t)$, noted $L_{\varphi}(\omega)$.



Real life is more like this.
Note that PLL locks in quadrature to eliminate in-phase AM.

- Oscillators show white and $1/f$ noise both for phase and frequency, i.e. $L_{\varphi}(\omega)$ (in log-log axis) contains segments with slopes 0, -1, -2 and -3.

Phase noise

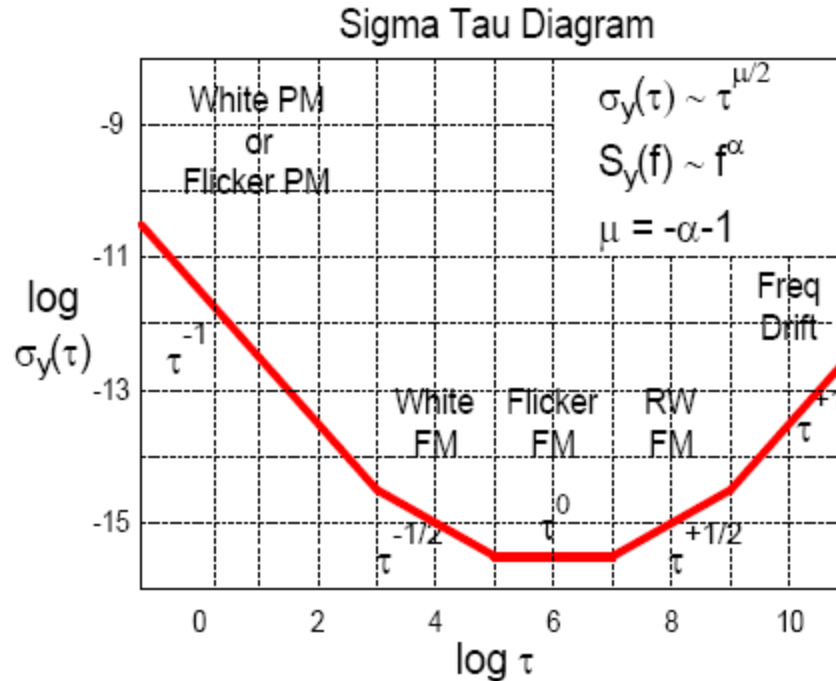


- Thanks to Parseval, jitter is the integral under this curve (use common sense to choose integration limits).
- Beware of deterministic jitter outside integration limits! This is often why you get worse readings in time-domain instruments.
- Best to ask three instruments for their opinion: Spectrum Analyzer, Phase Noise setup and time-domain jitter analyzer, taking into account that in principle the latter gives you a result bigger by a factor $\sqrt{2}$ or so.

Allan variance

$$V(t) = [V_0 + \varepsilon(t)] \sin[2\pi\nu_0 t + \phi(t)] \quad \nu(t) = \nu_0 + \frac{1}{2\pi} \frac{d\phi}{dt} \quad y(t) = \frac{\Delta f}{f} = \frac{\nu(t) - \nu_0}{\nu_0} = \frac{1}{2\pi\nu_0} \frac{d\phi}{dt} = \frac{dx}{dt}$$

In principle you can find ADEV from PN, but not the other way around

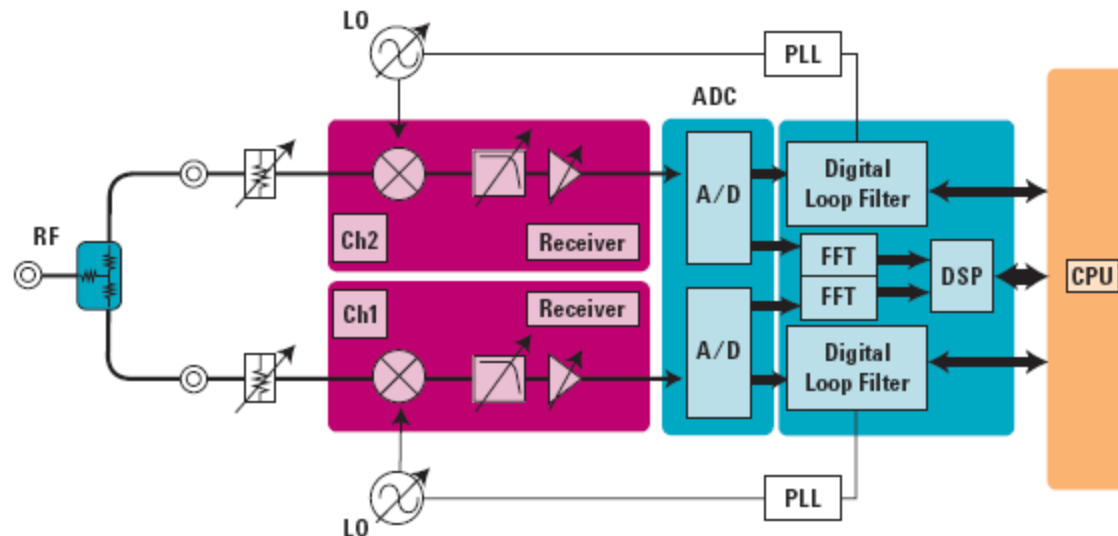


This could well be a GPS receiver output

$$\sigma_y^2(\tau) = \frac{1}{2(M-1)} \sum_{i=1}^{M-1} [y_{i+1} - y_i]^2$$

Beware! No dead time in between measurements → need for a special TIC

Phase noise measurement system example



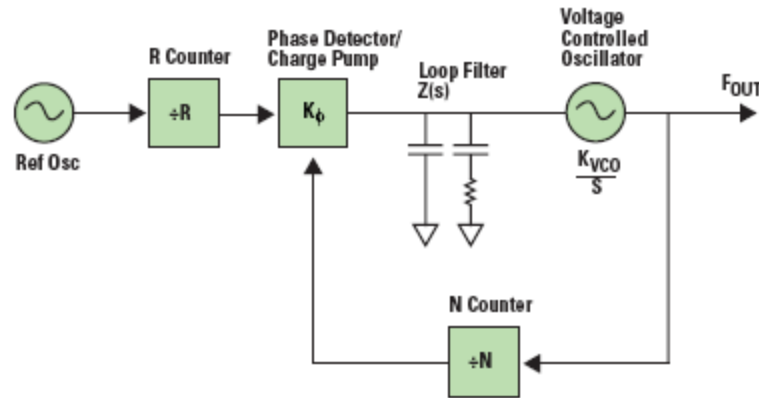
We'll do a E5052B demo in the lab later



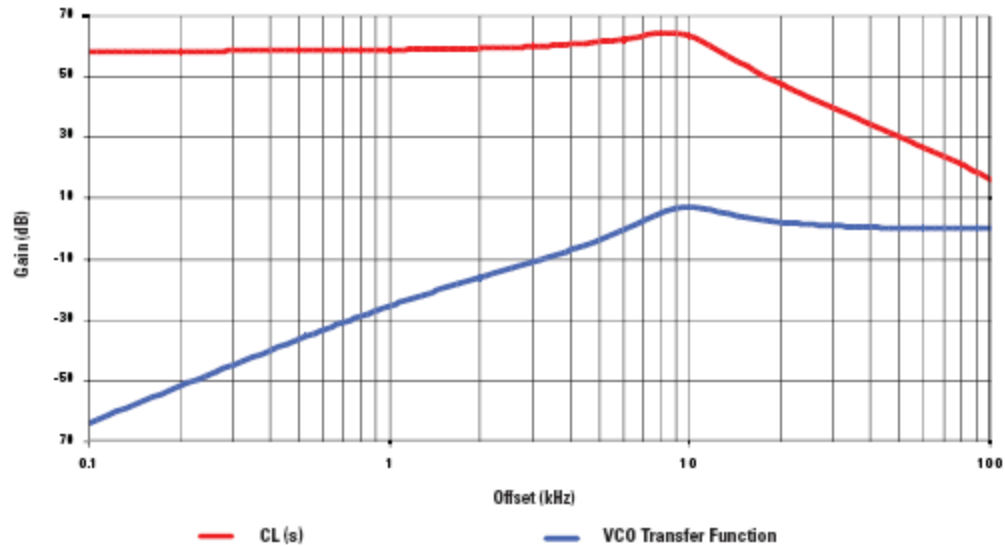
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PLL design basics



Design procedure nicely matches phase noise analysis.





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Timing building blocks



- In order to design this kind of timing systems, one needs:
 - To characterize frequency sources in the time and frequency domains.
 - To design high performance PLLs.
 - To measure phases and delays.
 - To generate precise phase shifts and delays.

Next presentation

