Characterization and Measurement of Phase Noise and Jitter

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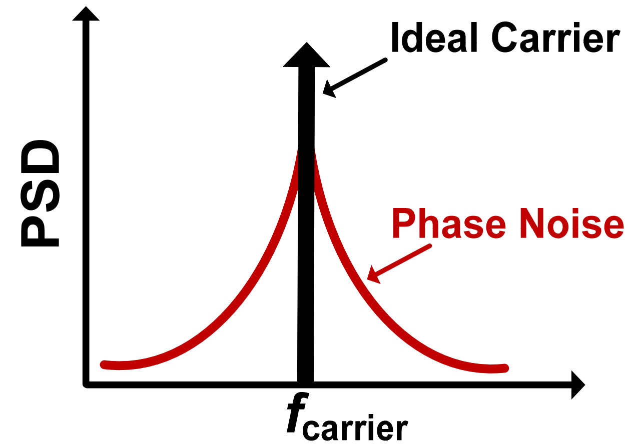
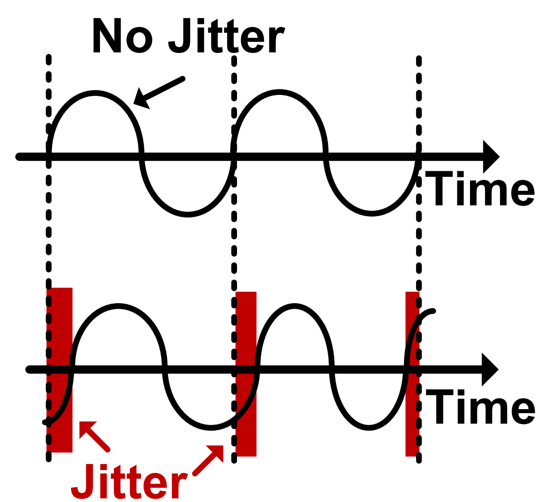
Phase Noise vs. Jitter

- **Phase noise (PN)**
  - Commonly used in RF systems to represent frequency or phase inaccuracy
  - Power-spectral-density (PSD) of frequency or phase inaccuracy

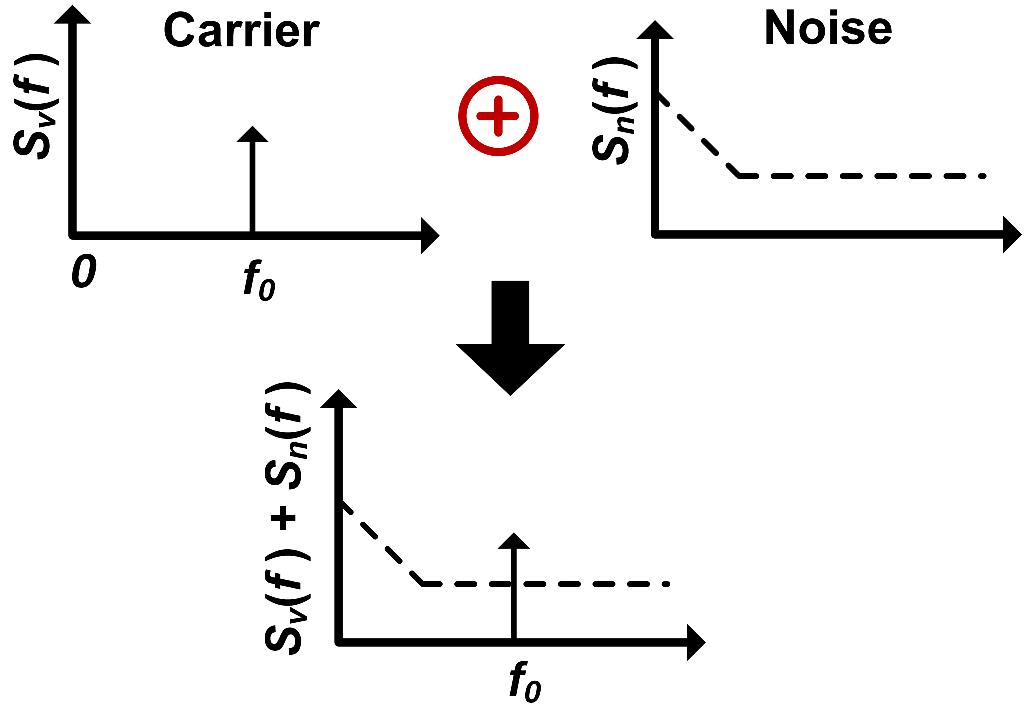


- **Jitter**
  - Refers to sampling timing error or clock edge uncertainty in digital or analog systems
  - Time domain measure



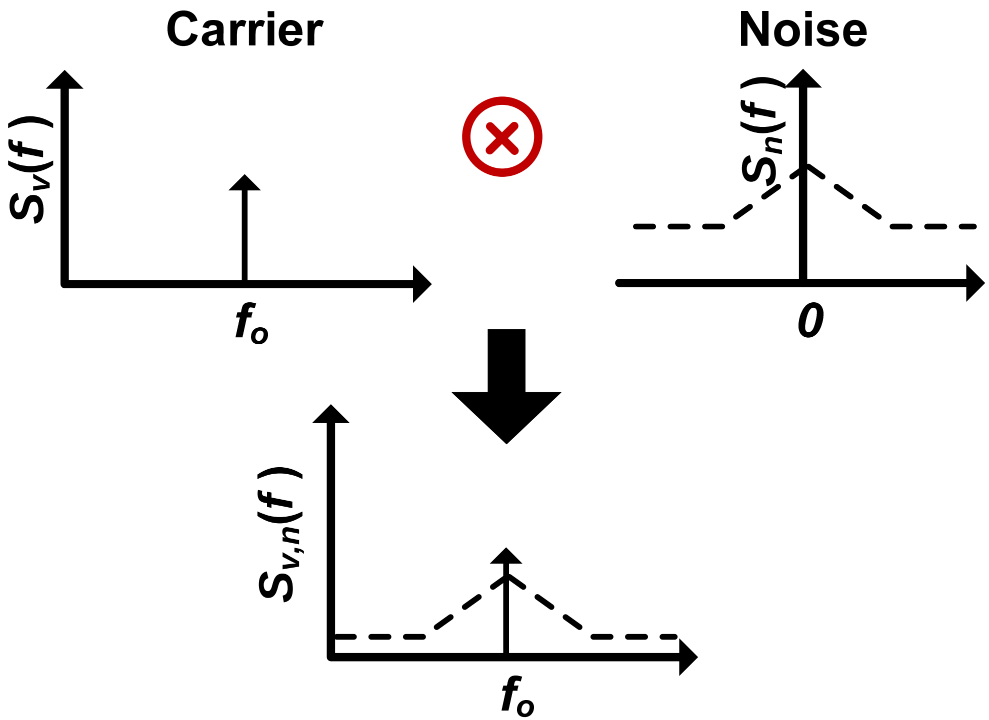
From measurement stand point, PN remains to be the most accurate way to characterize RF Analog & Digital systems

Phase Noise Types: Additive Noise



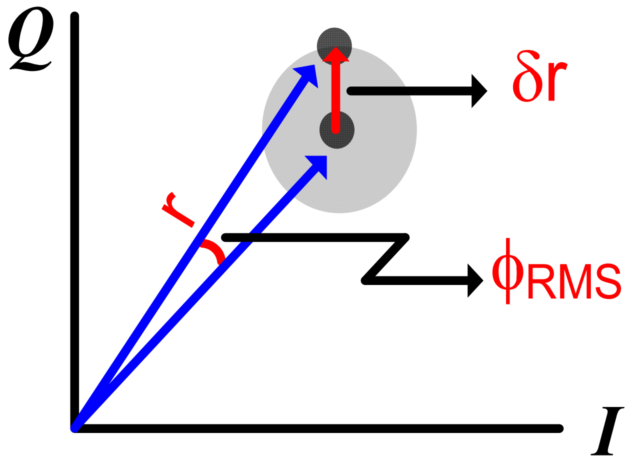
- **Amplifier added noise**
- **Noise added is independent of signal power**
  - **Increasing signal power will result in lower phase noise**

Phase Noise Types: Multiplicative Noise



- **Associated with presence of noise in either amplitude gain path (AM noise) or phase gain path (PM noise)**
  - **Example: varactor AM to PM noise conversion**
- **Unlike additive noise, multiplicative noise scales with carrier power**
  - **Phase noise is independent of the carrier power**

RMS PE & EVM



$\delta r \approx \phi_{RMS} * r$

$EVM (\%) = \delta r / r$

$\approx \phi_{RMS}$ (rad)

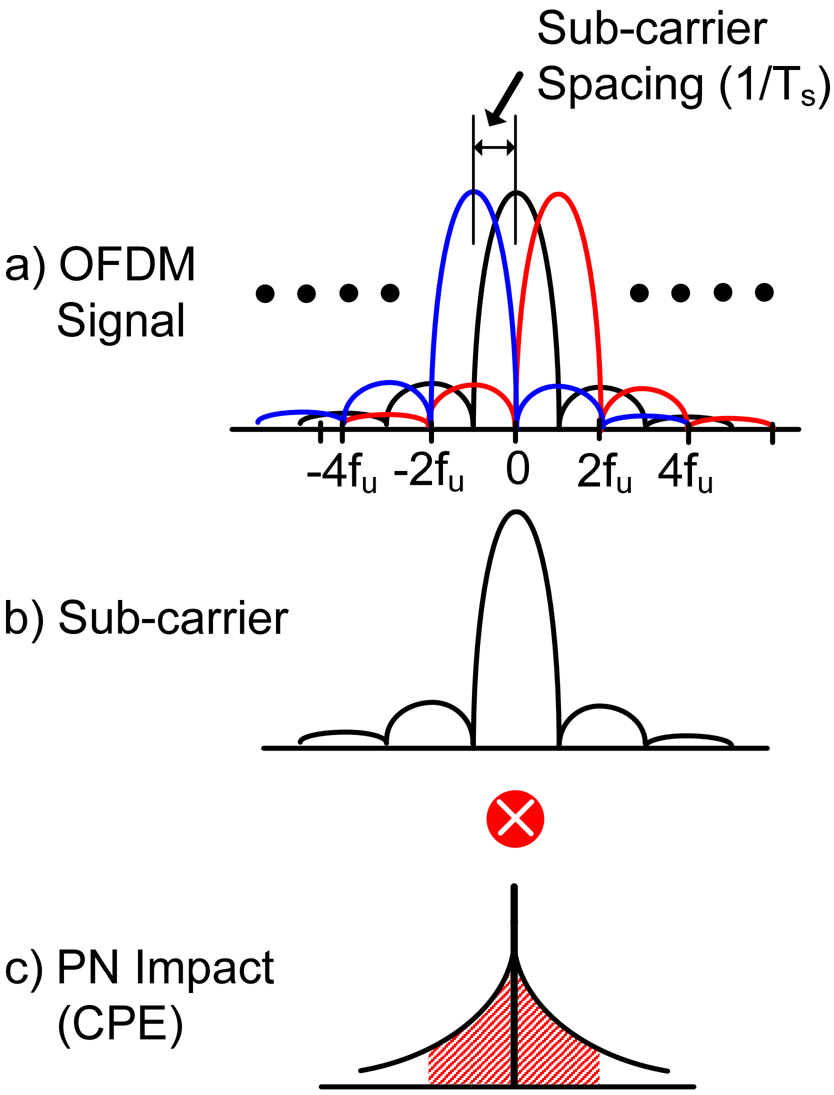
$EVM (dB) = 20\log(\phi_{RMS})$

- Mixing of close-in phase noise of the LO signal with the desired signal causes symbol rotation
  - Results in shifting of adjacent constellation points
  - Increases probability of making an error (i.e. BER)
- For a phase modulated signal, RMS PE specifies a measure of signal to noise ratio (SNR)

Impact of Phase Noise on OFDM Systems

1) Common Phase Error (CPE)

- **Self-mixing of each sub-carrier with the low frequency part of its *own phase noise***
- **All sub-carriers (including pilots) are rotated by the same random phase angle**
- **Phase tracking algorithms use the pilot symbols to measure this rotation and compensate all carriers accordingly**



WiMAX Example

- **For 802.16e; sub-carrier spacing; f_u = 10kHz**
- **Assumption: channel BW= 10 MHz**

$$SNR_{ICI} > 30dB\ (64QAM3/4) + 10\ dB\ (margin)$$

$$\rightarrow 10\log\left(\frac{1}{2\cdot\int_{1kHz}^{5MHz} 10^{\frac{\mathcal{L}(f)}{10}}df}\right) > 40dB$$

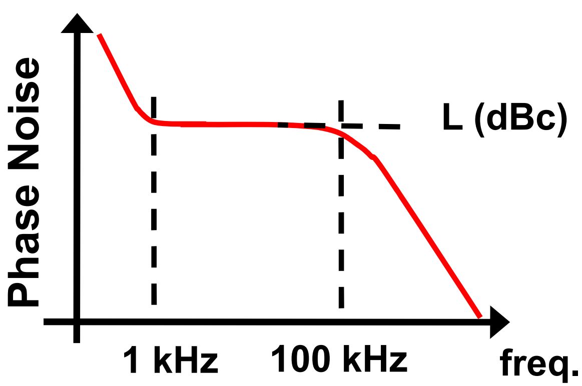
$$\rightarrow 10\log\left(\int_{1kHz}^{5MHz} 10^{\frac{\mathcal{L}(f)}{10}}df\right) < -43dBc$$

$$\approx 10\log\left(\int_{1kHz}^{100kHz} 10^{\frac{\mathcal{L}(f)}{10}}df\right) < -43dBc$$

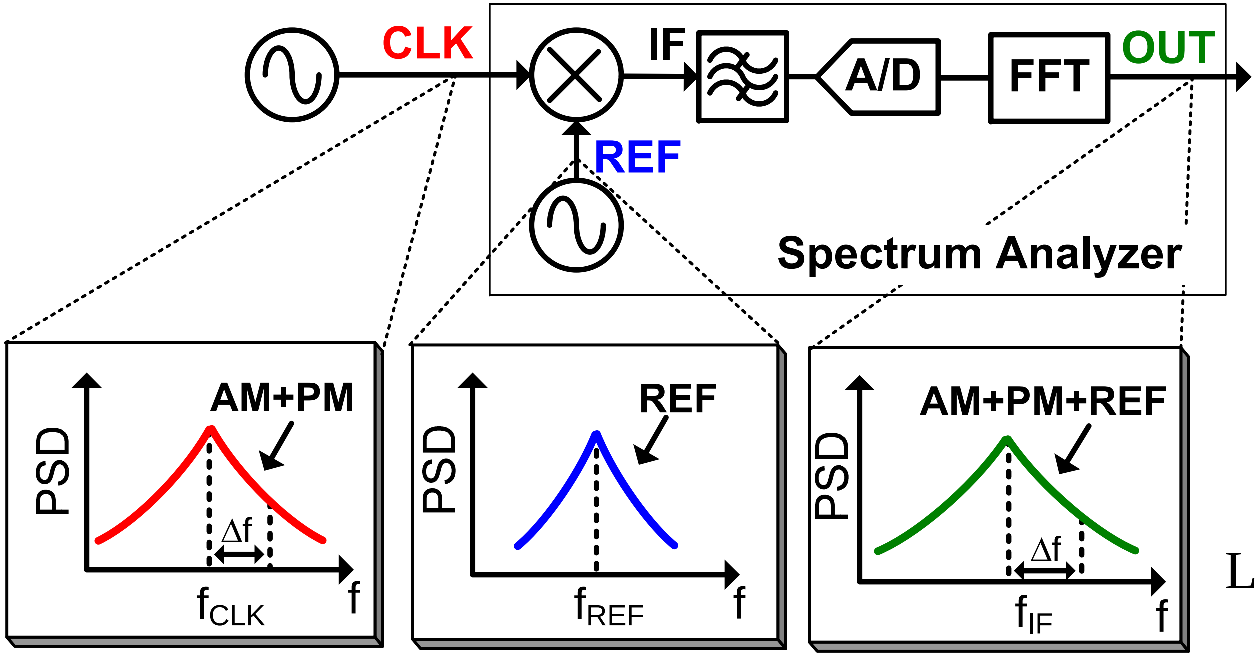
$$= 10\log\left(10^{\frac{L}{10}}\cdot 99e5\right) < -43dBc$$

$$\rightarrow L < -93\ dBc/Hz$$

Modulation	EVM(%)
QPSK1/2	-15
QPSK3/4	-18
16QAM1/2	-20.5
16QAM3/4	-24
64QAM1/2	-26
64QAM2/3	-28
64QAM3/4	-30



PN Measurement: Direct Method



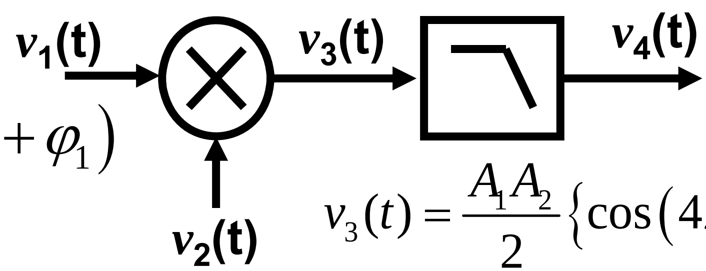
Target: PM
Noise : AM, REF

$$L(f) = S_v(f_0 \pm f)(dB) - P_c(dB)$$

- **Pass-band measurement**
  - **Need high speed & high dynamic range A/D**
- **Cannot distinguish AM vs. PM noise**
  - **Need a limiter to suppress AM**
- **Requires REF source**
  - **Phase noise floor set by REF noise (Noise floor ~ -150 dBc/Hz)**

PN Measurement: Indirect Method

- **Demodulate the carrier and then extract the phase fluctuation term at baseband**
- **Extracted baseband signal contains the spectral density of the amplitude fluctuations, $S_A(f)$ or the phase fluctuations, $S_\phi(f)$:**
  - **AM: $(\phi_1 - \phi_2) = n\pi$**
  - **PM: $(\phi_1 - \phi_2) = \pi/2 + n\pi$**



$$v_4(t) = \frac{A_1 A_2}{2}\left[\cos\left(\varphi_1 - \varphi_2\right)\right]$$

$$v_1(t) = A_1 \cos\left(2\pi f_o t + \varphi_1\right)$$

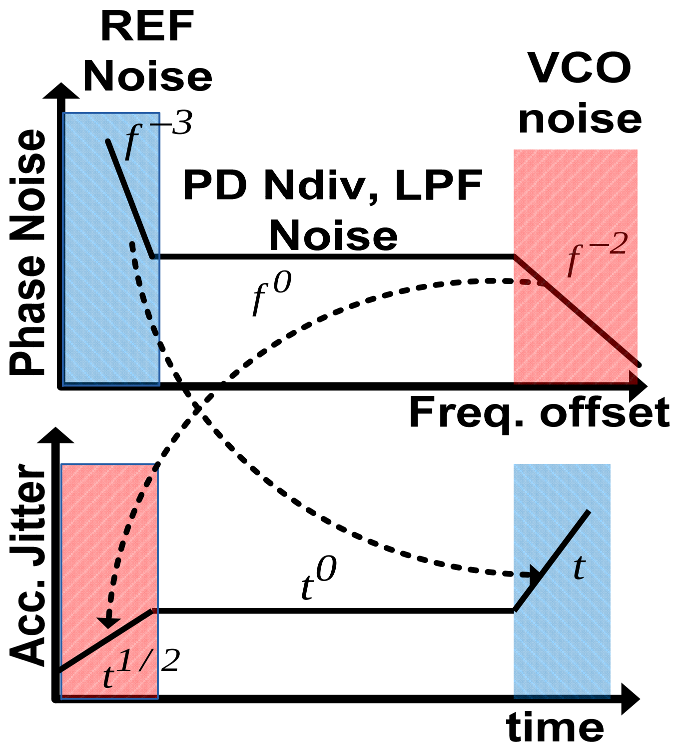
$$v_3(t) = \frac{A_1 A_2}{2}\left\{\cos\left(4\pi f_o t + \varphi_1 + \varphi_2\right) + \cos\left(\varphi_1 - \varphi_2\right)\right\}$$

$$v_2(t) = A_2 \cos\left(2\pi f_o t + \varphi_2\right)$$

Jitter Types

- Bounded, aka Deterministic Jitter (DJ)
  - Clock duty cycle distortion (DCD)
    - Transistor rise and fall time mismatch
  - Periodic (sinusoidal) jitter
    - Clock spurs
  - Data-dependent jitter (DDJ)
    - Intersymbol interference (ISI) related jitter
    - Channel induced (channel loss, crosstalk, line/load impedance mismatch, etc..)
  - Constrained to a maximum and minimum phase deviation within a given time interval
    - Measured as peak-to-peak value, J_{pp}^{D}
- Random Jitter
  - Phase noise (Thermal and 1/f noise)
  - Modeled statistically using a Gaussian distribution with a given variance; i.e. RMS phase error, J_{RMS}^{R}
    - Jitter grows unbounded as time increases

Mapping Phase Noise to Jitter



$$\Delta t_{RMS}^2 = 2\frac{T_s^2}{\pi^2}\int_0^{\infty} S_{\varphi}(f)\sin^2(\pi f \tau)df$$

$$= \frac{T_s^2}{\pi^2}\int_0^{\infty} 10^{\frac{L(f)}{10}} \sin^2(\pi f \tau)df$$

- Direct jitter measurement in time is limited by accuracy of digital scopes
  - Need ultra high speed sampling scopes (Limited BW/ cost $$)
- Alternatively, measure PN in freq. domain and convert it to acc. jitter
  - Ultra low noise and high BW phase noise measurement equipment (low $$ option)
    - Sub-ps resolution