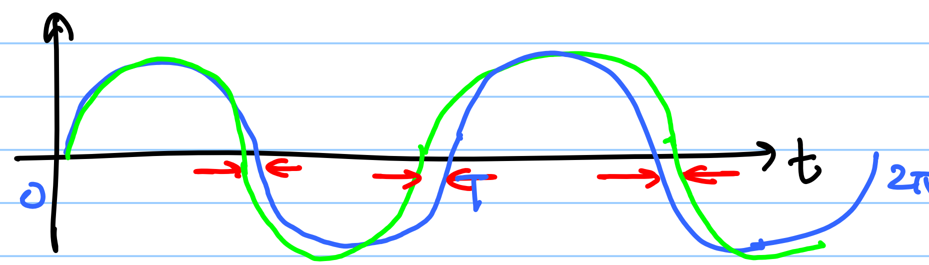
ECE 504 - Lecture 20

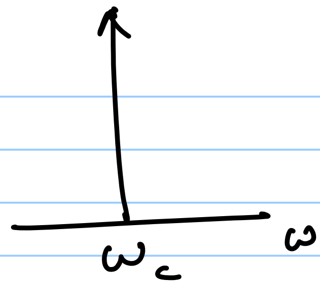
Note Title 11/1/2016

Oscillator Phase Noise :

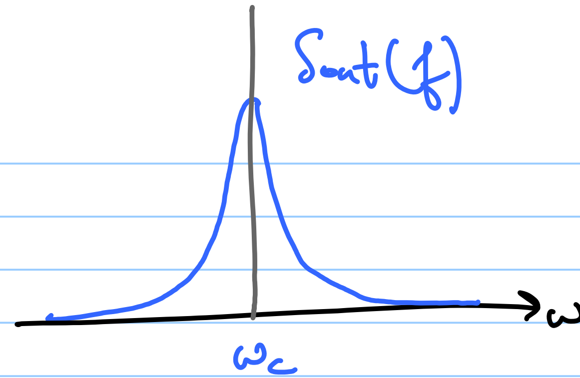
$$V_{out}(t) = A\cos(\omega_c t + \phi_n(t))$$

↳ $\phi_n(t)$ is a random phase quantity that deviates the zero crossing from the multiple of clock period.



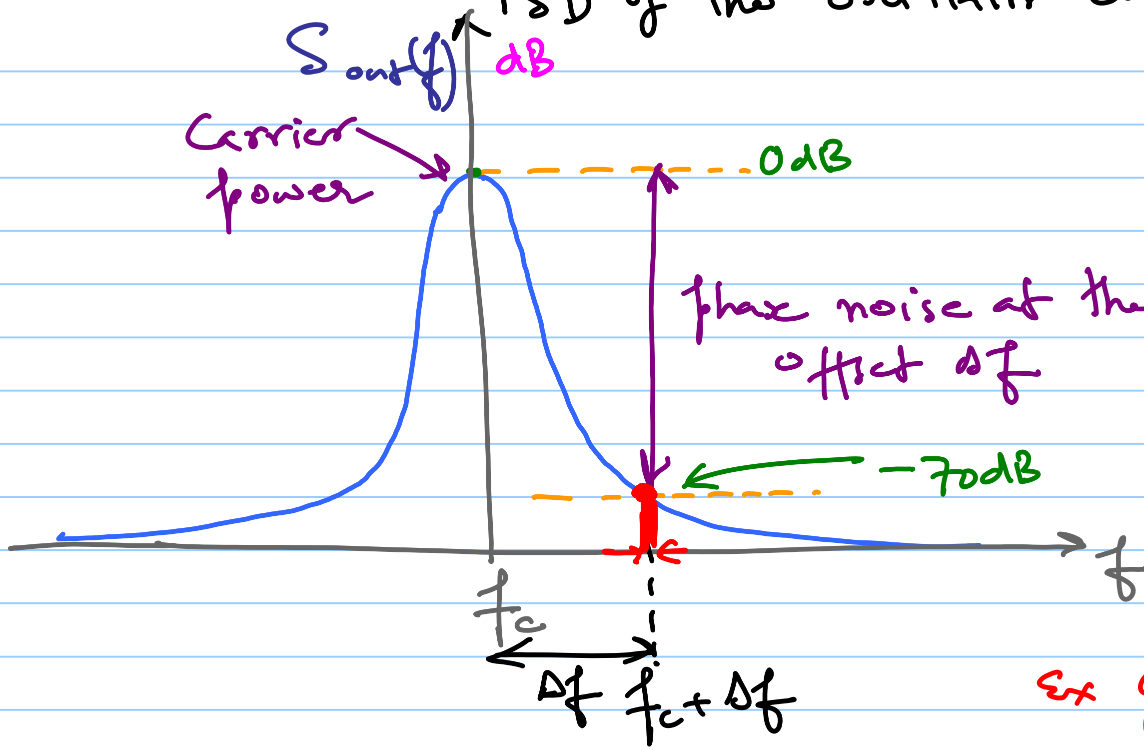


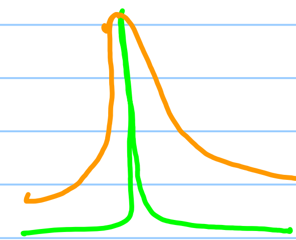
Ideal oscillator



Oscillator with phase noise

PSD of the oscillator output



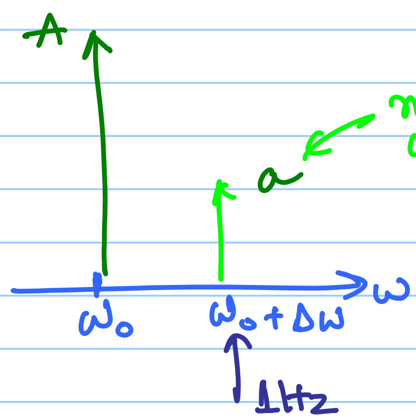


Example
phase noise is
-70 dBc/Hz at an offset $\Delta f = 1$kHz

Ex GSM:
< -115 dBc/Hz at 600 kHz offset

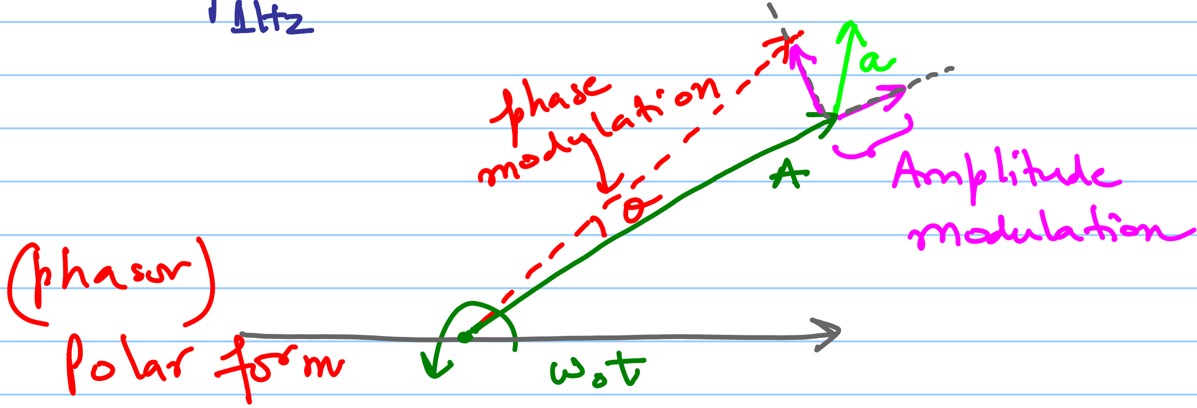
Phase Noise Overview

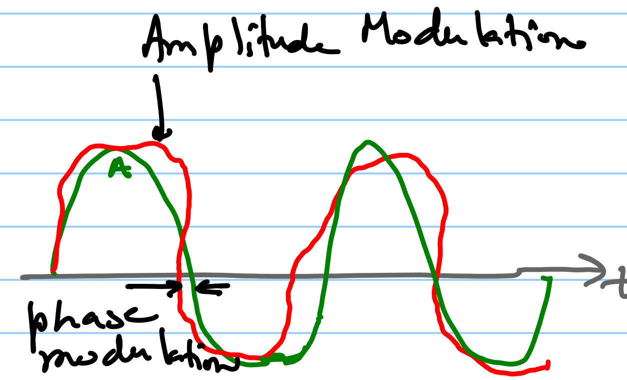
$a \ll A$



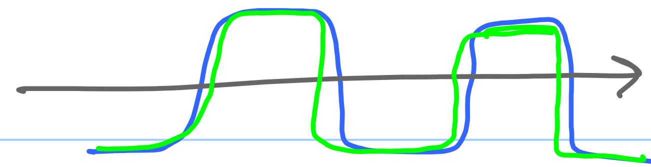
overall waveform

$$x(t) = A\cos\omega_0 t + \underbrace{a\cos((\omega_0+\Delta\omega)t)}$$





↳ Both AM & PM



↳ The composite waveform is applied to a hard limiter

↳ clips the magnitude and removes AM

↳ only phase modulation remains

After hard limiting, it can be shown that

$$x_{lim}(t) = \frac{A}{2}\cos\omega_0 t - \frac{a}{2}\cos((\omega_0+\Delta\omega)t) + \frac{a}{2}\cos((\omega_0-\Delta\omega)t)$$

$$\simeq \frac{A}{2}\cos\Big(\omega_0 t - \underbrace{\frac{2a}{A}\sin(\Delta\omega t)}_{}\Big)$$

PM component

↳ Narrowband random noise in the vicinity of ω_0 results in a a phase whose spectrum has the same shape as that of the noise, but translated by ω_0 and normalized by $\frac{A}{2}$

$$x_{lim}(t) \simeq \frac{A}{2}\cos\left(\omega_0 t - \frac{2}{A}\, a\sin(\Delta\omega t)\right)$$

$\Delta\omega$ effect

$a \cdot \cos\left(\underbrace{(\omega_0 + \Delta\omega)}\, t\right)$

In general,

narrowband noise

$$x(t) = A\cos\omega_o t + n(t)$$

$\hookrightarrow$ $n(t) = n_I(t)\cos\omega_o t - n_Q(t)\sin\omega_o t$

n_I & n_Q have the same spectrum

$\hookrightarrow$ quadrature components

$$x(t) = \left(A + n_I(t)\right)\cos\omega_o t - n_Q(t)\sin\omega_o t$$

$$= \sqrt{\left(A+n_I(t)\right)^2 + n_Q^2(t)}\cdot\cos\Big[\omega_o t + \underbrace{\tan^{-1}\frac{n_Q(t)}{A+n_I(t)}}_{\phi_n(t)}\Big].$$

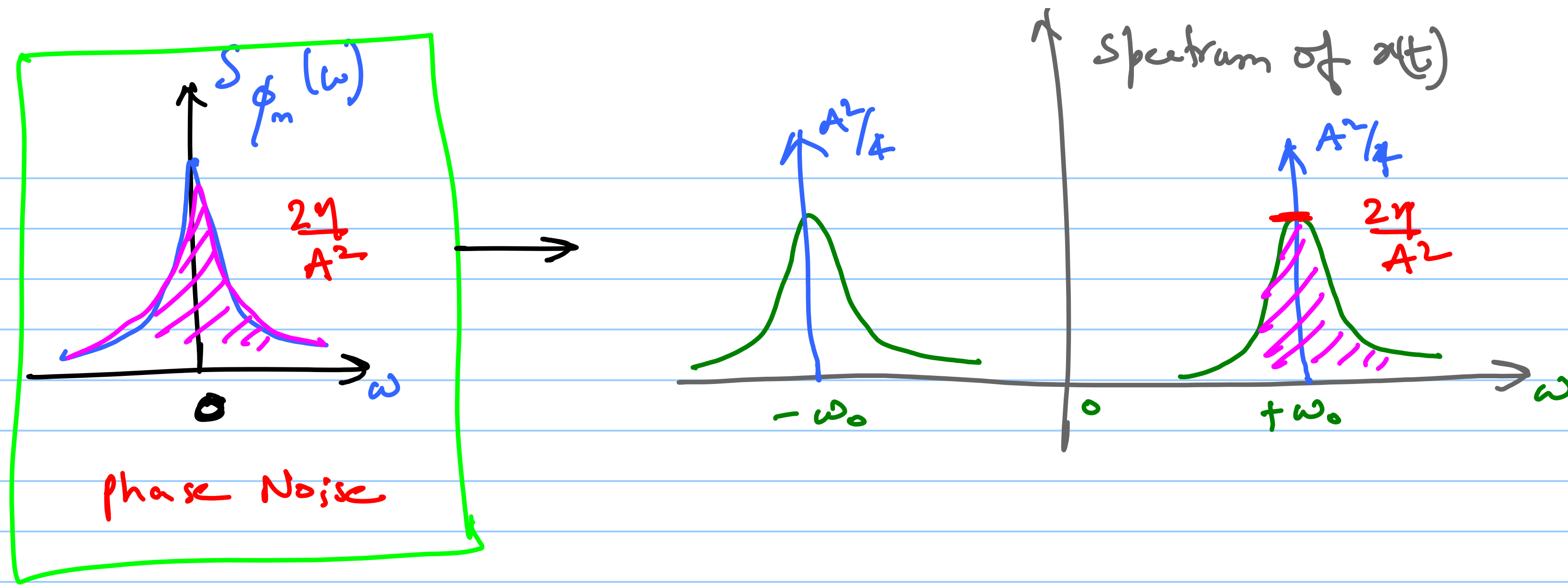
Since, $n_I(t)$, $n_Q(t) \ll A$

$$\phi_n(t) \simeq \frac{n_Q(t)}{A}$$

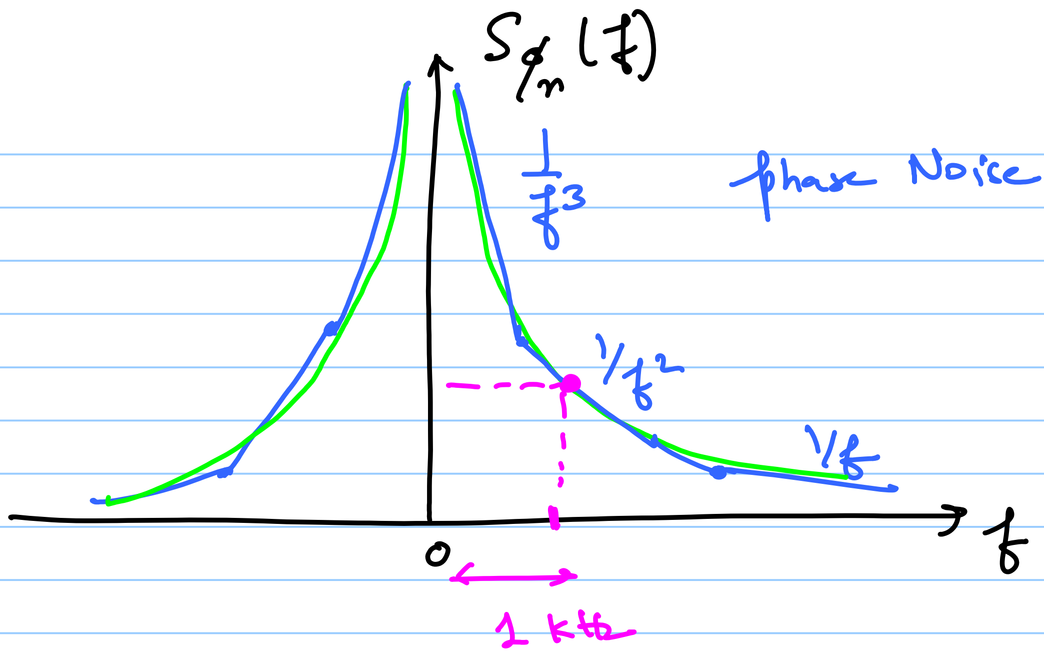
Power spectral density

$$S_{\phi_n}(\omega) = \frac{S_{n_Q}(\omega)}{A^2}$$

relate the phase noise, $\phi_n(t)$ to oscillator's noise component, $n_Q(t)$

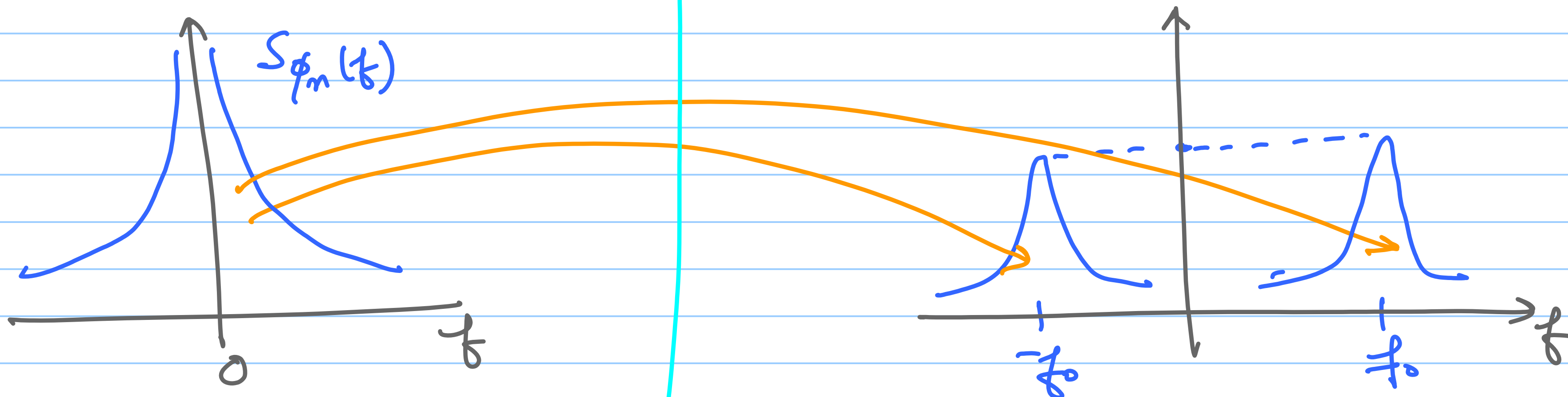


$S_{\phi_n}(\omega)$
$\frac{2\eta}{A^2}$
ω
0
Phase Noise
Spectrum of x(t)
$A^2/4$
$A^2/4$
$\frac{2\eta}{A^2}$
$-\omega_0$
0
$+\omega_0$
ω



$\phi_n(t) \rightarrow$ phase domain signal

Phase domain ($\phi_n(t)$) Voltage domain ($x(t)$)



Noise in PLLs

Noise Sources

Deterministic

Supply noise
Coupling
Substrate Noise

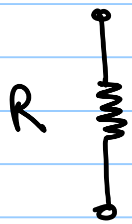
Random

→ Thermal Noise
→ Flicker Noise

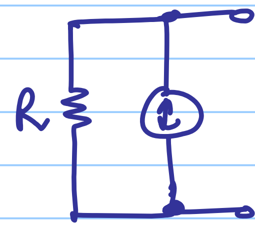
↳ Reference feedthrough

Thermal Noise

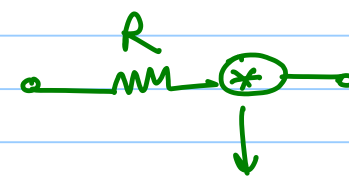
mean square value
↳ power in 1Hz BW



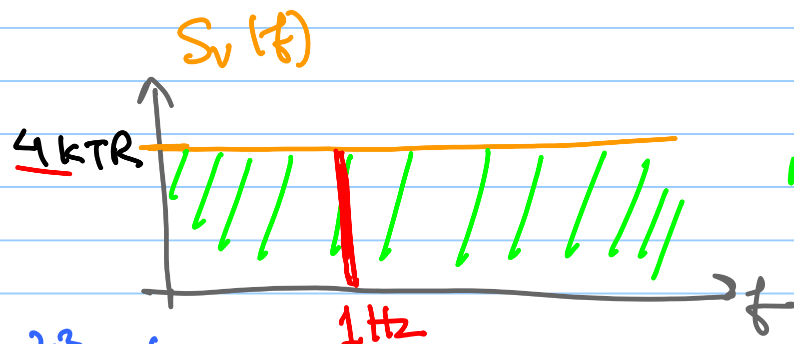
$\Rightarrow$



$$\overline{I_n^2} = \frac{4kT}{R} \triangleq$$



$$\overline{V_n^2} = 4kTR$$

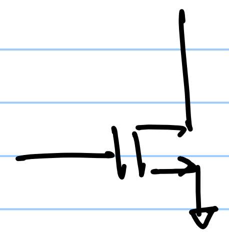


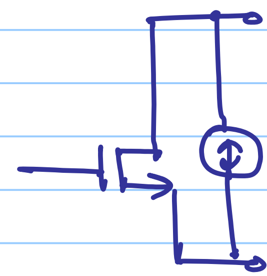
$$\overline{V_n^2} = 4kTR$$

Boltzmann's constant

$$k = 1.38 \times 10^{-23}\ J/K$$

Transistor in Saturation

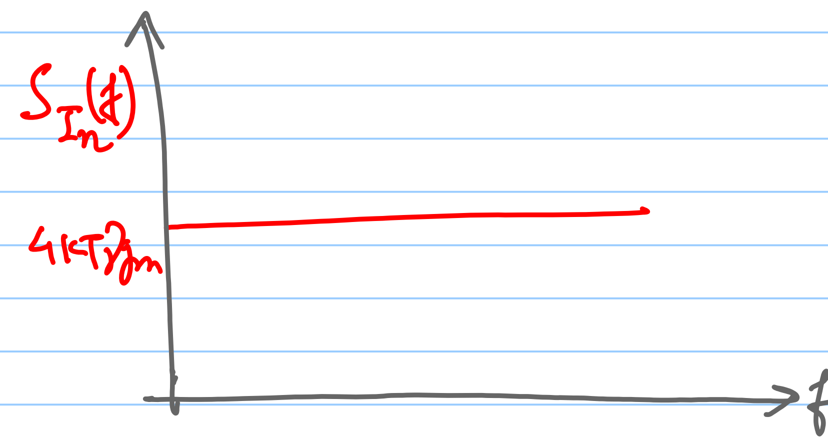


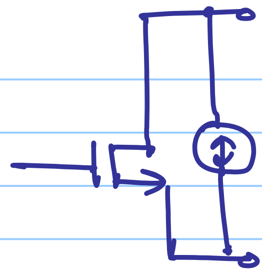


$$\overline{I_n^2} = 4kT\gamma g_m$$

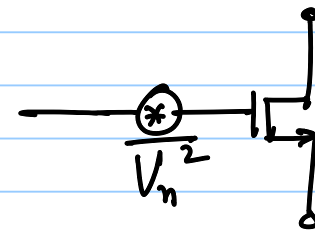
$\gamma = 2/3$ for long channel

$L \geq 10\mu m$



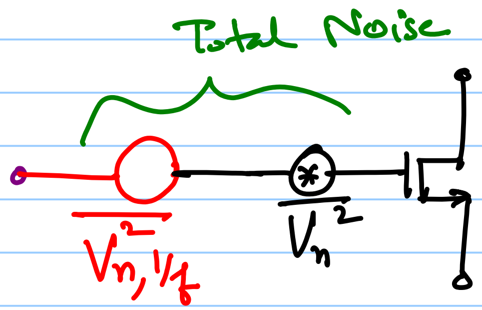


$\overline{I_n^2} = 4kT\gamma g_m$ $\equiv$



$$\overline{V_n^2} = \frac{4kT\gamma}{g_m}$$

Flicker Noise



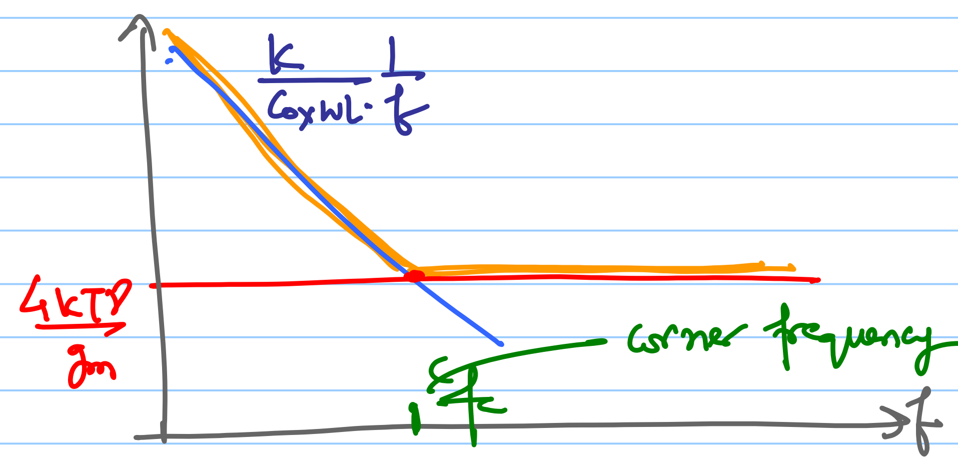
$$\overline{V_n^2} = \frac{4kT\gamma}{g_m}$$

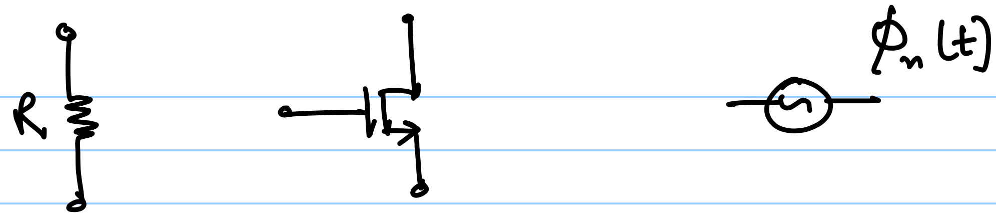
process constant

$$S_{n,1/f} = \frac{K}{C_{ox}WL} \cdot \frac{1}{f}$$

$\overline{V_{n,1/f}^2} \rightarrow$ frequency dependent noise

$$S_{n,1/f} \propto \frac{1}{f}$$





Generic Noise Analysis:

* small signal analysis with several noise sources

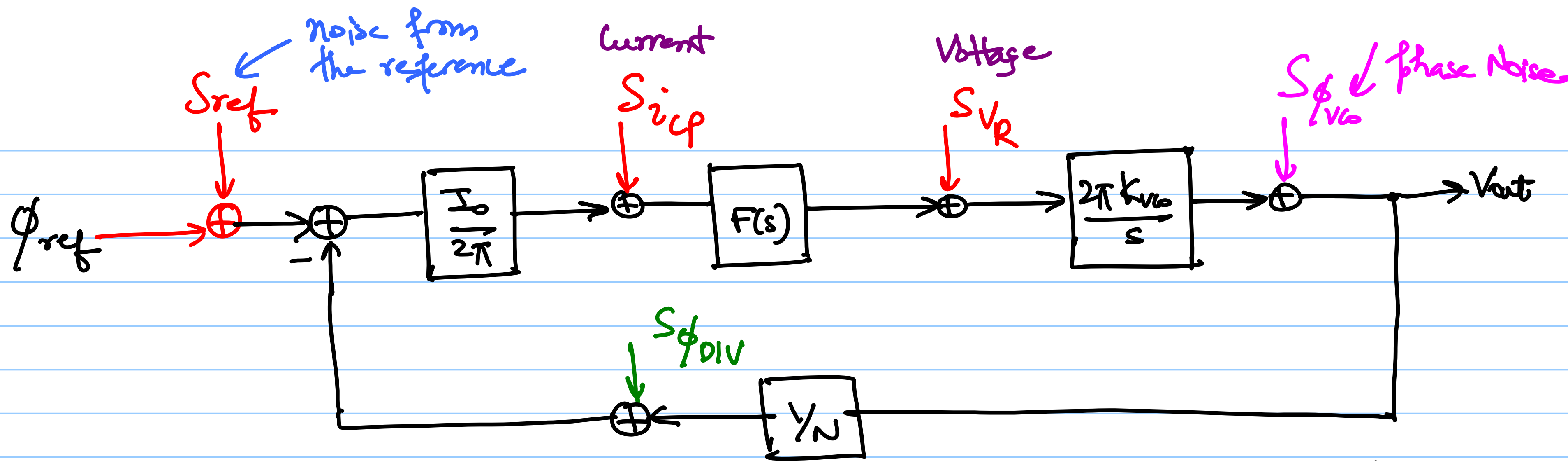
Procedure:

1. Indentify all noise sources
2. Calculate (estimate from simulations) PSD of each noise source $S_i(f)$

④ Evaluate transfer function from each of noise sources to the output, $H_i(f)$

↳ output noise contribution $|H_i(f)|^2 \cdot S_i(f)$

⑤ Sum all the contributions to obtain total output noise $= \sum_i |H_i(f)|^2 \times S_i(f)$



PSD ⇒ power spectral density

$S_{\phi ref}$: Reference clock noise PSD

$S_{i_{cp}}$: PFD | CP noise PSD

S_{v_R} : Loop filter resistor noise PSD

$S_{\phi_{VCO}}$: VCO Phase Noise PSD

$S_{\phi_{DIV}}$: Divider Noise PSD

Noise Transfer Functions : $\left(H_i(f)\right)$

Loop gain $\Rightarrow$ $L(s) = \dfrac{I_0}{\cancel{2\pi}} \cdot F(s) \cdot \dfrac{\cancel{2\pi} K_{VCO}}{S \cdot N} = \dfrac{I_0 K_{VCO}}{N} \cdot \dfrac{F(s)}{s}$

$NTF_{ref}(s) = \dfrac{\phi_{out}}{\phi_{ref}}(s) = \dfrac{N \cdot L(s)}{1 + L(s)}$ LPF