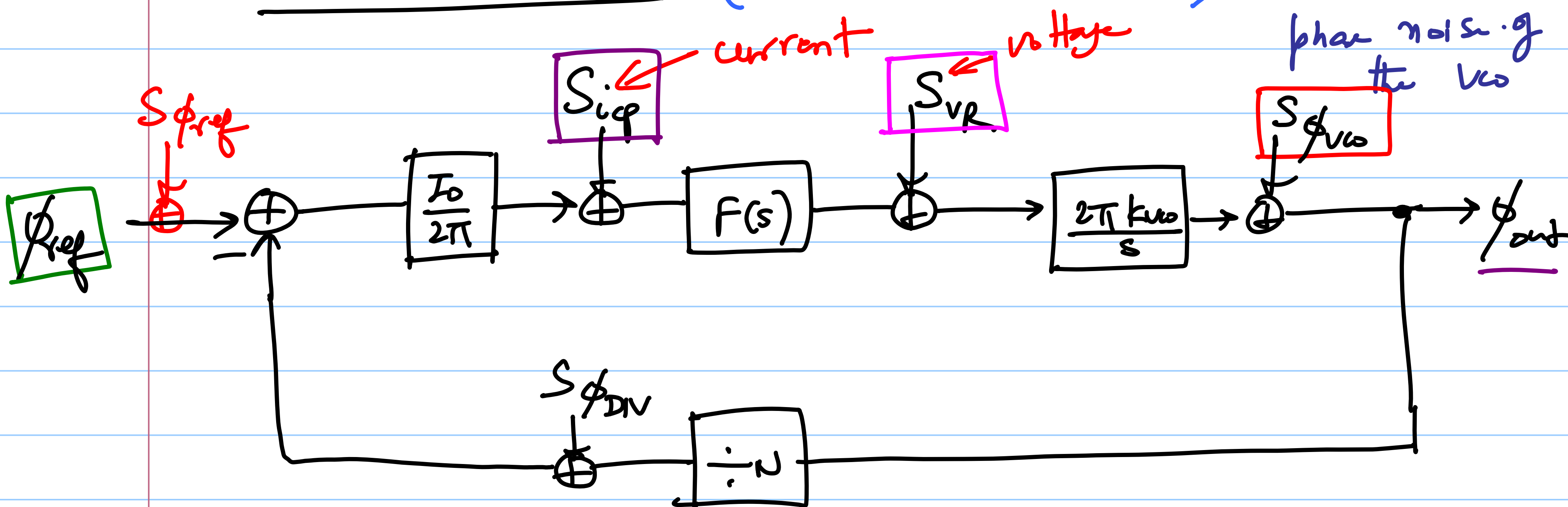
ECE 518- lecture 20

Note Title 3/31/2015

Noise in PLL (Phase domain Model)



$S_{\phi_{ref}}$ = Reference clock PSD

$S_{i_{cp}}$ = PFD/CP noise PSD

$S_{v_R} \Rightarrow$ loop filter resistor noise PSD

$S_{\phi_{VCO}} \Rightarrow$ VCO phase noise PSD

$S_{\phi_{div}} \Rightarrow$ Divider noise PSD

Noise Transfer functions (NTF)

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

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

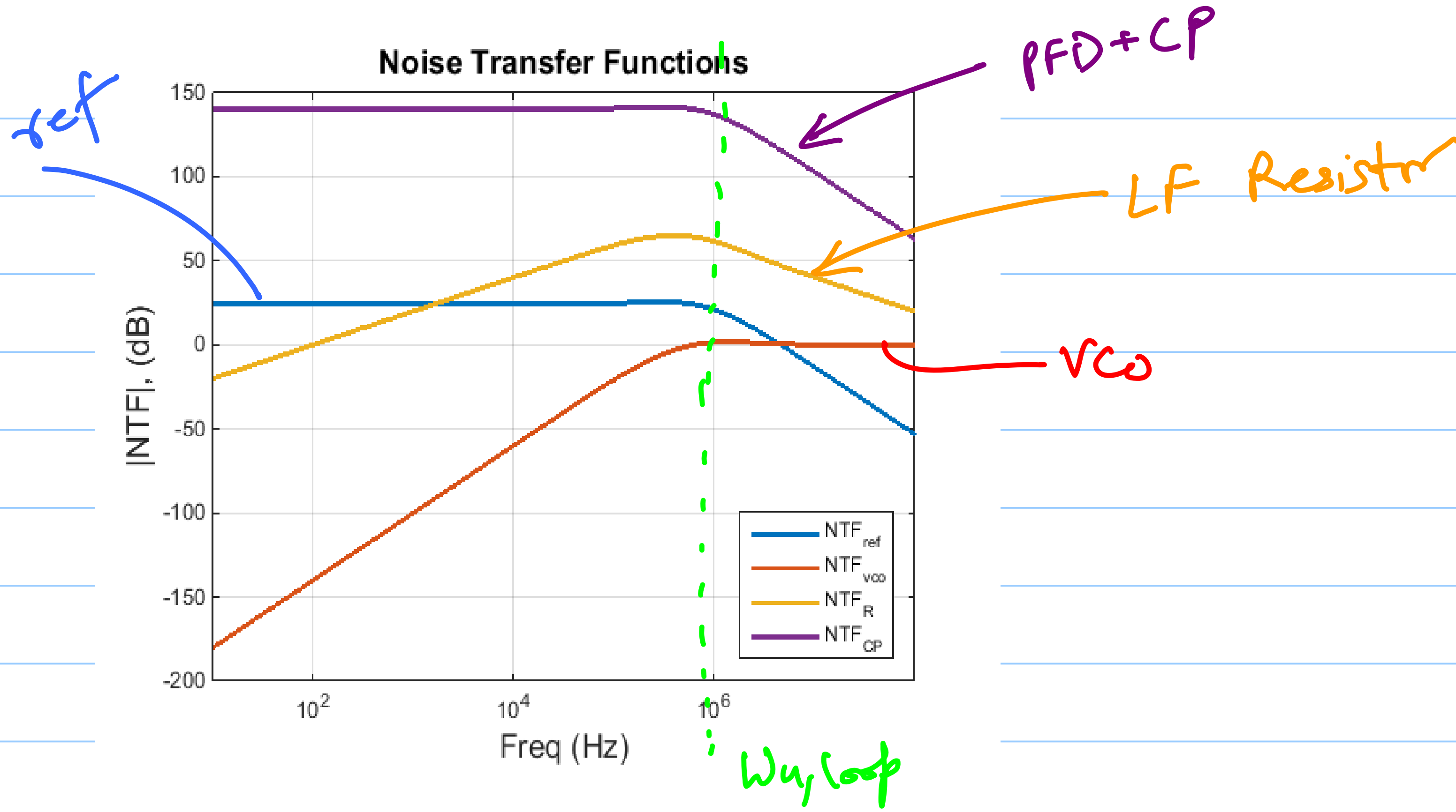
$NTF_{DIV}(s) = NTF_{ref}(s) \leftarrow$ same entry point as ϕ_{ref}

LPF

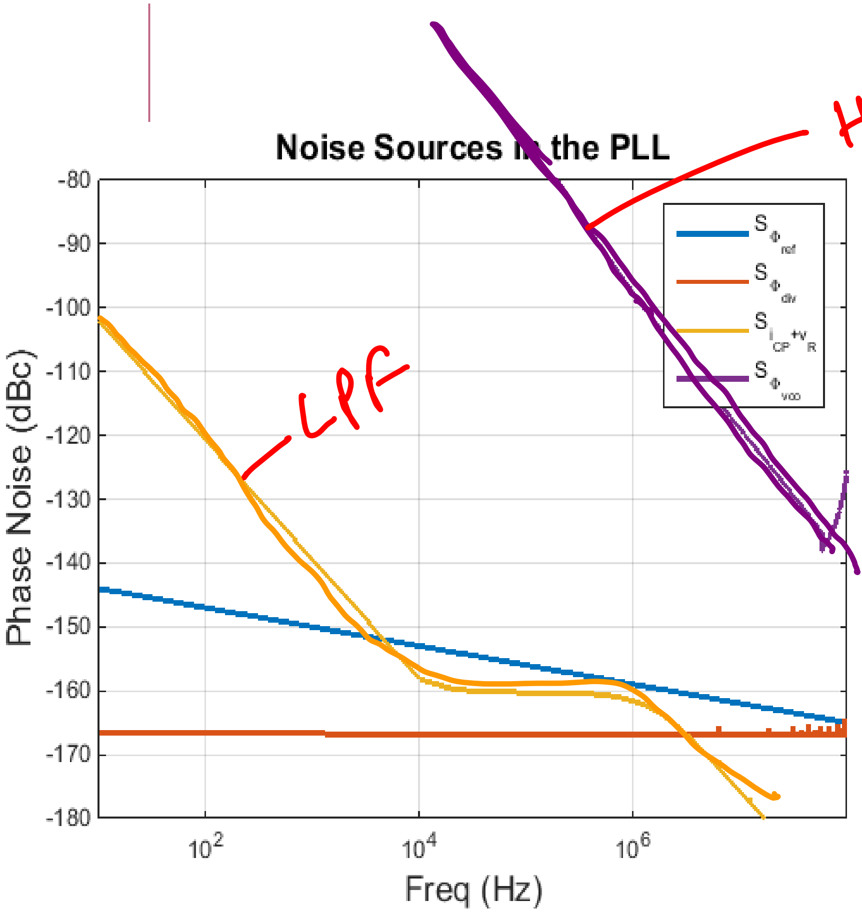
$$NTF_{cp}(s) = \frac{\phi_{out}}{i_{cp}}(s) = \frac{NTF_{ref}(s)}{I_{cp}/2\pi}$$ LPF

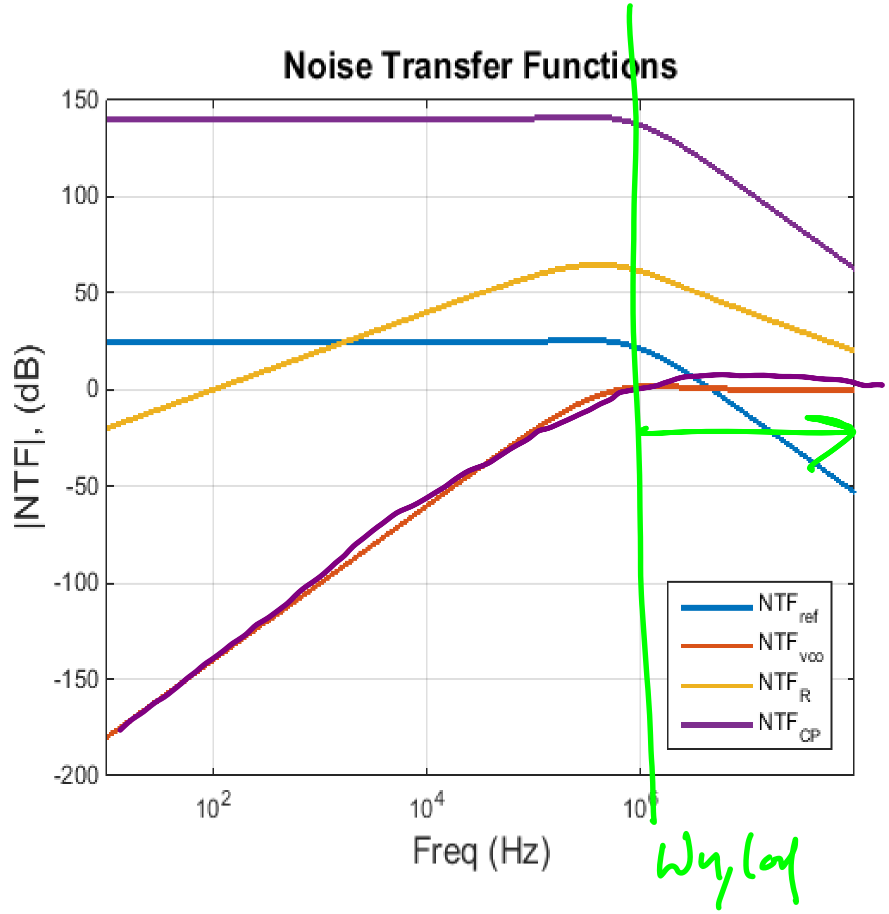
$$NTF_{R}(s) = \frac{\phi_{out}(s)}{v_{R}(s)} = \frac{\frac{2\pi K_{vco}}{s}}{1 + L(s)}$$ BPF

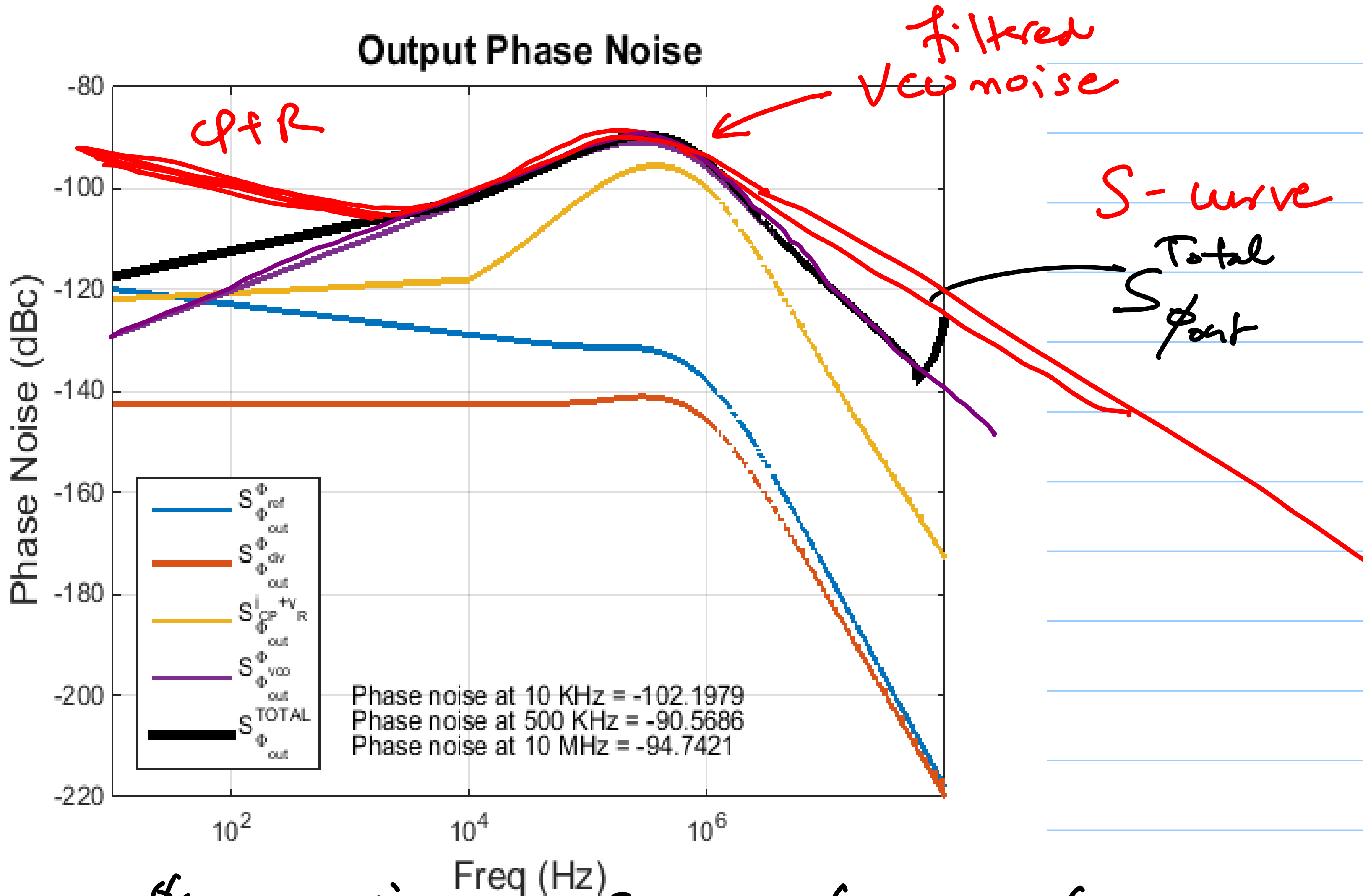
$$NTF_{vco}(s) = \frac{\phi_{out}}{\phi_{vco}}(s) = \frac{1}{1 + L(s)}$$ HPF



Noise Transfer Functions
150
100
50
0
-50
-100
-150
-200
|NTF|, (dB)
10^2
10^4
10^6
Freq (Hz)
NTF_{ref}
NTF_{vco}
NTF_R
NTF_{CP}
ref
PFD+CP
LF Resistr
VCO
Wu,loop


Noise Sources in the PLL
Phase Noise (dBc)
Freq (Hz)
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
10^2
10^4
10^6
S_Φref
S_Φdiv
S_iCP+vR
S_Φvco
LPF
HPF


Noise Transfer Functions
|NTF|, (dB)
Freq (Hz)
150
100
50
0
-50
-100
-150
-200
10^2
10^4
10^6
NTF_ref
NTF_vco
NTF_R
NTF_CP
ωu,lo



$$S_{\phi_{out}}^{Total} = S_{\phi_{out}}^{\phi_{ref}} + S_{\phi_{out}}^{i_{cp}} + S_{\phi_{out}}^{v_R} + S_{\phi_{out}}^{\phi_{vco}} + S_{\phi_{out}}^{\phi_{div}}$$

Total Phase Noise (power) $= \sigma_{\Delta\phi}^2 = \int_0^\infty S_{\phi_{out}}^{Total}(f)\,df$ (radians)^2

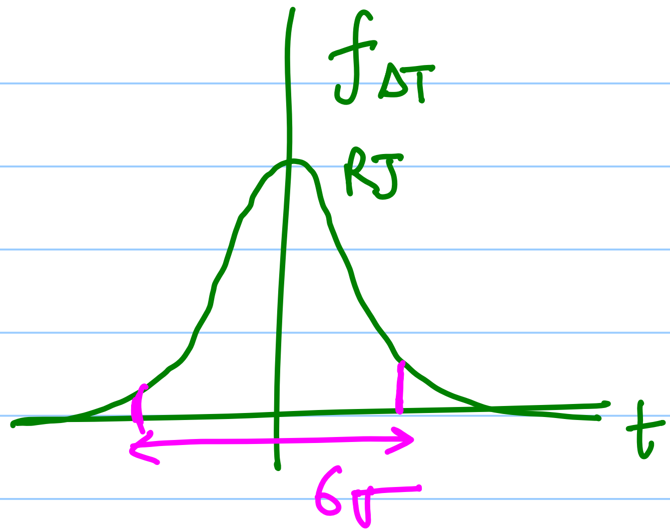
$$\sigma_{\Delta\phi} = \sqrt{\int_0^\infty S_{out}^{Total}(f)\,df} \cdot \frac{360^\circ}{2\pi} \quad \text{[degrees]}$$

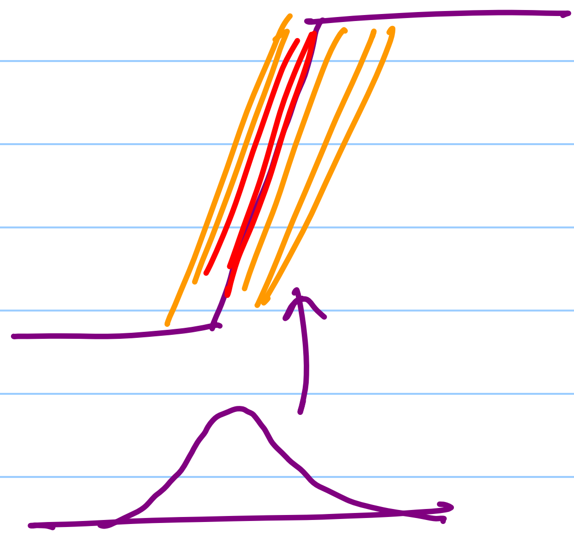
$$\sigma_{\Delta T} = \sqrt{\int_0^\infty S_{out}^{Total}(f)\,df} \cdot \frac{T_{vco}}{2\pi} \quad \text{(sec)}$$

↳ Evaluated using trapz function in MATLAB

$\Rightarrow$ $\sigma_{\Delta T} \sim 2$ ps rms | RJ : random jitter

DJ : deterministic jitter

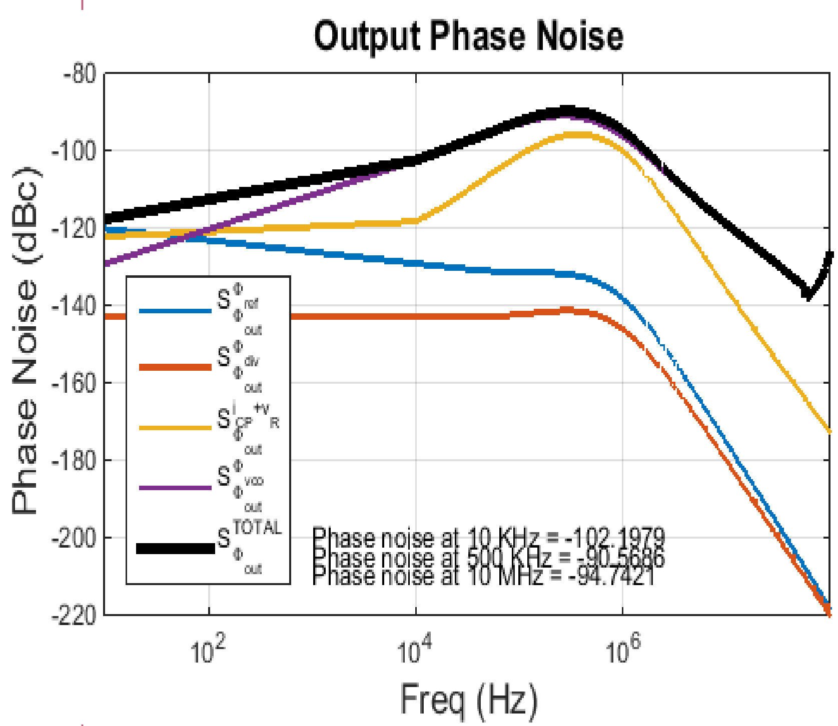




Large $\omega_{n,loop}$ $\Rightarrow$ VCO phase noise $\downarrow$

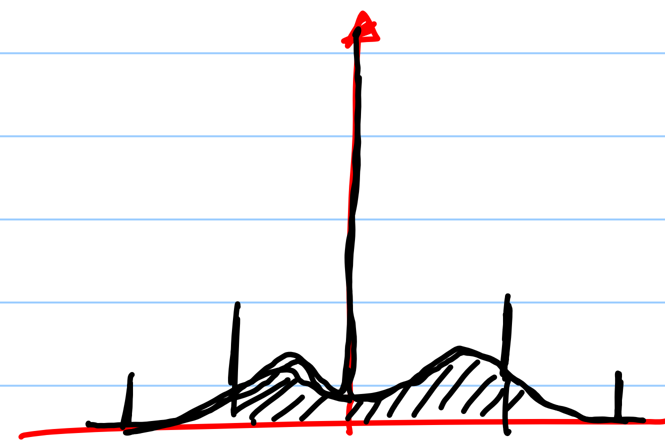
CP+R noise $\uparrow$

faster settling



PLL 1 GHz

Spectrum Analyzer



1 GHz

$$S_{v_R}(f) = 4kTR \,, \qquad S_{i_{cp}}(f) \propto I_{cp}$$

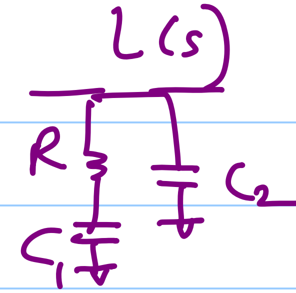
$$R \downarrow \;\Rightarrow\; C_1 \uparrow$$ large Area

$$\omega_z = \frac{1}{RC_1}$$

$$S_{v_R} \simeq 4kTR \Rightarrow S_{\phi_{out}}^{v_R} \propto K_{vco}^2 \cdot R$$

$\Rightarrow$ noise from R is increased by $\boxed{K_{vco}^2}$

Drawbacks of a Large VCO gain



$$LG(s) = \frac{K_{VCO} I_{cp}}{2\pi} \cdot \frac{s + \frac{1}{RC_1}}{s^2 C_2 \left(s + \frac{1}{R C_1 \| C_2}\right)}$$

increase $K_{VCO} \Rightarrow I_{cp} \downarrow$ for the same loop dynamics

But low $I_{cp} \Rightarrow g_m \downarrow$

$$S_{i_{cp}} \propto \frac{8}{3} KT g_m$$ ✓

noise drops

$$\boxed{S_{\phi_{out}}^{v_R} \propto K_{VCO}^2}$$

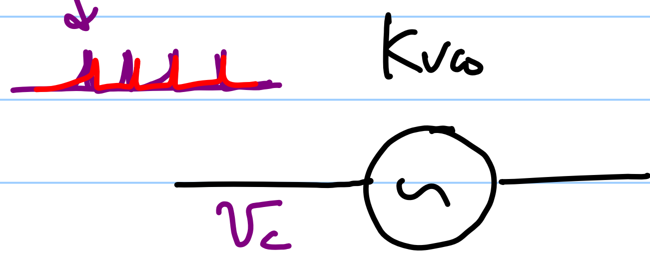
const

$$\omega_{UGloop} \cong \frac{K_{VCO} \cdot I_{CP}}{2\pi} \cdot \frac{1}{C_1 + C_2}$$

$K_{VCO} \uparrow \Rightarrow C_1 \uparrow$ for I_{CP} const.

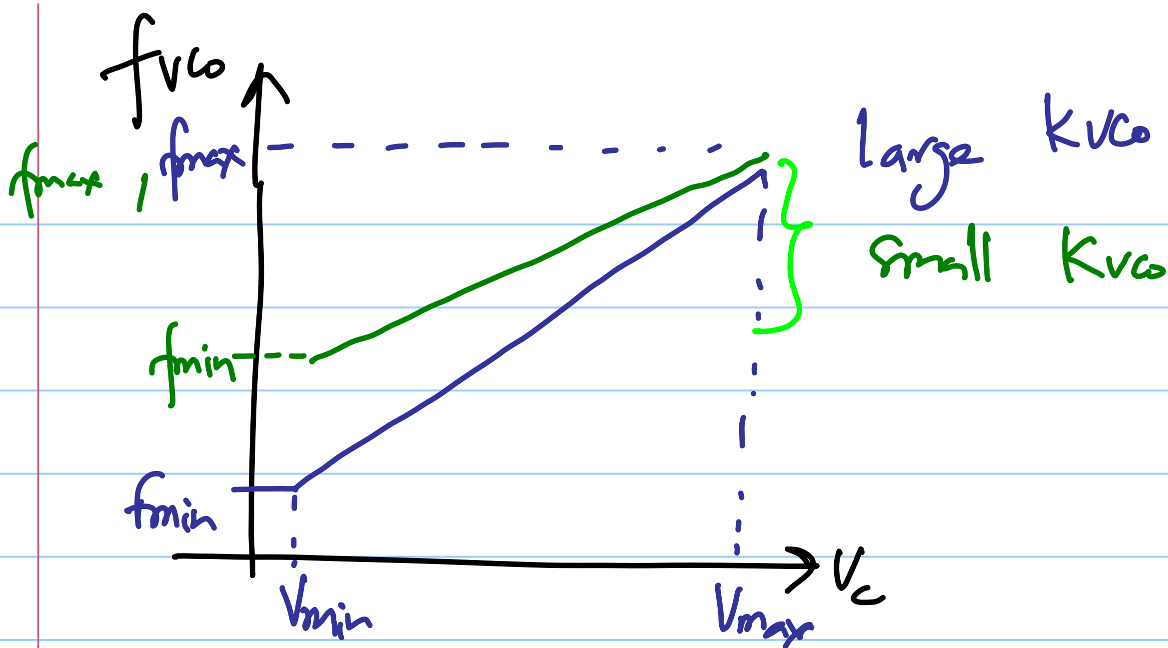
$\Rightarrow$ Large Area

V_c due to disturbance in cp mismatch



More reference feedthrough

$\Rightarrow$ more spurs in the output.



Smaller Kvco

(−) Reduced VCO operating range

+ Better noise performance (LF noise)

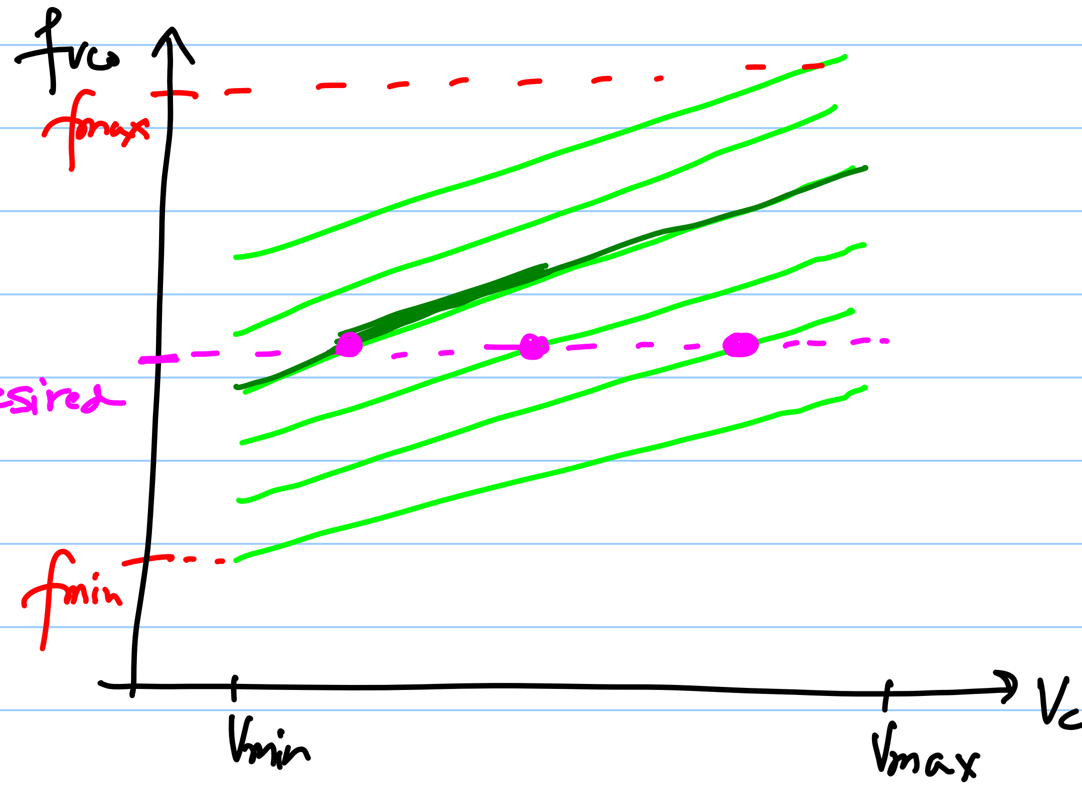
+ Smaller C_1

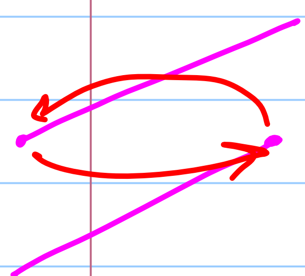
+ Better spur performance

Increasing operating Range with lower Kvco

* Generate multiple low-gain Vco transfer curves

* pick a suitable operating curve

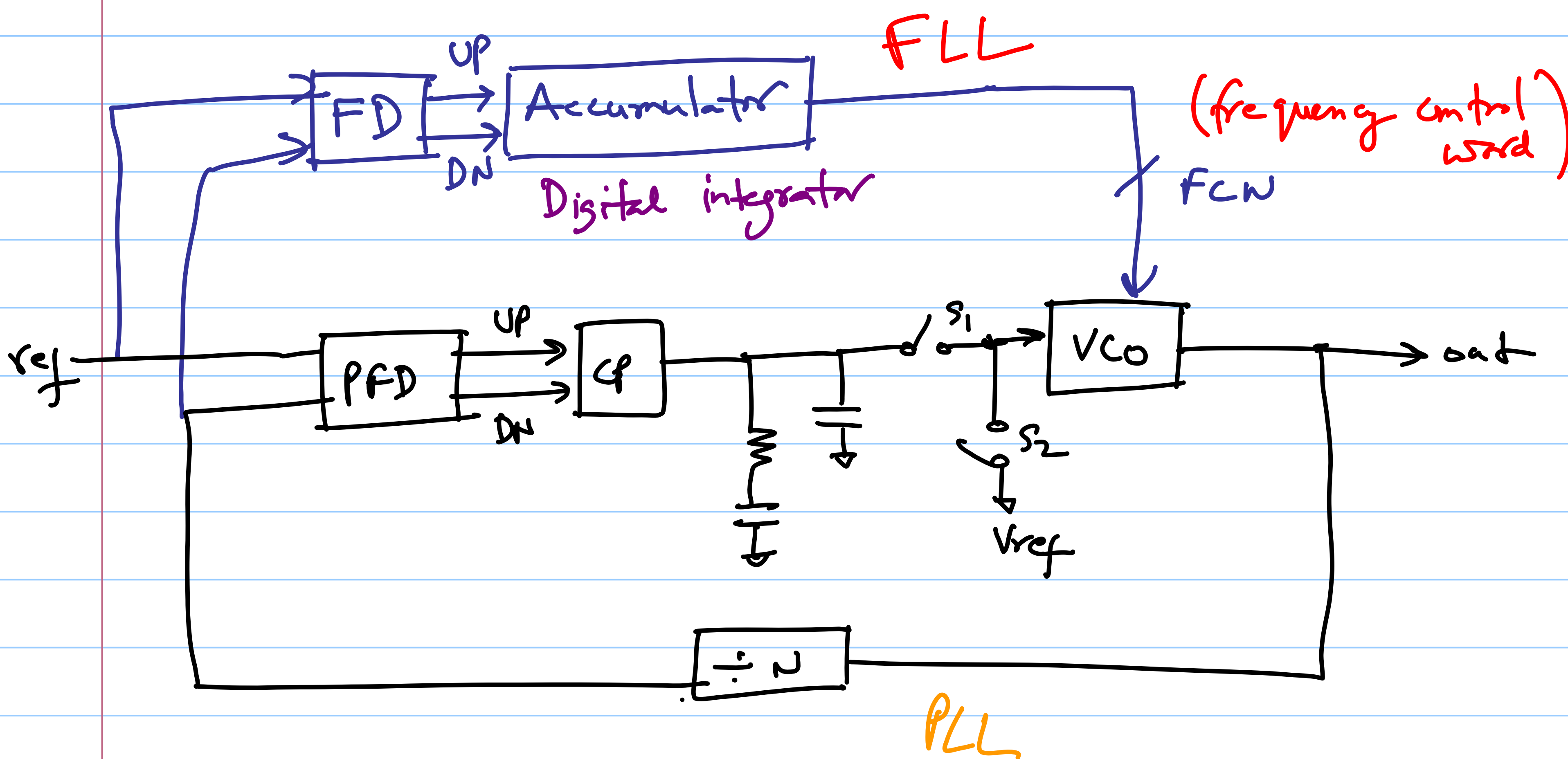




fine tuning $\longrightarrow$ V_c

Coarse tuning to select b/w these curves

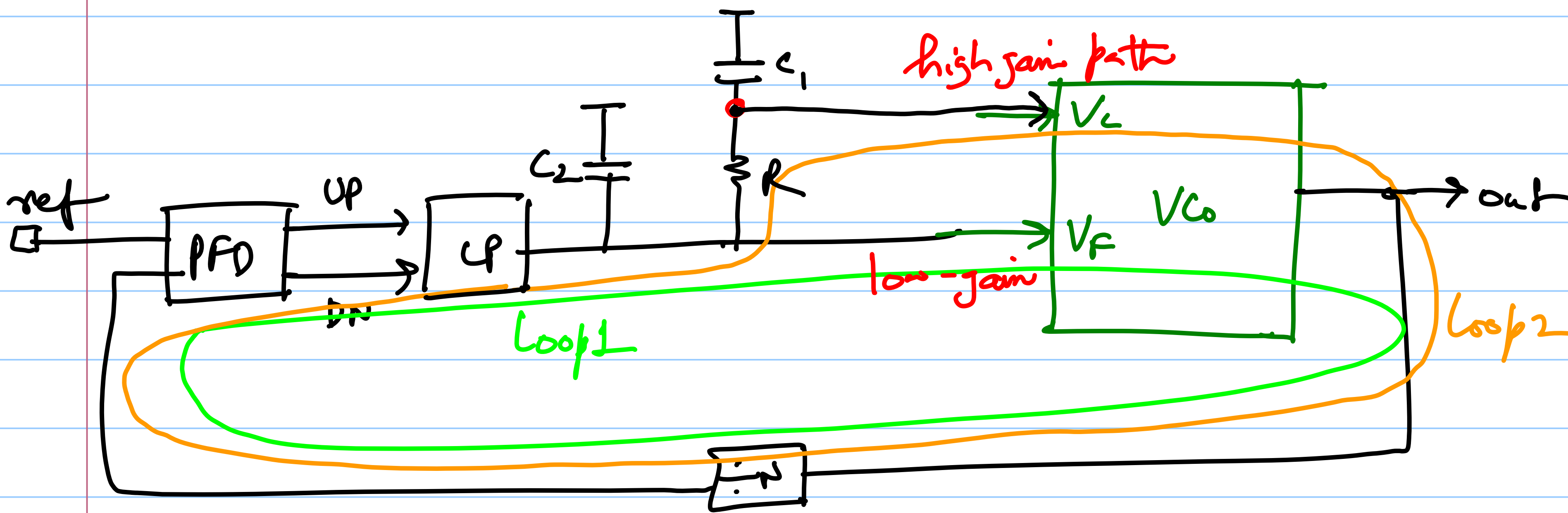
Split-tuned PLL (with Digital Tuning)



(−) limited tuning range due to frozen frequency control word

(−) susceptible to PVT variations

Split tuned with continuous tuning



* VCO controlled using two voltages

  high-gain V_C : Coarse control ← works similar to FLL

  low-gain V_F : fine control

* Two coupled feedback loops

↳ potential instability