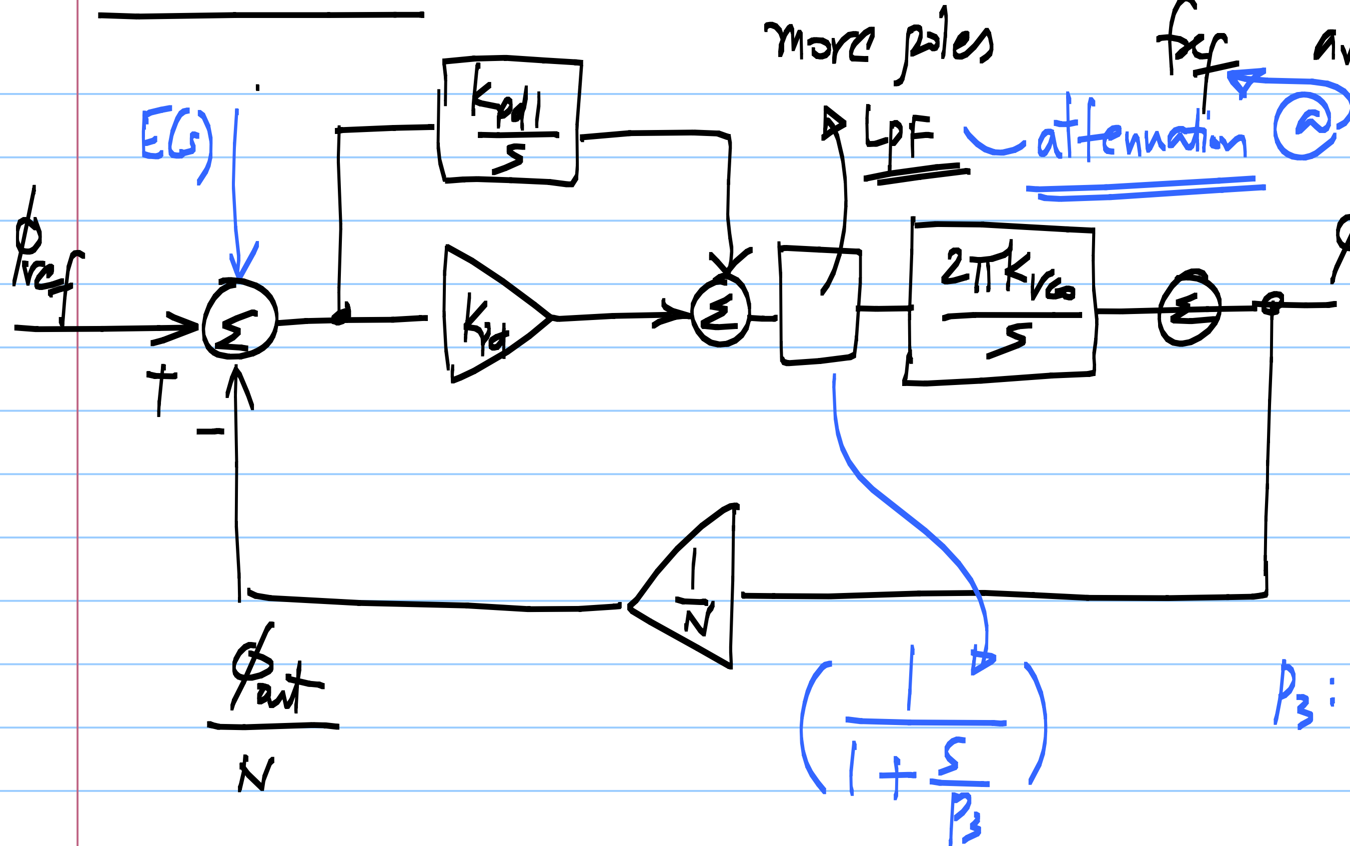
Lecture 50:

$e(t)$: Contains components at f_{ref} and its harmonics well beyond the unity loop gain frequency

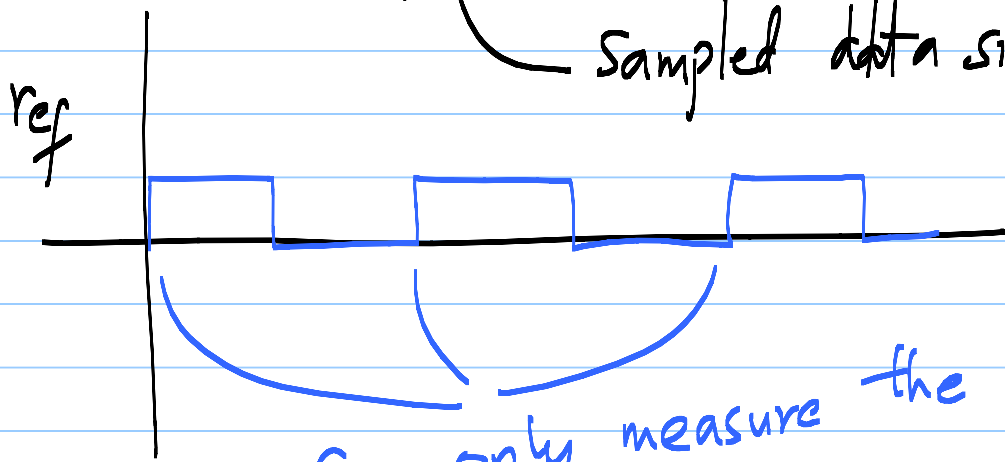


$p_3: \gg \omega_{u,loop}$.

Phase:

$\phi_{ref}(t)$: continuous-time

— sampled data signal – sampled at f_{ref}

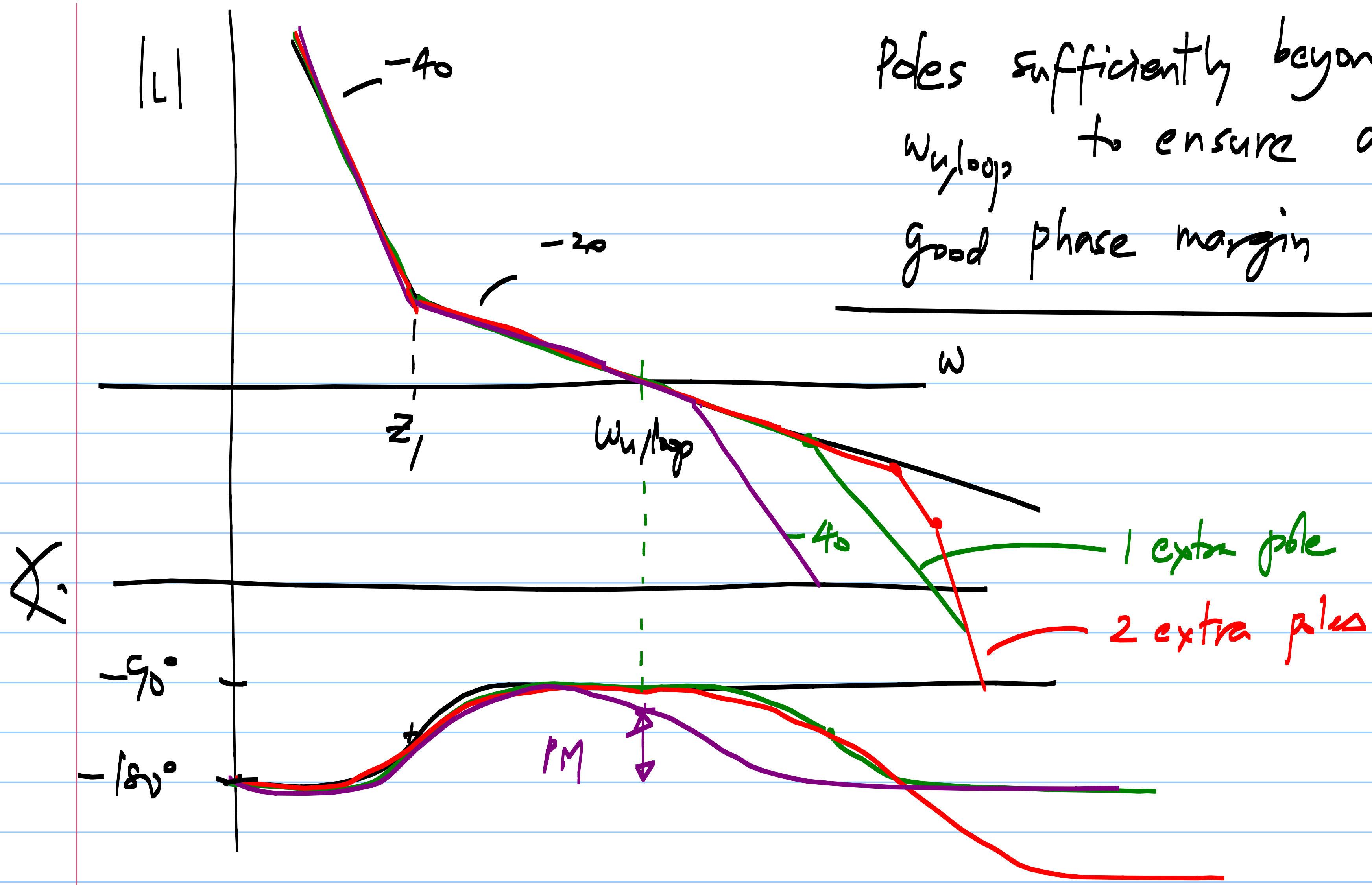


Can only measure the phase at the zero crossings

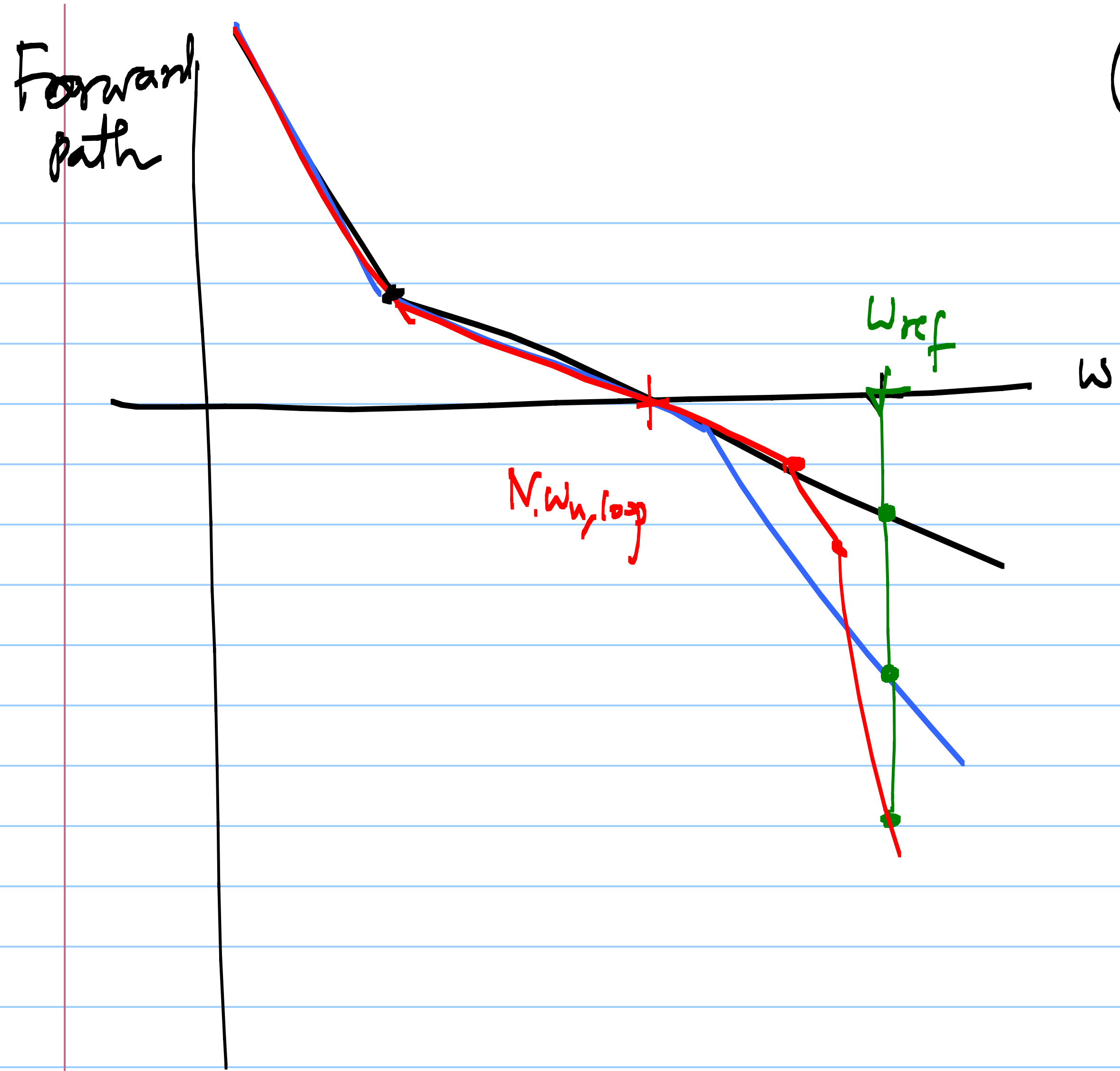
Continuous-time approximation valid if

$$f_{ref} \gg \frac{\omega_{u,loop}}{2\pi}$$

Poles sufficiently beyond $\omega_{u,loop}$ to ensure a good phase margin

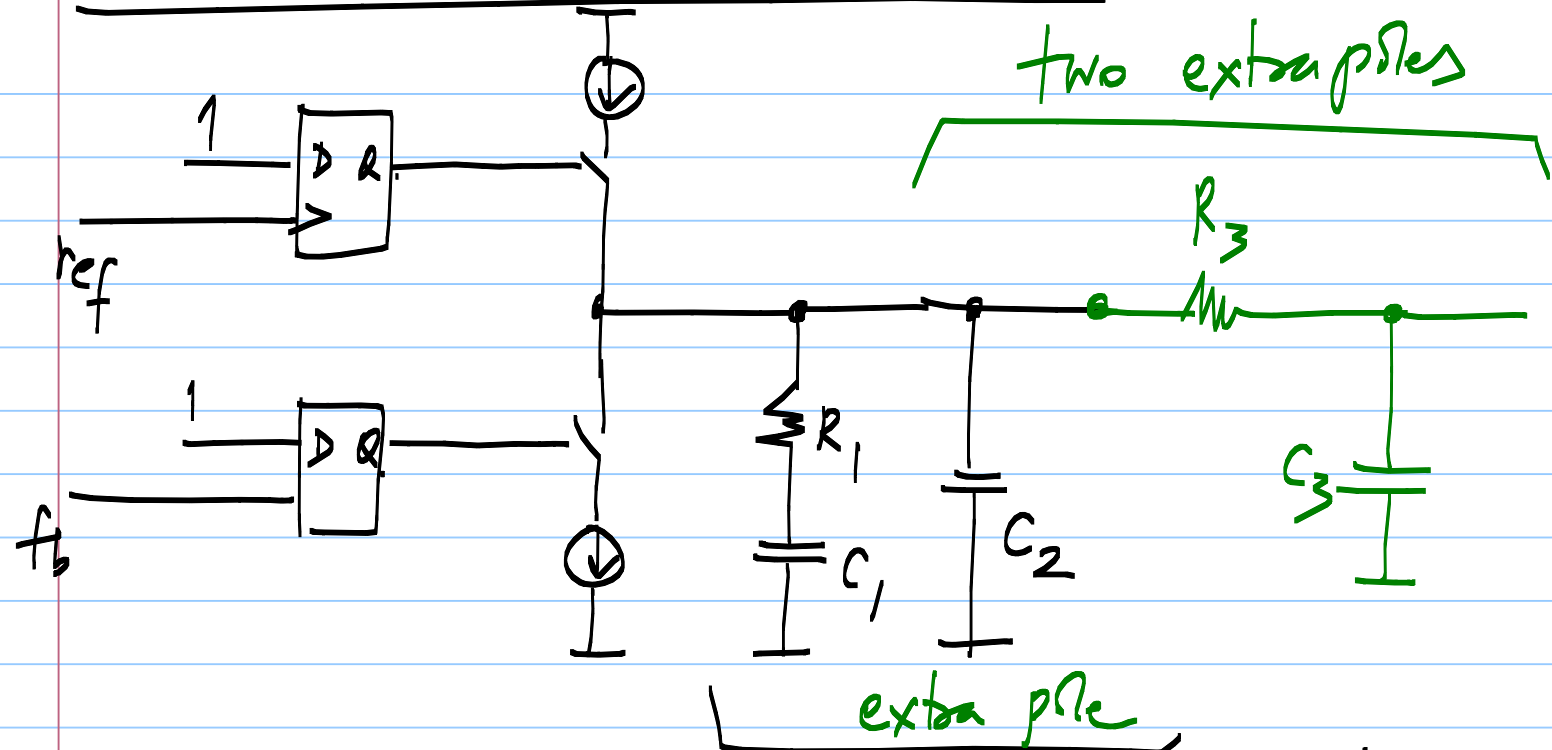


$$\left(K_{pd} + \frac{K_{pd,1}}{s}\right) \cdot \frac{2\pi K_{vco}}{s} \frac{1}{\left(1+\frac{s}{p_3}\right)}$$



Poles have to be below the reference frequency in order to attenuate feedthrough components.

Type II PLL w/ charge pump:

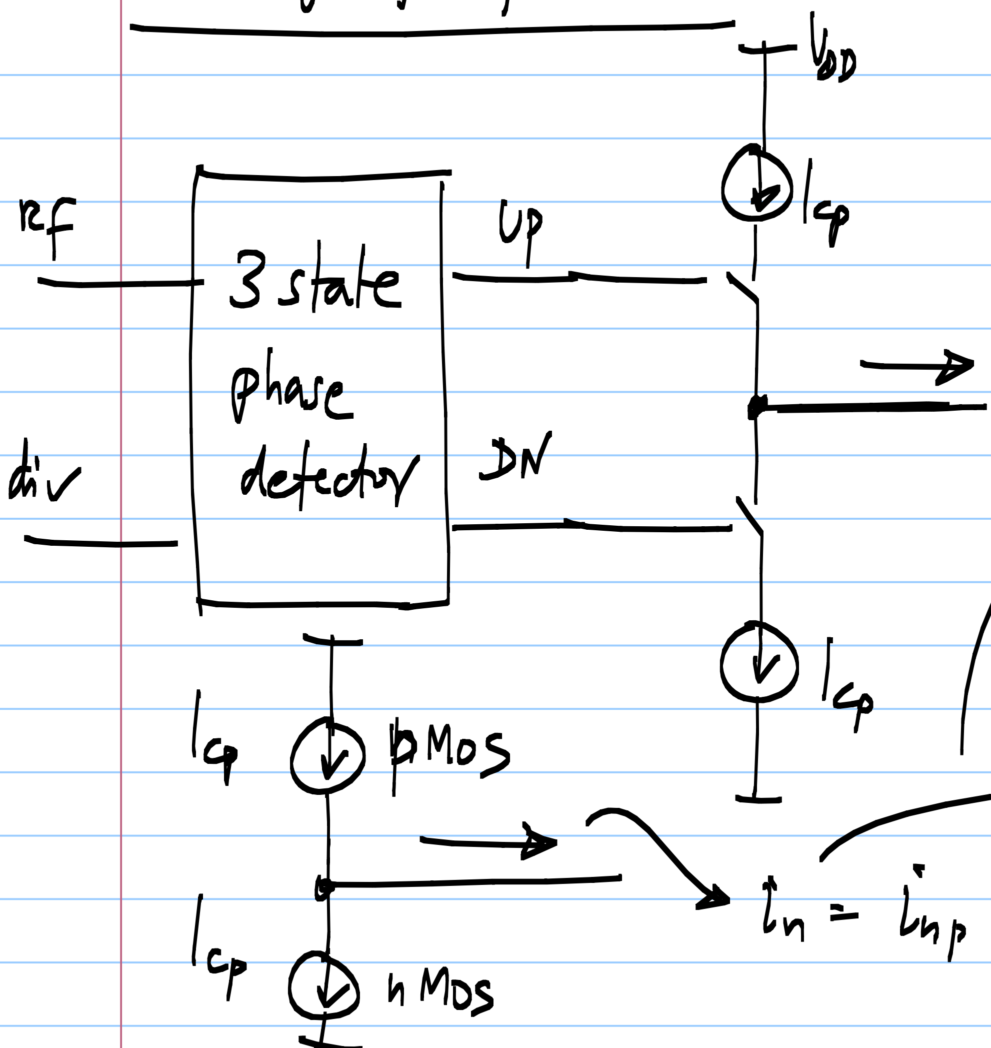


1 extra pole: add C_2. pole @ $\dfrac{1}{R_1\left(\frac{C_1 C_2}{C_1+C_2}\right)}$ rad/s

Random noise in a PLL:

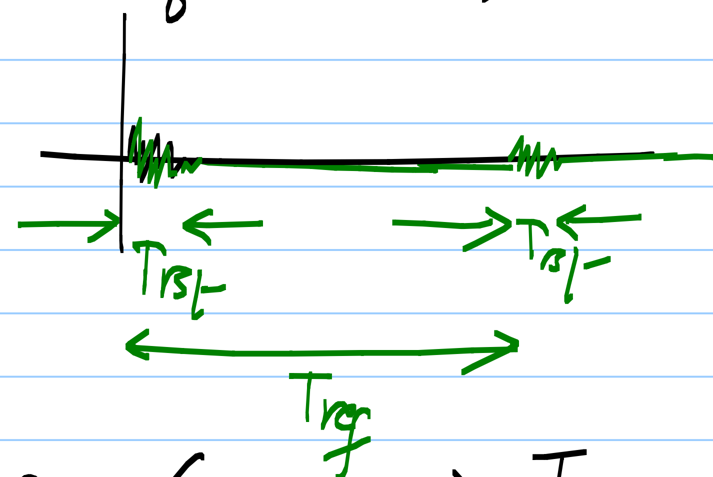
* Reference oscillator: phase noise (ϕ_{ref})
* VCO : phase noise (ϕ_{VCO})
* Charge pump noise (current source noise)
* Loop filter noise (e.g. resistor)

Charge pump noise:



$i_n = i_{n,p} + i_{n,n}$

* UP, DN: on for a duration of T_{rst} (reset time of the PD)



$$S_n = \left(S_{inp} + S_{inn}\right) \cdot \frac{T_{rst}}{T_{ref}}$$

$$\frac{\phi_{out}}{\phi_{ref}} = N \cdot \frac{1 + s/z_1}{1 + \frac{s}{z_1} + \frac{s^2}{\omega_{n,loop} \cdot z_1}} = \frac{\phi_{out}}{\phi_{n,cp}}$$

$\phi_{n,cp}$ → input ref. noise of the charge pump

$$S_{in} = (S_{inp} + S_{inn}) \cdot \frac{T_{rst}}{T_{ref}}$$

$$S_{\phi n,cp} = \frac{S_{in}}{(I_{cp}/2\pi)^2} = \left(\frac{2\pi}{I_{cp}}\right)^2 \left[S_{inp} + S_{inn}\right] \left(\frac{T_{rst}}{T_{ref}}\right)$$

$$S_{out,cp} = \left(\frac{2\pi}{I_{cp}}\right)^2 \left[S_{inp} + S_{inn}\right] \cdot \left(\frac{T_{rst}}{T_{ref}}\right) \cdot \left|\frac{\phi_{out}}{\phi_{n,cp}}\right|^2$$

$$S_{out,cp} = \left(\frac{2\pi}{I_{cp}}\right)^2 \left[S_{inp} + S_{inn}\right] \cdot \left(\frac{T_{rst}}{T_{ref}}\right) \cdot \left|\frac{\phi_{out}}{\phi_{n,cp}}\right|^2$$

* Reduce T_{rst}/T_{ref}

* Increase I_{cp}
  - reduce R — $K_{pd} = \frac{I_{cp} R}{2\pi}$
  - Increase C — $K_{pd,1} = \frac{I_{cp}}{2\pi C}$

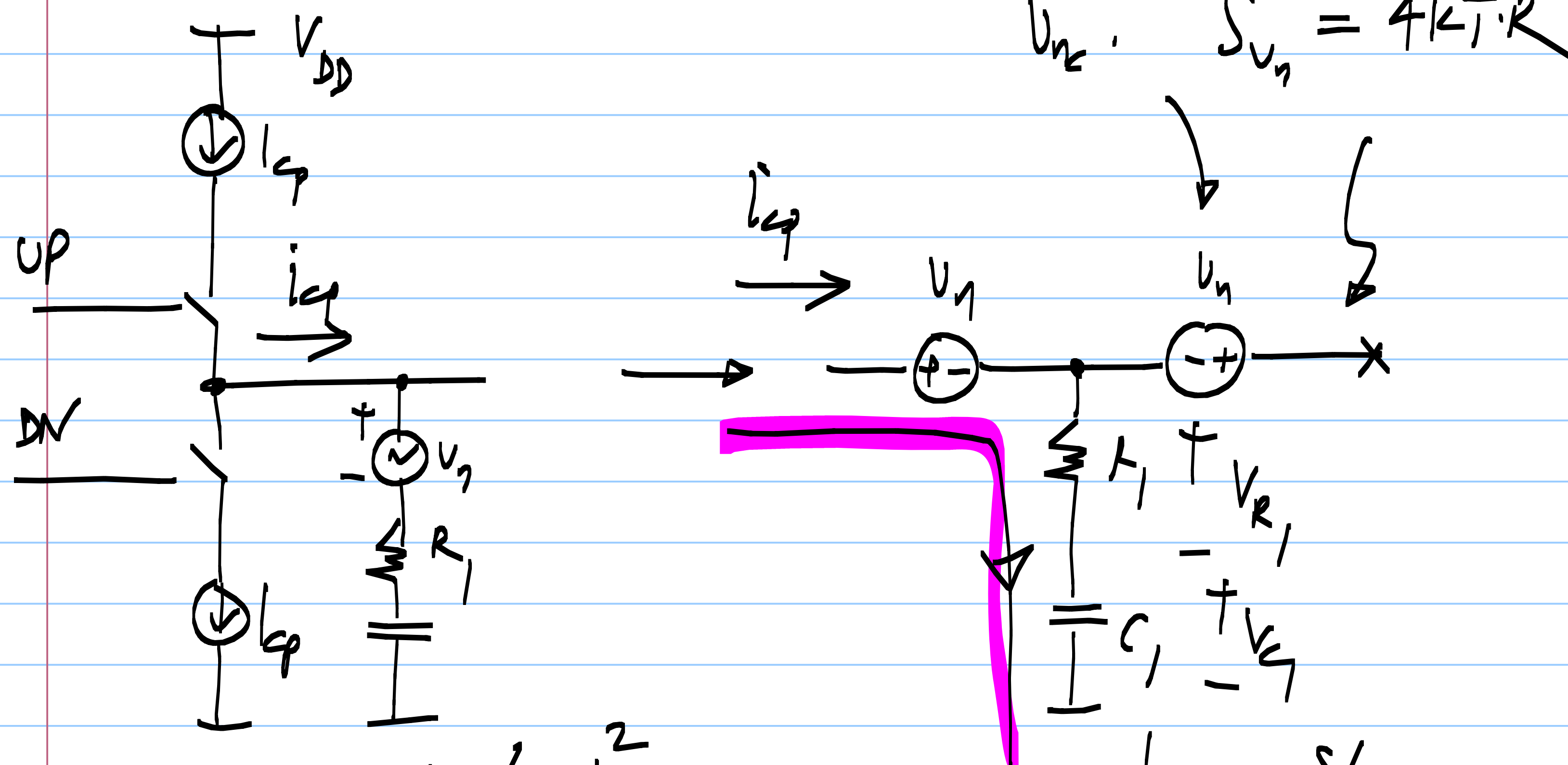
$$\frac{4\pi^2}{I_{cp}^2} \frac{8}{3} kT (g_{mp} + g_{mn}) \left(\frac{T_{rst}}{T_{ref}}\right) \left|\frac{\phi_{out}}{\phi_{ncp}}\right|^2$$

$$= \frac{4\pi^2}{I_{cp}} \cdot \frac{8}{3} kT \left[\frac{g_{mp}}{I_{cp}} + \frac{g_{mn}}{I_{cp}}\right] \left(\frac{T_{rst}}{T_{ref}}\right) \left|\frac{\phi_{out}}{\phi_{ncp}}\right|^2$$

$$\left[\frac{2}{V_{GSP} - V_{TP}} + \frac{2}{V_{GSn} - V_{Tn}}\right]$$

* Increase $\begin{cases} V_{GSP} - V_{TP} \\ V_{GSN} - V_{Tn} \end{cases}$

Contribution of the loop filter:



$s = j2\pi f$

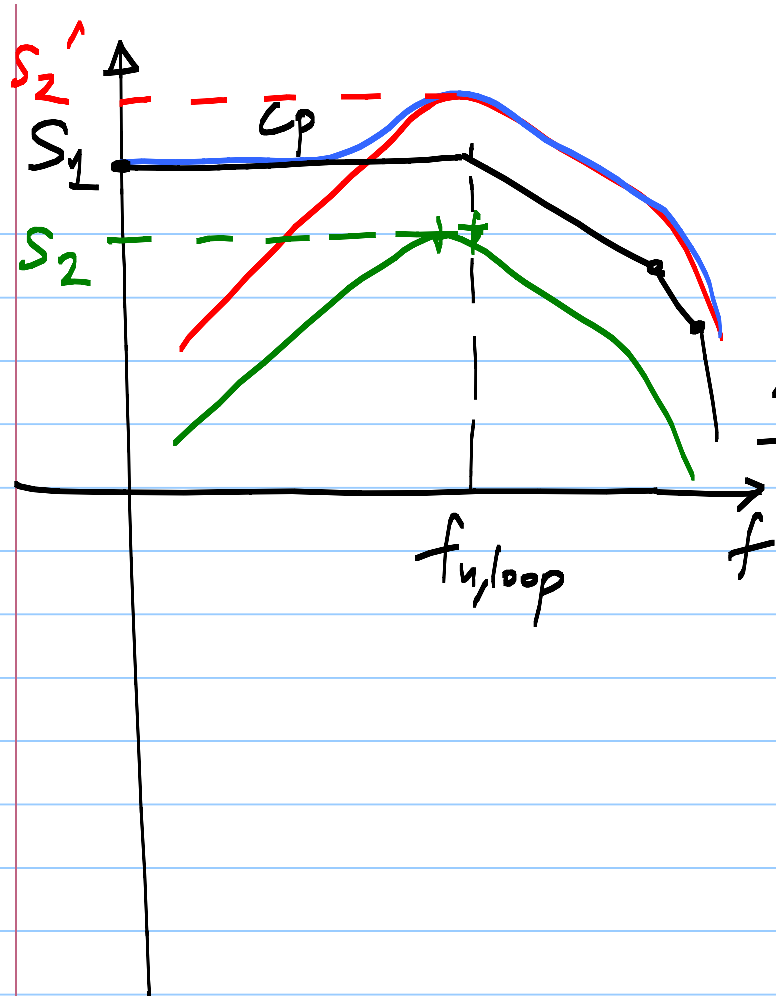
$$S_{\phi out} = S_{v_n} \cdot \left| \frac{\phi_{out}}{v_{nc}} \right|^2 = 4kTR \cdot \left| \frac{N}{K_{pd}} \right|^2 \cdot \left| \frac{s/z_1}{1 + s/z_1 + \frac{s^2}{\omega_{loop} z_1}} \right|^2$$

$$S_{\phi_{out}} = 4kTR \cdot \left|\frac{N}{K_{pd}}\right|^2 \cdot \left|\frac{s/z_1}{1 + \frac{s}{z_1} + \frac{s^2}{\omega_{uloop} \cdot z_1}}\right|^2_{s=j2\pi f}$$

* Reduce R
  - Increase I_{cp} — $K_{pd} = I_{cp} \cdot R / 2\pi$
  - Increase C — $K_{pd,1} = I_{cp} / 2\pi C$

  } Impedance scaling

* Increase K_{pd}
  - Reduce K_{vco}



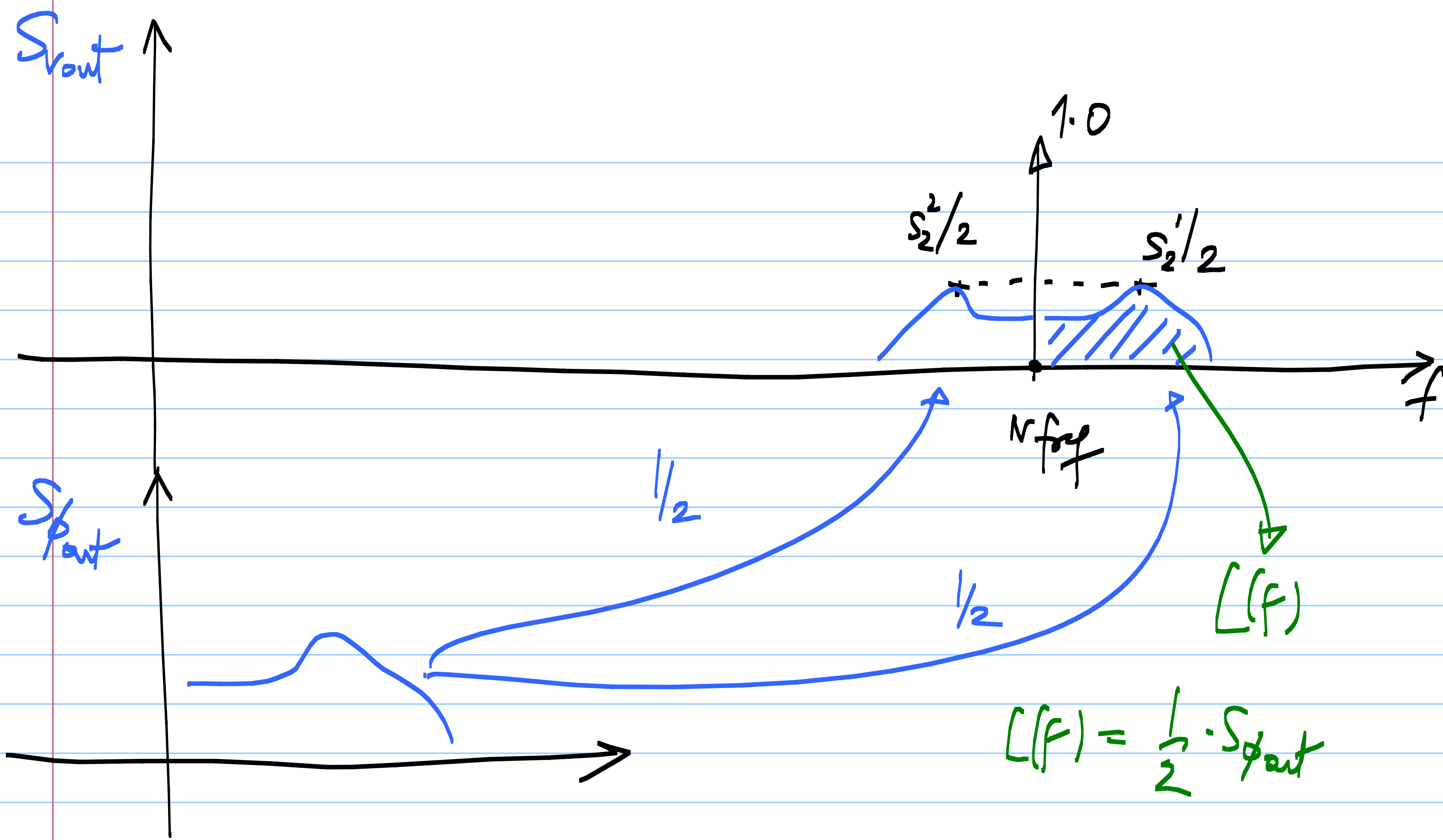
Noise in ϕ_{out} due to charge pump:

$$\frac{4\pi^2}{I_{cp}^2} \frac{8}{3} kT (g_{mp} + g_{mn}) \left(\frac{T_{rst}}{T_{ref}}\right) \left|\frac{\phi_{out}}{\phi_{ncp}}\right|$$

$$S_1 = \frac{4\pi^2}{I_{cp}^2} \cdot \frac{8}{3} kT (g_{mp} + g_{mn}) \left(\frac{T_{rst}}{T_{ref}}\right) \cdot N^2$$

rad^2/Hz $\{1/\text{Hz}\}$

$$S_2 = 4kTR \left|\frac{N}{K_{pd}}\right|^2$$



$S_{v_{out}}$
1.0
$S_2^2/2$
$S_2^1/2$
Nf_{ref}
f
$S_{\phi_{out}}$
1/2
1/2
L(f)
$L(f) = \frac{1}{2} \cdot S_{\phi out}$