ECE 518 - Lecture 16

Note Title 3/14/2013

$f_{out} = 1\,GHz$

$f_{ref} = 10\,MHz$

$\omega_{3dB} \simeq \omega_{u,loop} = 2\pi \cdot 400k\ rad/s$

$$\text{settling time} \triangleq 4.7\tau = \frac{4.7}{\omega_{3dB}} = 12.5\,\mu s$$

How many cycles $\simeq$ 12,500

Simulate for > 12.5 k cycles

Type-II PLL loop dynamics:

$$L(s) = \frac{2\pi K_{PD,I} K_{VCO}}{N s^2}\left(1 + \frac{s K_{PD}}{K_{PD,I}}\right)$$

$$K_{PD,I} = \frac{I_0}{2\pi C}$$

$$K_{PD} = \frac{I_0 R}{2\pi}$$

* Closed-loop transfer function

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

$$= \frac{N \cdot \left(1 + \frac{s K_{PD}}{K_{PD,I}}\right)}{s^2 \frac{N}{2\pi K_{PD,I} K_{VCO}} + \frac{s K_{PD}}{K_{PD,I}} + 1}$$

$$= \frac{N\left(1 + \frac{2\zeta}{\omega_n} s\right)}{\frac{s^2}{\omega_n^2} + \frac{2\zeta s}{\omega_n} + 1} \triangleq \frac{N\left(2\zeta\omega_n s + \omega_n^2\right)}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

"2^{nd}-order system"

$\Rightarrow$ Natural frequency, $\omega_n = \sqrt{\dfrac{2\pi K_{PD,I} K_{VCO}}{N}} = \sqrt{\dfrac{I_o K_{VCO}}{CN}}$

$\Rightarrow$ Damping factor, $\zeta = \dfrac{K_{PD}}{2}\sqrt{\dfrac{2\pi K_{VCO}}{N K_{PD,I}}} = \dfrac{R}{2}\sqrt{\dfrac{I_o K_{VCO}}{NC}}$

$\Rightarrow$ Quality factor, $Q = \dfrac{1}{2\zeta} = \dfrac{1}{R}\sqrt{\dfrac{NC}{I_o K_{VCO}}}$

zero: $\quad z_1 = -\dfrac{K_{PD,I}}{K_{PD}} = \dfrac{-1}{RC}$ @ LHP zero

$\omega_z = \dfrac{1}{RC}$

poles: roots of $D(s) = s^2 + 2\zeta\omega_n s + \omega_n^2 = 0$

$$\omega_{p_{1/2}} = \omega_n \left[-\zeta \pm \sqrt{\zeta^2 - 1} \right]$$

$\zeta < 1$

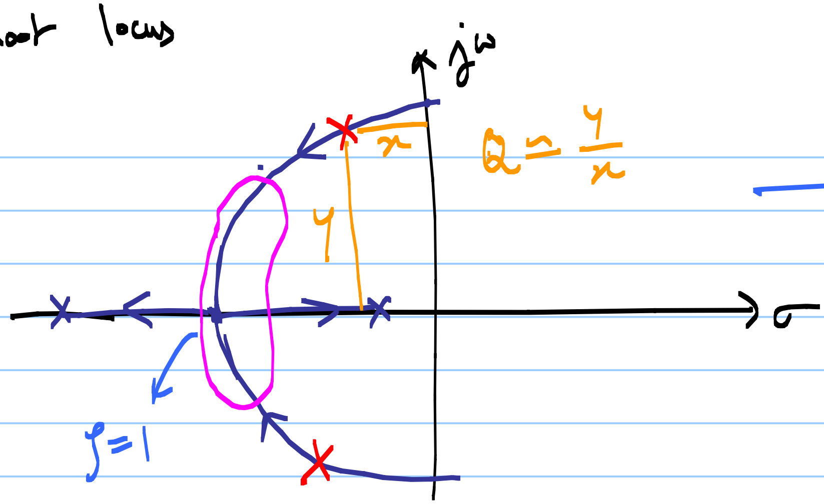
Note that: $\omega_z = -\dfrac{\omega_n}{2\zeta}$

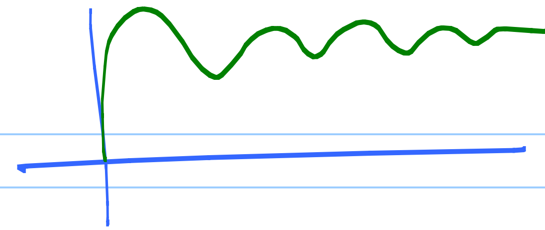
* for well separated poles (& real) $\zeta > 1$

$$\omega_{p_1} \simeq \frac{\omega_n}{2\zeta}, \quad \omega_{p_2} \simeq 2\zeta\omega_n$$

$$\Rightarrow \omega_n = \sqrt{\omega_{p_1}\omega_{p_2}} \leftarrow \text{Geometric Mean}$$

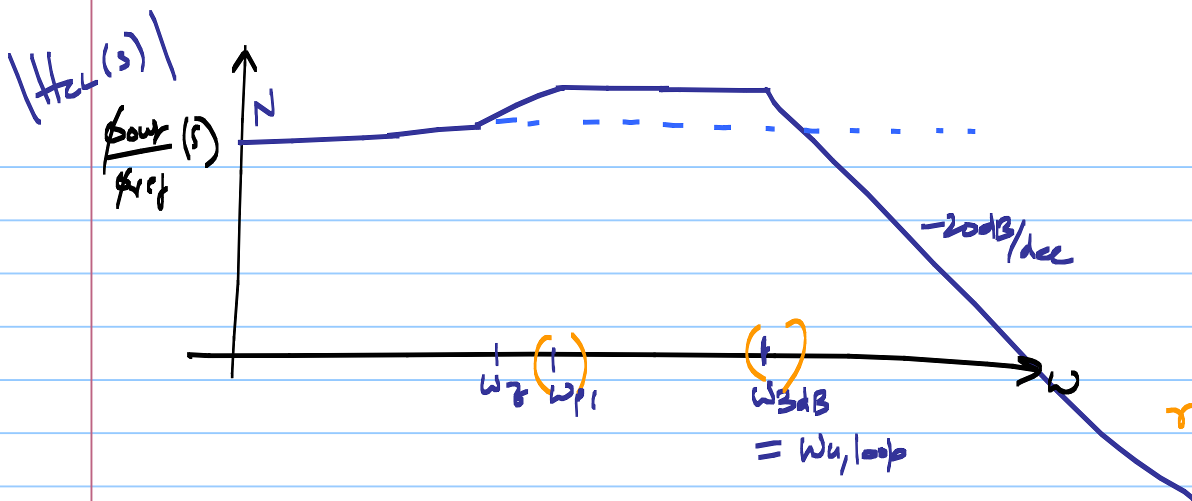
Root locus





high-Q poles

⇒ more transient ringing.



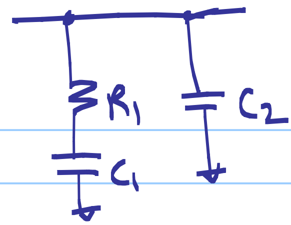
ω_z & ω_{p1} form a doublet

$\omega_z \lesssim \omega_{p1}$

real poles

$$PM \underset{\text{related}}{\longleftrightarrow} \zeta$$

$\boxed{3^{rd}\text{-order PLL}}$



$$Z(s) = \left(\frac{b}{b+1}\right)\frac{\left(s/\omega_z + 1\right)}{s C_1\left(\frac{s}{(b+1)\omega_z} + 1\right)}$$

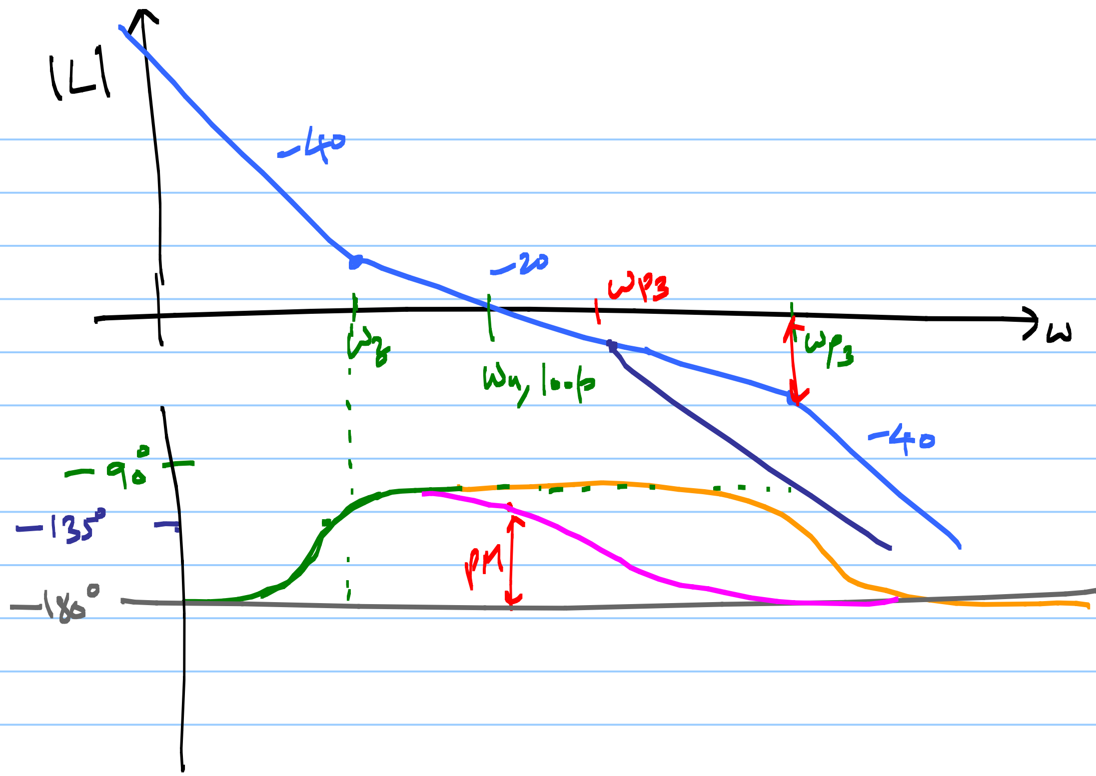
$$\boxed{b = \frac{C_1}{C_2}}, \quad \omega_z = \frac{1}{R_1 C_1}$$

$$\omega_{p2} = \frac{1}{R_1\, C_1 \| C_2} = \omega_z (b+1)$$

zero

$$L(s) = \frac{K_{vco} I_o}{N}\left(\frac{b}{b+1}\right)\frac{\left(s/\omega_z + 1\right)}{s^2 C_1\left(\frac{s}{\omega_z(b+1)} + 1\right)}$$

Type-II $\qquad$ 3^{rd}-pole


|L|
-40
-20
ωp3
ω
ωz
ωp3
ωu, loop
-40
-90°
-135°
-180°
PM

$$PM = \tan^{-1}\left(\frac{\omega_{u,loop}}{\omega_z}\right) - \tan^{-1}\left(\frac{\omega_{u,loop}}{\omega_{p3}}\right) \qquad b = \frac{C_1}{C_2}$$

$$\Rightarrow PM = \tan^{-1}\left(\frac{\omega_{u,loop}}{\omega_z}\right) - \tan^{-1}\left(\frac{\omega_{u,loop}}{(b+1)\,\omega_z}\right) \qquad b = \frac{C_1}{C_2}$$

A CMOS Frequency Synthesizer with an Injection-Locked Frequency Divider for a 5-GHz Wireless LAN Receiver

Hamid R. Rategh, *Student Member, IEEE*, Hirad Samavati, *Student Member, IEEE*, and Thomas H. Lee, *Member, IEEE*

$$PM = \tan^{-1}\left(\frac{\omega_{u,loop}}{\omega_z}\right) - \tan^{-1}\left(\frac{\omega_{u,loop}}{(b+1)\,\omega_z}\right)$$

$$\frac{\partial PM}{\partial \omega_{u,loop}} = 0 \Rightarrow \text{Maxima}$$

$$PM = PM_{max} \quad \text{for} \quad \omega_{u,loop} = \sqrt{b+1}\,\omega_z$$

$$\phi_m = PM_{max} = \tan^{-1}\left(\sqrt{b+1}\right) - \tan^{-1}\left(\frac{1}{\sqrt{b+1}}\right) = f(b)$$

$$\tan^{-1}A - \tan^{-1}B = \tan^{-1}\left(\frac{A-B}{1+AB}\right)$$

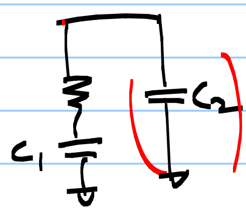
$$b = 2\left(\tan^2\phi_m + \tan\phi_m\sqrt{1+\tan^2\phi_m}\right)$$

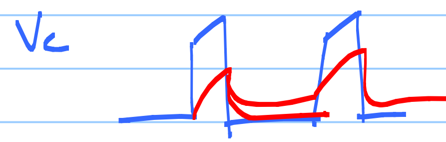
$$PM_{max} = f(b)$$

* $\frac{C_1}{C_2} = b < 1 \Rightarrow PM = 20^\circ$

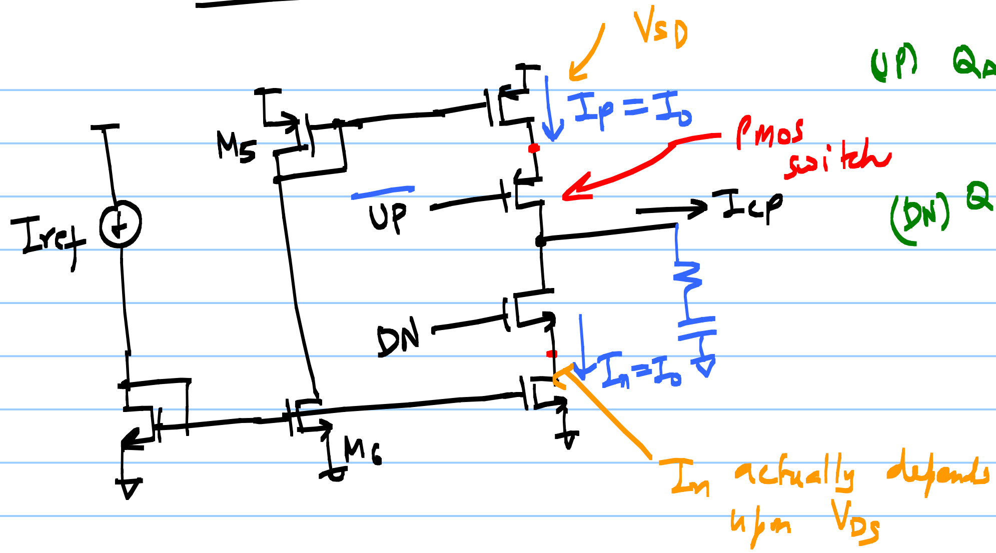
$\Rightarrow$ ringing

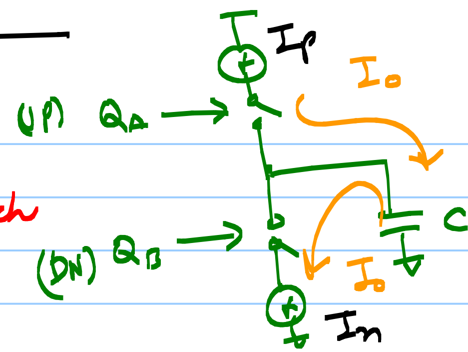
* $b = \frac{C_1}{C_2} = 5 \Rightarrow \zeta = 0.783$





Simple Charge Pump Design

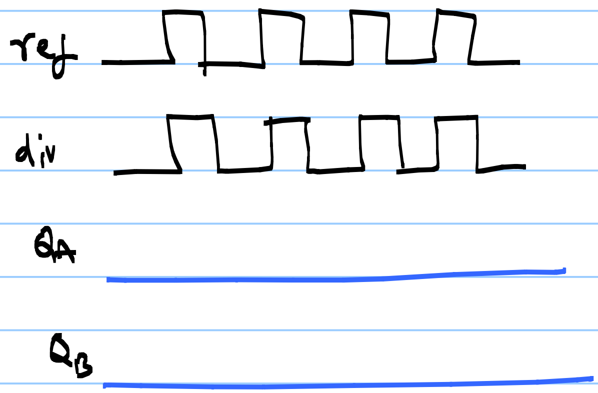




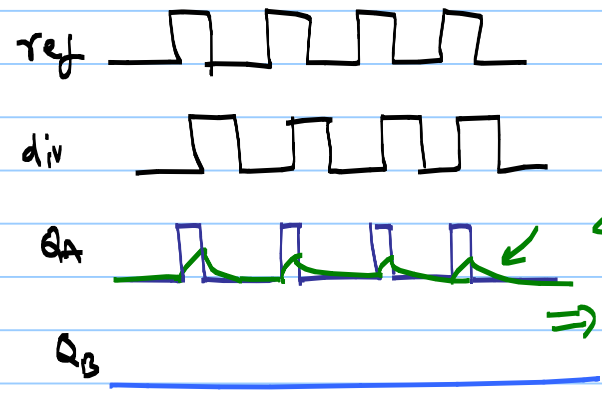
① PFD/CP dead zone

QA/QB has to turn the switch ON

$\Delta\phi = 0$, ideal case $T_{rst} = 0$

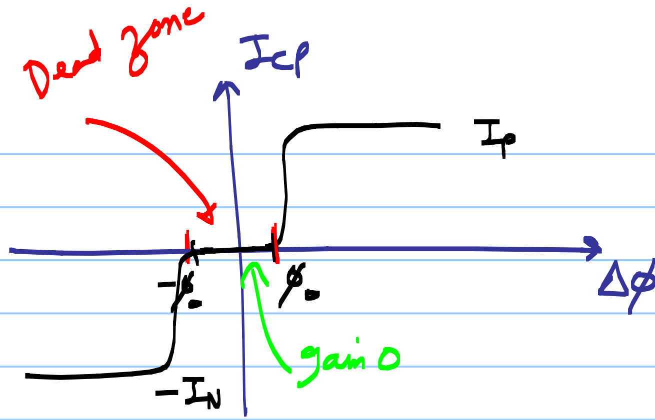


$0 < \Delta\phi < \phi_0$



$< V_{THN}$

$\Rightarrow I_p = 0$



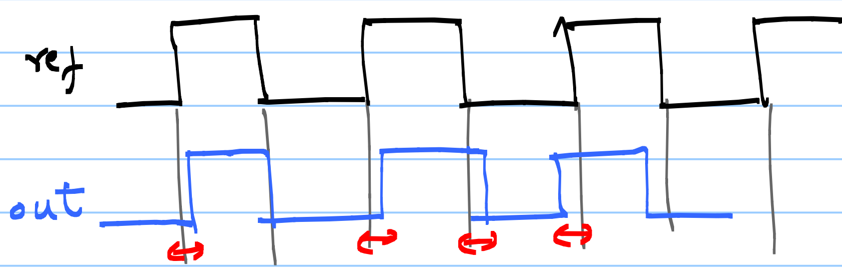
I_{cp} is no longer a f^n of $\Delta\phi_0$

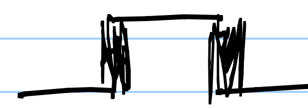
$\Rightarrow |L| = 0$

$\Rightarrow$ output phase is not locked

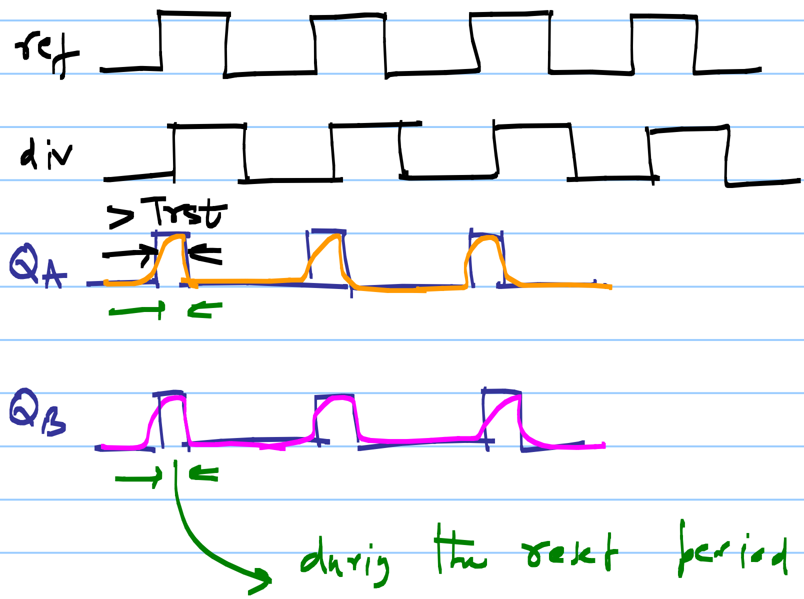
$\Rightarrow$ VCO accumulates phase error

NB!





* use coincident pulses on Q_A & Q_B to eliminate the dead zone.

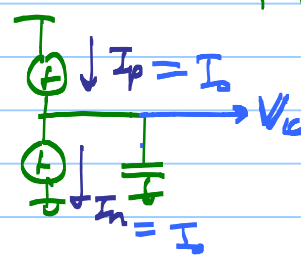


Select T_{rst} that $\Delta\phi > \phi_0$

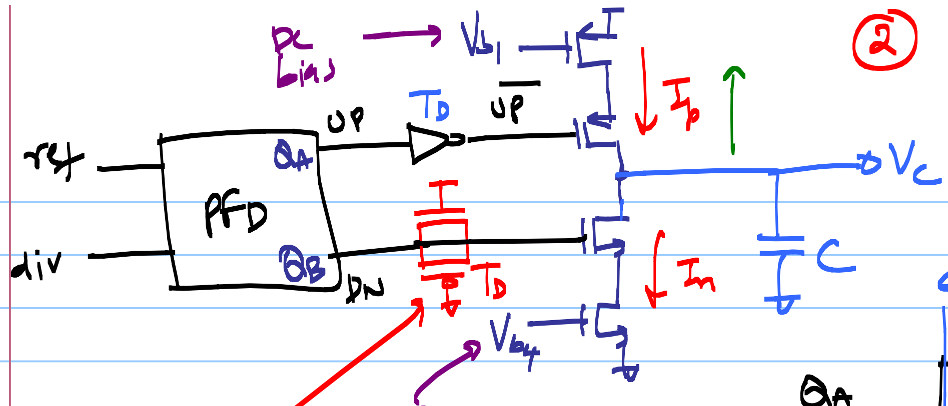
↓

Q_A & Q_B allowed to reach full logic-level

↳ turn the switches on



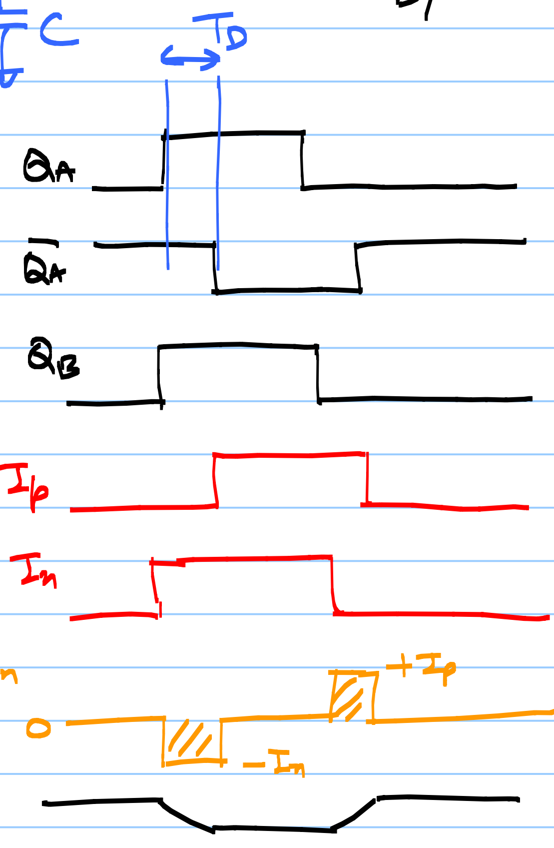
② UP/DN Skew



Add buffer / TG to match the inverter delay

locked state

$\Delta\phi = 0$



ripples in the VCO control voltage