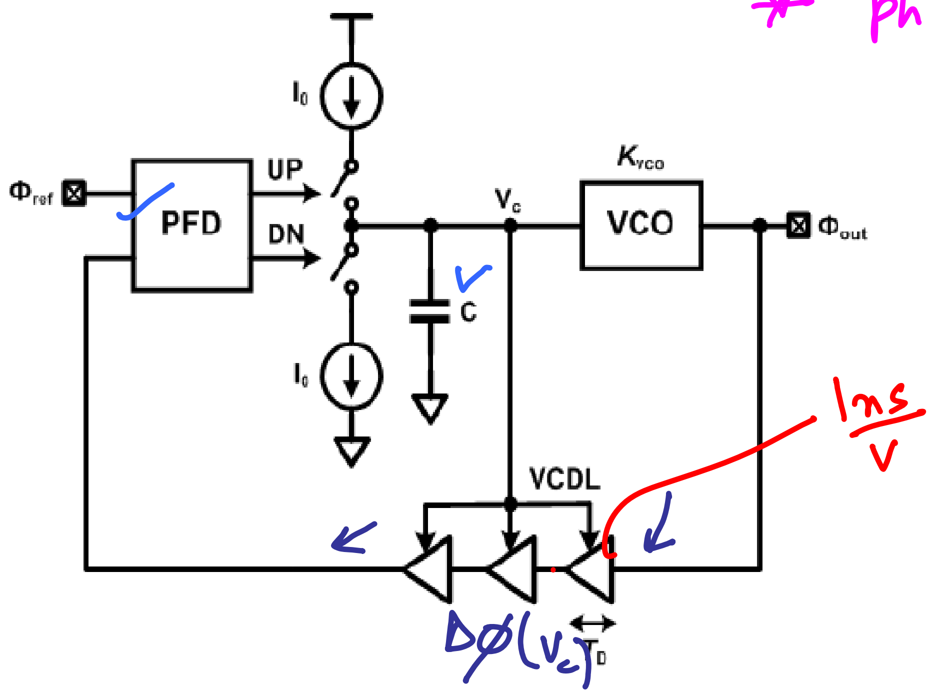
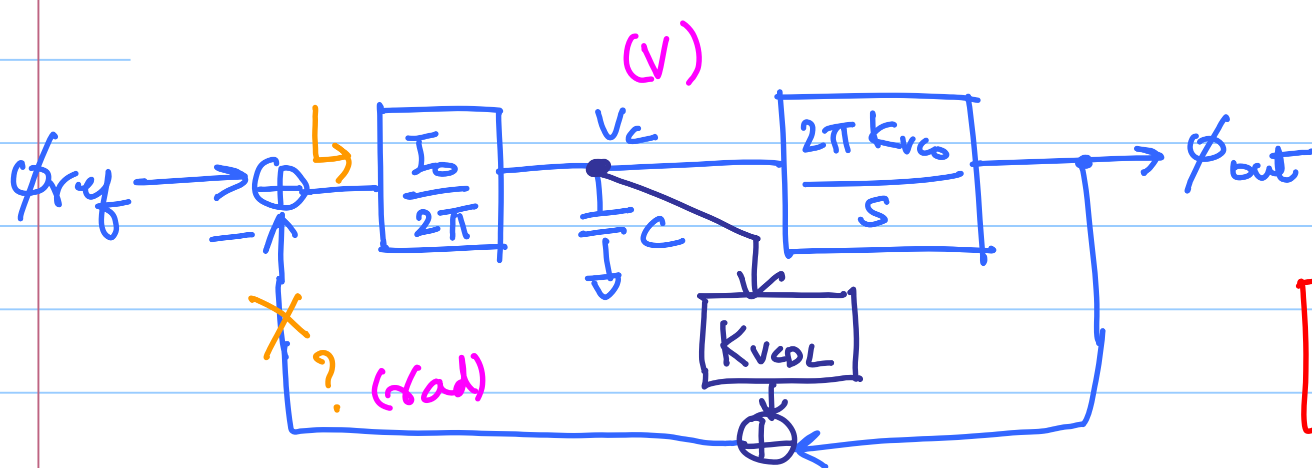
ECE 518 – Lecture 24

Note Title 4/14/2015



(a) (10 points) Draw the phase-domain small signal block diagram in steady state.



* phase-domain proportional path

$T_{ck} = 2ns$

$K_{vco} = 150\ \frac{MHz}{V}$

$K_{VCDL} = 3\frac{ns}{V}$

$\triangleq \frac{3\frac{ns}{V}}{T_{ck}} \times 2\pi\ \frac{rad}{V}$

$\boxed{K_{VCDL} = 3\pi\ \frac{rad}{V}}$

(b) $$L(s) = \frac{I_o}{2\pi}\cdot\frac{1}{sC}\left(\frac{2\pi K_{vco}}{s} + K_{vcoL}\right)$$

proportional path
↳ adds LHP zero in the loop-gain

$$= \frac{\cancel{2\pi} I_o K_{vco}}{\cancel{2\pi} C\ s^2}\left(1 + \frac{s K_{vcoL}}{2\pi \cdot K_{vco}}\right)$$

$$= \frac{I_o K_{vco}}{C s^2}\left(1 + \frac{s}{\omega_z}\right)$$

$s = -\omega_z$
LHP zero

$$\omega_{p_1} = \omega_{p_2} = 0$$

$$\omega_z = \frac{2\pi K_{vco}}{K_{vcoL}}$$

(c) (10 points) Determine the value of capacitor C to achieve loop-gain phase-margin of 45°.

$\omega_{u,loop} \leftarrow$ loop BW

$$L(s) = \frac{I_o K_{VCO}}{C\ s^2}\left(1 + \frac{s K_{VCDL}}{2\pi \cdot K_{VCO}}\right)$$

$\omega \simeq \omega_{u,loop} >> \omega_z$

$$\simeq \frac{I_o}{C} \cdot \frac{\cancel{K_{VCO}}}{s^{\cancel{2}}} \times \frac{\cancel{s} K_{VCDL}}{2\pi \cancel{K_{VCO}}}$$

$$\boxed{\omega_{u,loop} \simeq \frac{I_o K_{VCDL}}{2\pi C}}$$

Approximated

Phase margin for Type-II poles & 1 zero

$$\phi_M = \tan^{-1}\left(\frac{\omega_{u,loop}}{\omega_z}\right) = \tan^{-1}\left(\frac{I_o K_{VCDL}}{2\pi C} \times \frac{K_{VCDL}}{2\pi K_{VCO}}\right) = 45^\circ$$

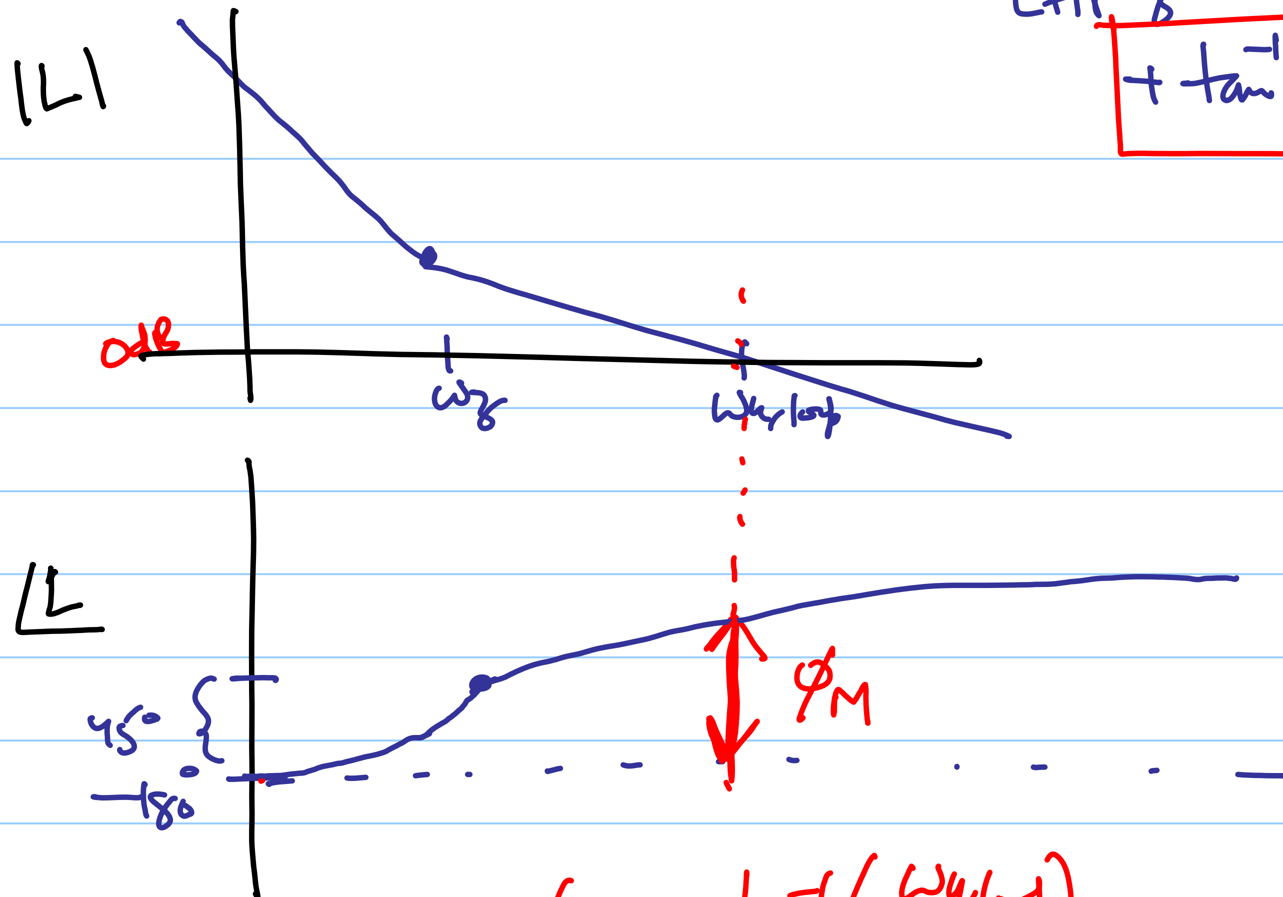
$$\frac{I_o K_{VCDL}^2}{(2\pi)^2 K_{VCO} \cdot C} = \tan(45^\circ) = 1$$

$$\Rightarrow \boxed{C = ?}$$

LHP zero adds to the phase

$$\boxed{+\tan^{-1}\left(\frac{\omega}{\omega_z}\right)}$$

$\omega = \omega_{u,loop}$



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

(d) (10 points) Derive the expression for closed-loop transfer function $H_{cl}(s) = \frac{\Phi_{out}}{\Phi_{ref}}$.

$$H_{cl}(s) = \frac{L(s)}{1+L(s)}$$

$$L(s) = \frac{I_o K_{VCO}}{C\ s^2}\left(1 + \frac{s K_{VCO} L}{2\pi \cdot K_{VCO}}\right)$$

$$= \frac{\frac{I_o K_{VCO}}{Cs^2}\left(1+\frac{s K_{VCO} L}{2\pi K_{VCO}}\right)}{1 + \frac{I_o K_{VCO}}{Cs^2}\left(1+\frac{s K_{VCO} L}{2\pi K_{VCO}}\right)}$$

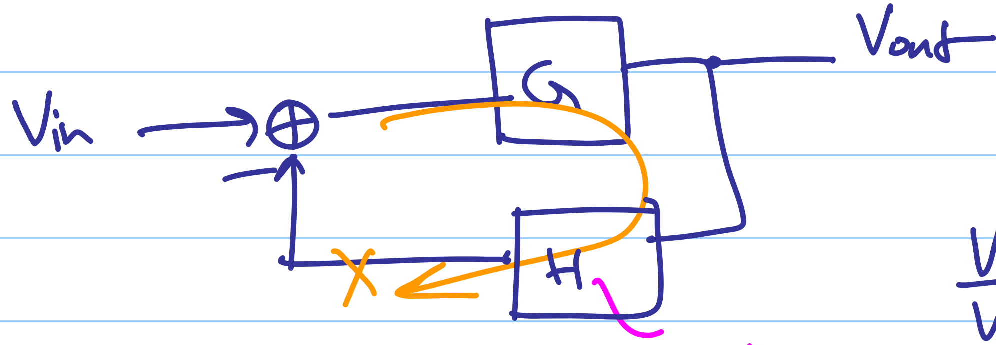
$$\boxed{H_{cl} = N \cdot \frac{L(s)}{1+L(s)}}$$

$$= \boxed{\frac{\frac{I_o K_{VCO}}{C}\left(1+\frac{s K_{VCO} L}{2\pi K_{VCO}}\right)}{s^2 + \frac{I_o K_{VCO} L}{2\pi C}s + \frac{I_o K_{VCO}}{C}}} = \frac{k \cdot (1+s/\omega_z)}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

$$\omega_n = \sqrt{\frac{I_o K_{VCO}}{C}}, \quad \xi = \frac{I_o K_{VCO}}{2\pi C} \cdot \frac{1}{2\omega_n}$$

(e) (5 points) Sketch open- and closed-loop Bode magnitude and phase plots for the PLL.

* Look into lecture notes



$$L = GH$$

$$\frac{V_{out}}{V_{in}} = \frac{G}{1 + GH} \quad L$$

$$H = \frac{1}{N}$$

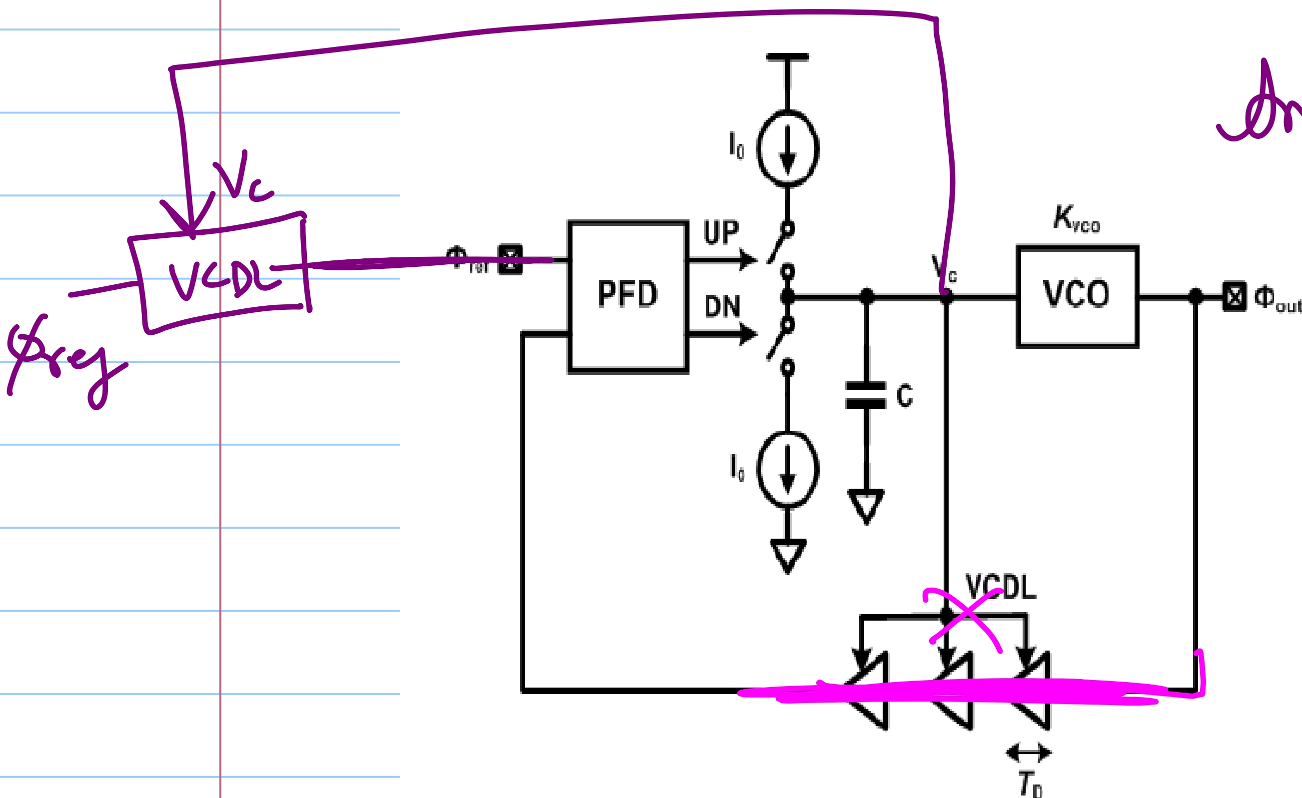
$$L = G \cdot H = \frac{G}{N}$$

$$G = N \cdot L$$

$$\frac{V_{out}}{V_{in}} = N \cdot \left(\frac{L}{1 + L} \right)$$

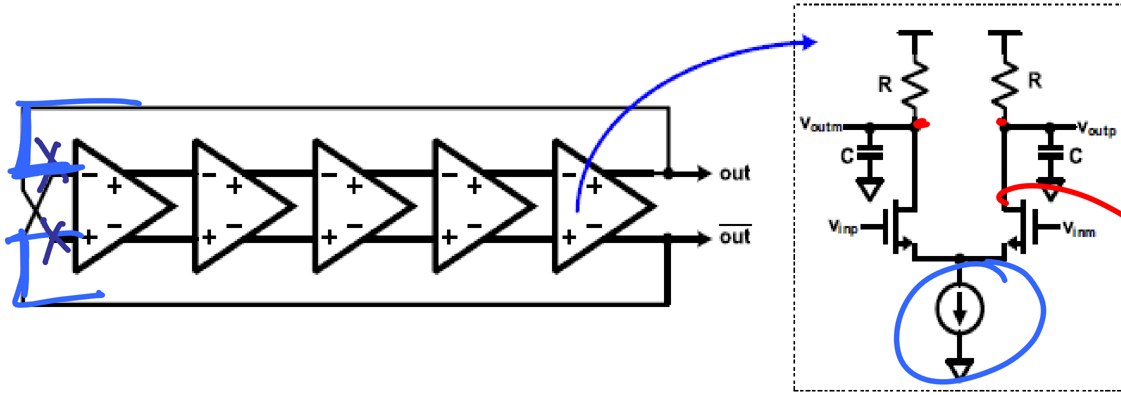
(f) (Bonus 5 points) What is the main difference between the above proportional control and the conventional proportional path using a resistor.

Another method



operating in saturation.

CM Logic Ring Oscillator



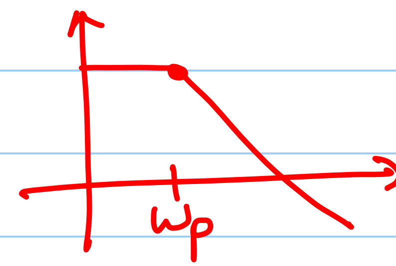
$$A_0 = \frac{g_m R}{(1+sRC)}$$

(a) (10 points) Find the frequency of oscillation ω_{osc} if $R = 1\,k\Omega$ and $C = 100\,fF$.

$$\omega_p = \frac{1}{RC}$$

loop gain

$$L(s) = \left(\frac{A_0}{1+\frac{s}{\omega_p}}\right)^5, \quad \angle L(j\omega) = -5\tan^{-1}\left(\frac{\omega}{\omega_p}\right)$$



To oscillate, $\angle L(j\omega_{osc}) = -180^\circ$ excess phase-shift

$$5\tan^{-1}\left(\frac{\omega_{osc}}{\omega_p}\right) = 180^\circ$$

$$\Rightarrow \quad \frac{\omega_{osc}}{\omega_p} = \tan\left(\frac{180^\circ}{5}\right) = \tan(36^\circ) = 0.726$$

~~Small - signal Analysis~~

$$\omega_{osc} = 0.726\ \omega_p$$

$$= \frac{0.726}{RC} = 7.265\ \text{Grad/s}$$

or 1.156 GHz

(b) (10 points) What is the minimum delay-cell transistor transconductance (g_{m1}) required for oscillation?

$$|L(\omega_{osc})| \geq 1$$

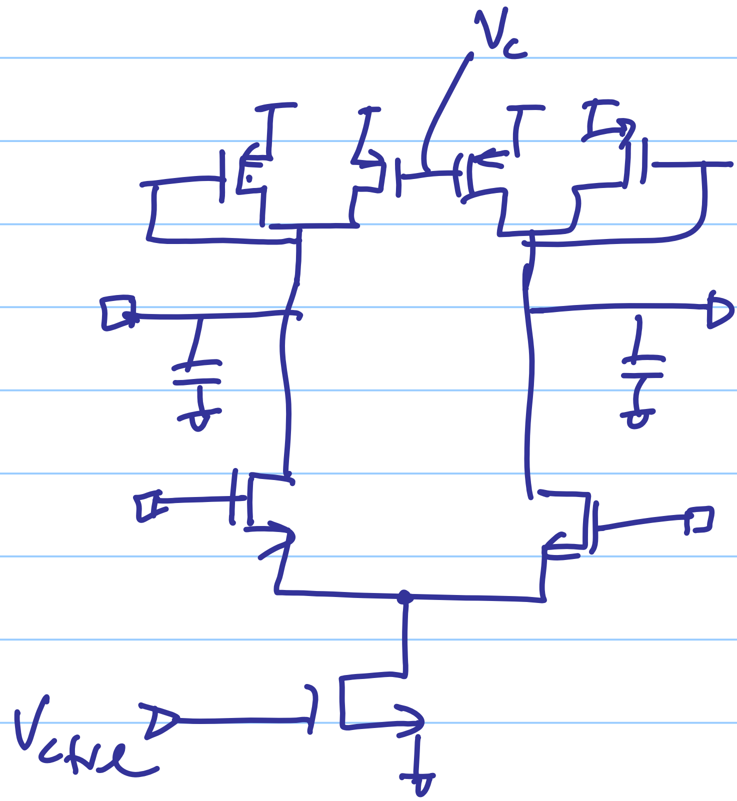
$$\left[\frac{g_m R}{\sqrt{1+\left(\frac{\omega_{osc}}{\omega_p}\right)^2}}\right]^5 \geq 1$$

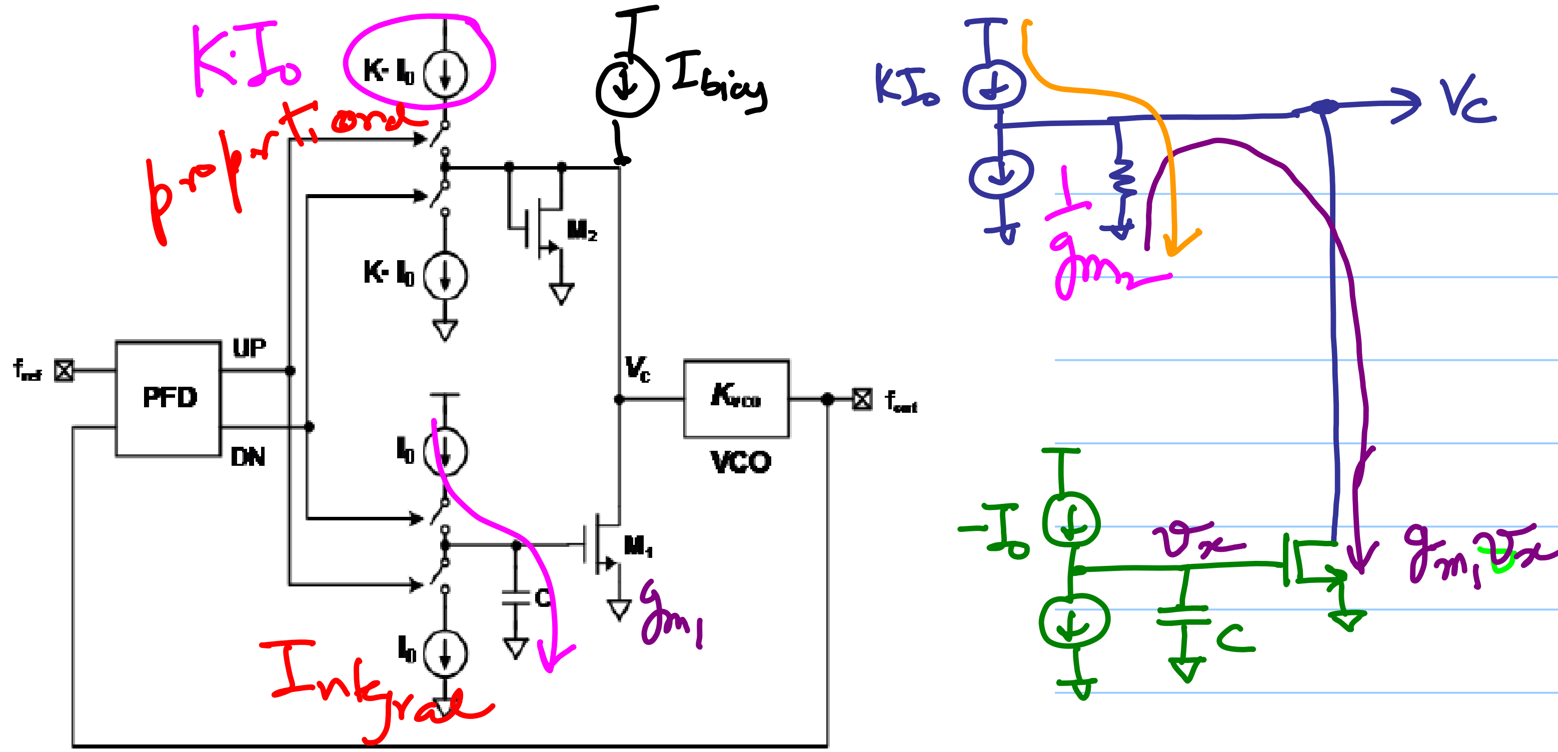
$$\Rightarrow \frac{g_m R}{\sqrt{1+\tan^2(36^\circ)}} \geq 1$$

$$\Rightarrow g_m R \geq 1.236$$

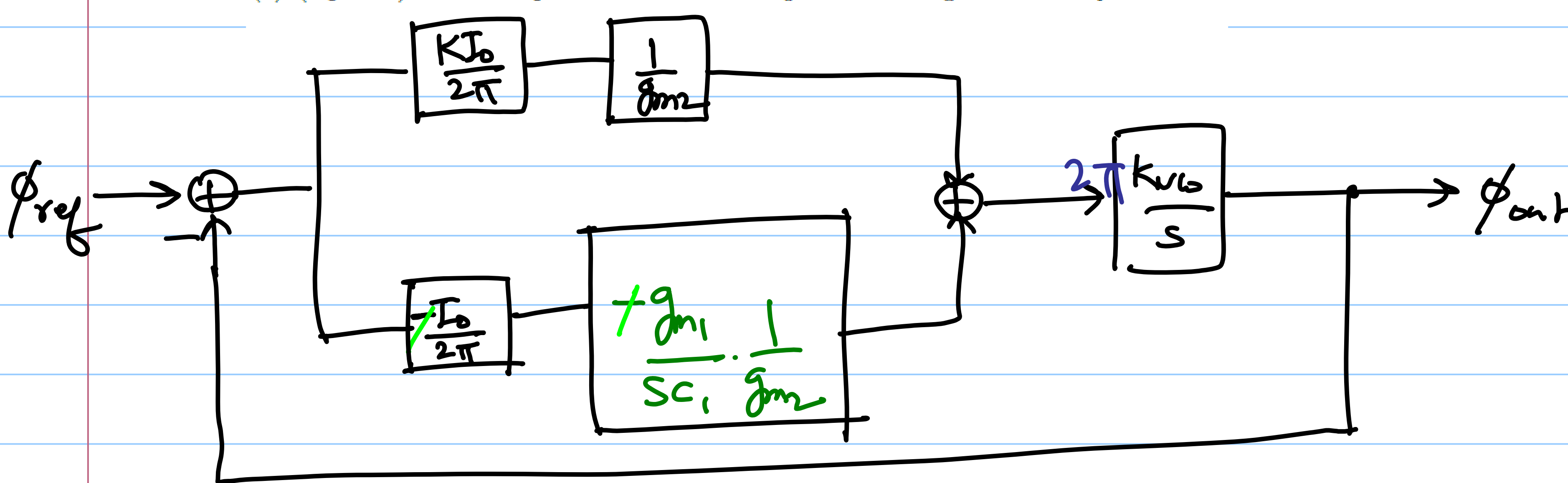
$$\Rightarrow \boxed{g_m \geq 1.236\ \frac{mA}{V}}$$

(c) (10 points) A 5-stage VCO needs to be designed based upon the above schematic. Draw schematic of a delay cell to achieve this with best possible PSRR.





(a) (5 points) Draw the phase-domain *small-signal* block diagram in steady state.



(b) (5 points) What is the effective loop-filter transfer function, $F(s) = \frac{V_c(s)}{I_0}$?

$$\frac{V_c(s)}{I_o} = \frac{K}{g_{m2}} + \left(\frac{g_{m1}}{g_{m2}}\right) \cdot \frac{1}{sC}$$

(c) (5 points) Find the expression for loop gain $L(s)$ and determine the pole and zero locations.

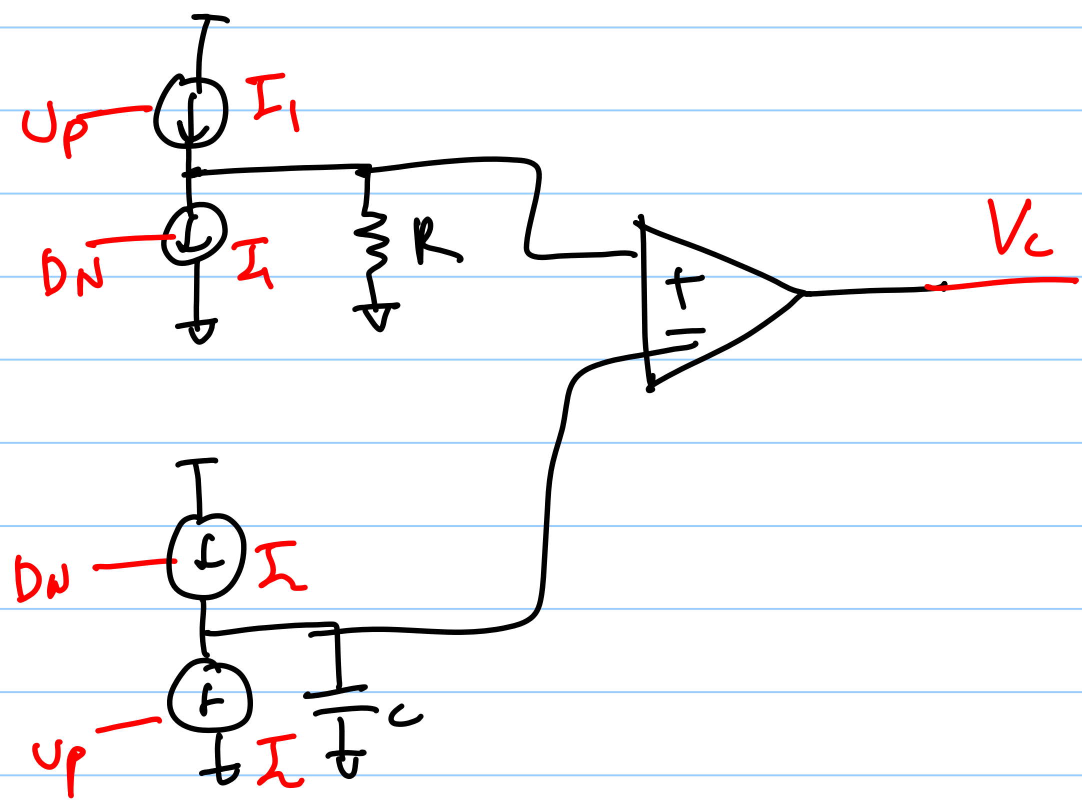
$$L(s) = \frac{I_o K_{vco} K}{s^2 \, g_{m2}} \left(s + \frac{g_{m1}}{KC} \right)$$

$\omega_{p1} = \omega_{p2} = 0$; $\boxed{\omega_z = -\frac{g_{m1}}{KC}}$ LHP zero.

$$H_{cL}(s) = \frac{L(s)}{1+L(s)}$$

(e) (5 points) In order to minimize the loop filter area, should K be minimized or maximized? Why?

maximize K to minimize area



Up
I1
DN
I1
R
+
−
Vc
DN
I2
C
Up
I2