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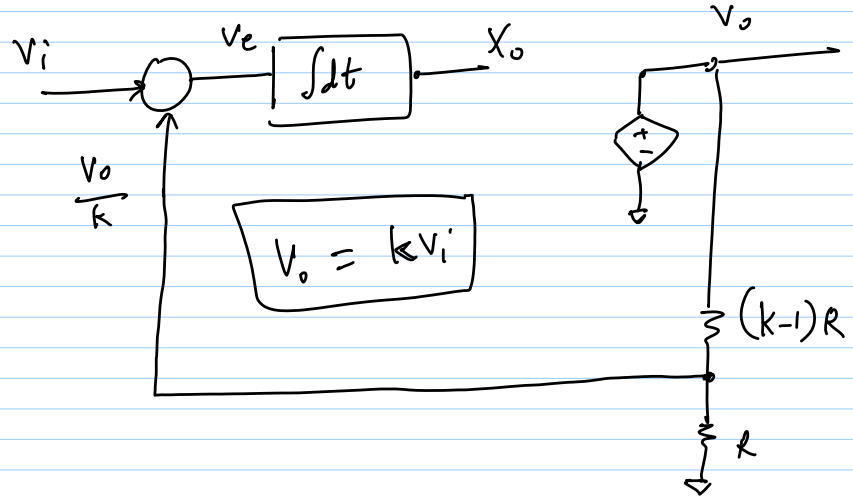
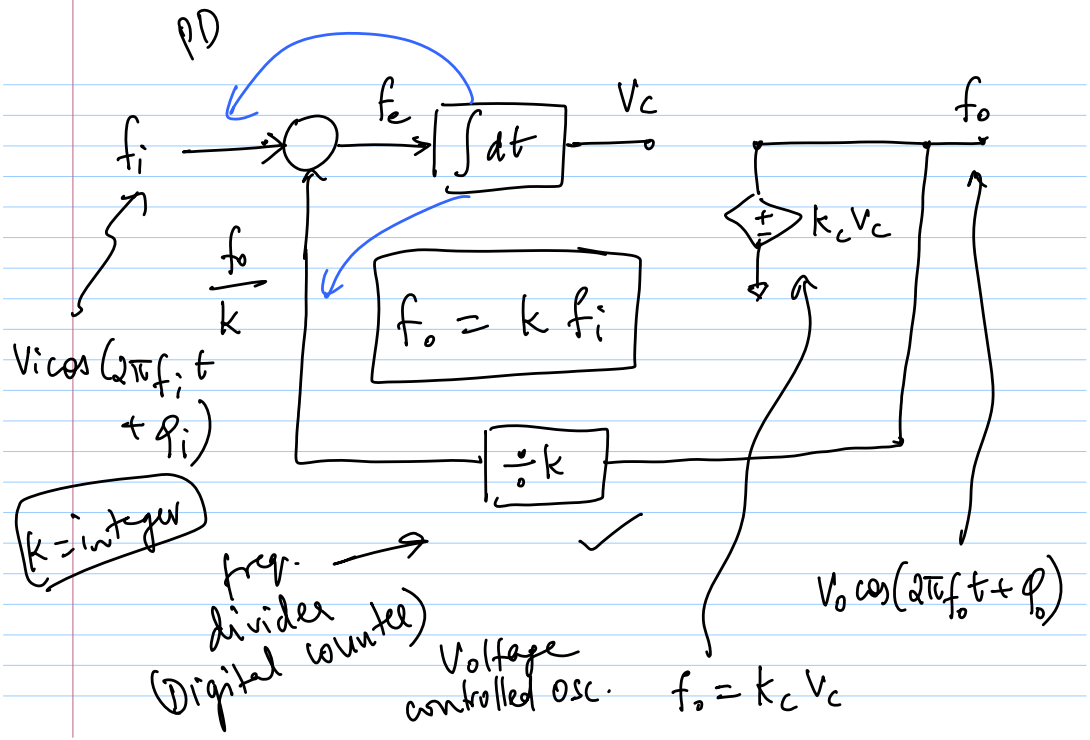
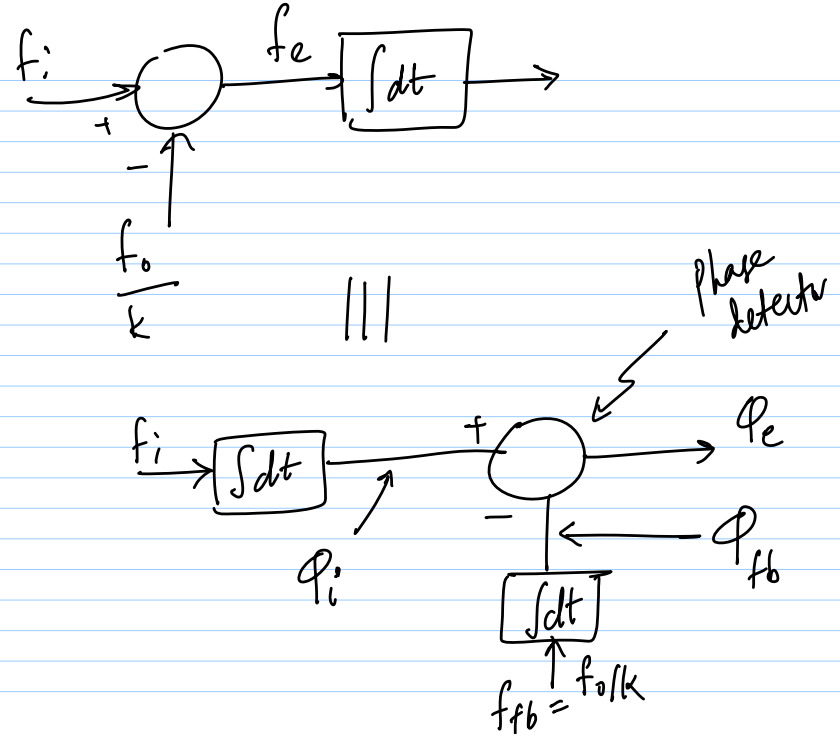
Phase locked loops





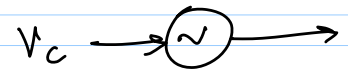


$$V = V_i \cos(2\pi f_i t + \theta)$$

$$\varphi_i = 2\pi f_i t + \theta$$

$$f = \frac{1}{2\pi}\frac{d\varphi_i}{dt} = f_i + \frac{1}{2\pi}\frac{d\theta}{dt}$$

VCO



(K_{VCO})

$= K_c$

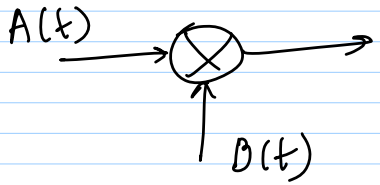
unit $= Hz/V$

$$f_o = f_{free} + K_{VCO} \cdot V_c$$

free running freq.

1) PD

a) Multiplier type PD



$$A(t) = A \sin(\omega_a t + \theta_a) \quad \text{(sine)}$$

$$B(t) = B\left[\frac{4}{\pi}\cos(\omega_b t + \theta_b) + \frac{4}{5\pi}\cos(3\omega_b t + \theta_b) + \cdots\right] \quad \text{(sq. wave)}$$

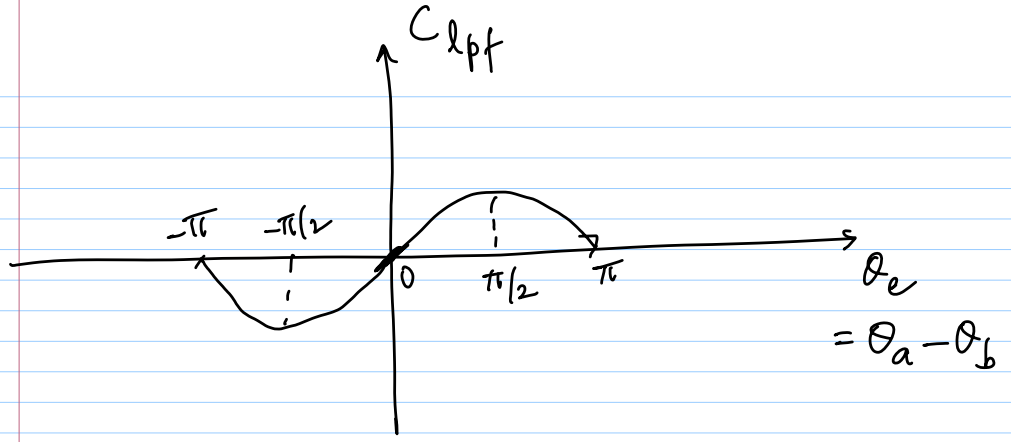
$$C(t) = A(t) \times B(t)$$

$$= \frac{4AB}{\pi}\left[\sin(\omega_a t + \theta_a)\cdot\cos(\omega_b t + \theta_b) + \frac{1}{3}\sin(\omega_a t + \theta_a)\cos(3\omega_b t + \theta_b) + \cdots\right]$$

$$= \frac{2}{\pi}AB\left[\sin\{(\omega_a - \omega_b)t + \theta_a - \theta_b\} + \sin\{(\omega_a + \omega_b)t + \theta_a + \theta_b\} + \cdots\right]$$

DC 성분

LPF gives $(\omega_a - \omega_b)t$ & $(\theta_a - \theta_b)$ term



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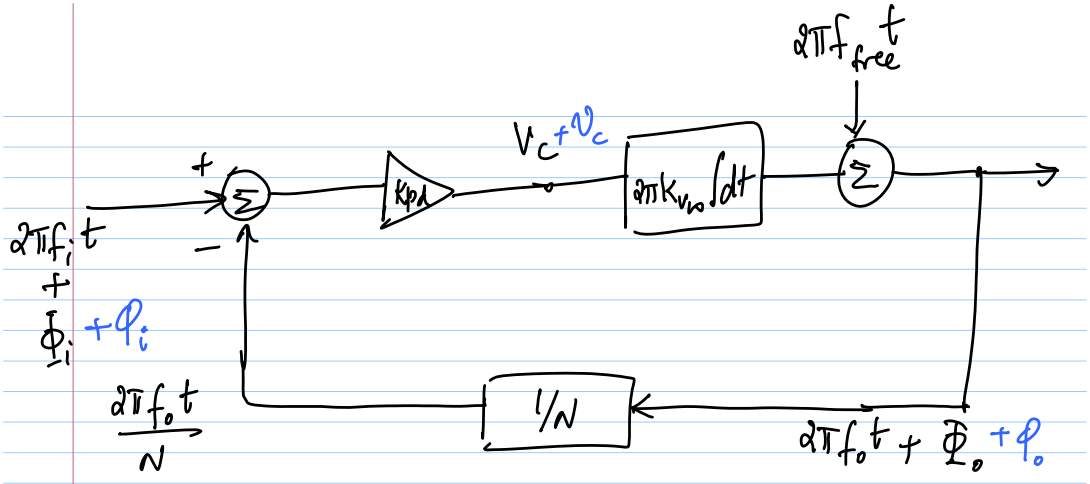
b) XOR PD

c) Digital PFD (phase freq. det.)



$$f_{vco} = f_{free} + K_{vco} \cdot V_c$$

$\hookrightarrow 2\pi f_{free} \cdot t$

$\rightarrow 2\pi K_{vco} \int V_c dt$

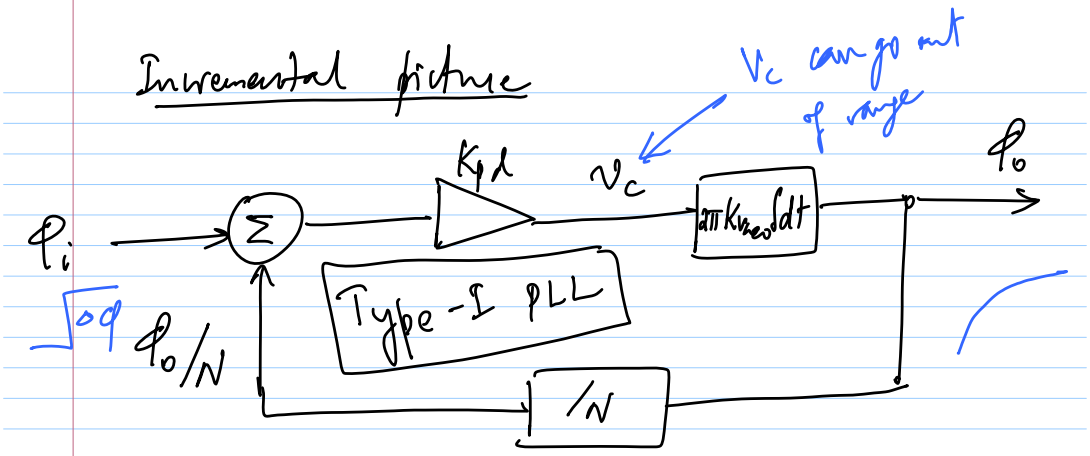
In steady state

$$f_o = f_i \cdot N$$

$$V_c = K_{pd}\left[\frac{\Phi_i}{} - \frac{\Phi_o}{N}\right]$$

$$= \left[\frac{N f_i - f_{free}}{K_{vco}}\right]$$

Incremental picture

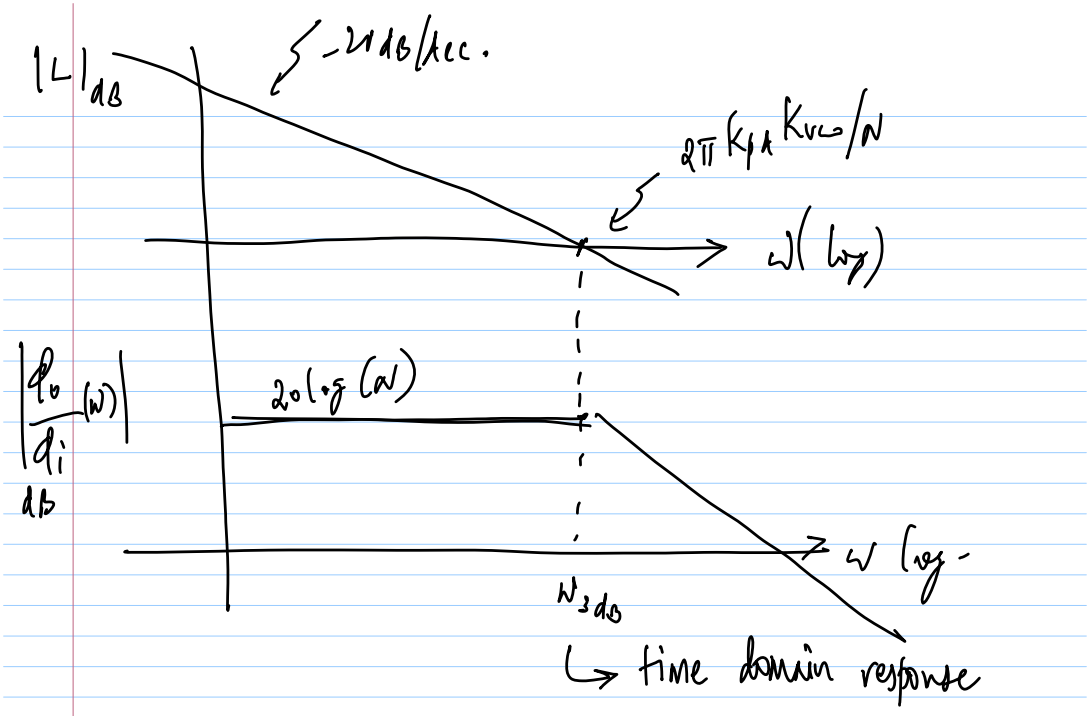


Loop gain $L(s) = \dfrac{2\pi K_{pd} K_{vco}}{Ns}$

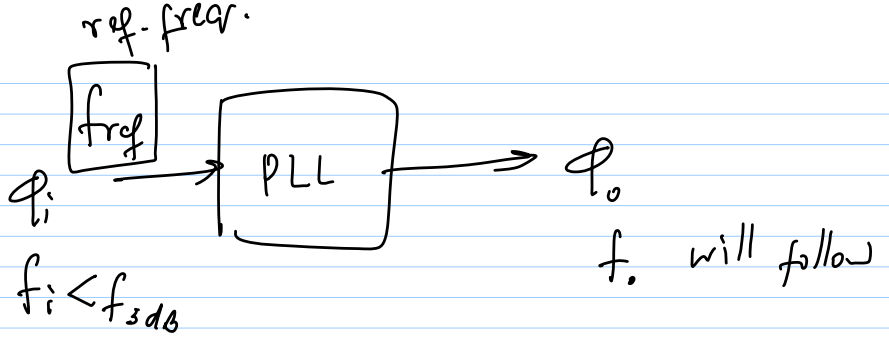
$$\frac{\phi_o}{\phi_i}(s) = N \cdot \frac{1}{1 + \dfrac{Ns}{2\pi K_{pd} K_{vco}}}$$

CL BW $f_{3dB} = \dfrac{K_{pd} K_{vco}}{N}$

$\omega_{3dB} = 2\pi \dfrac{K_{pd} K_{vco}}{N}$

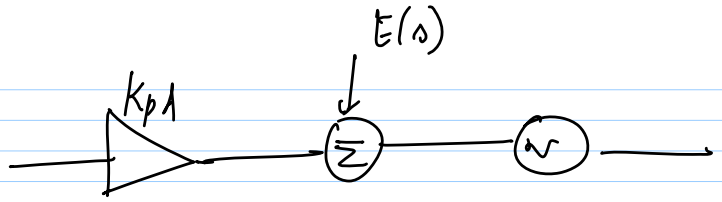


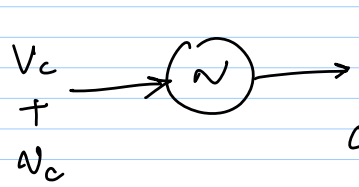
↳ time domain response



$f_i < f_{3dB}$

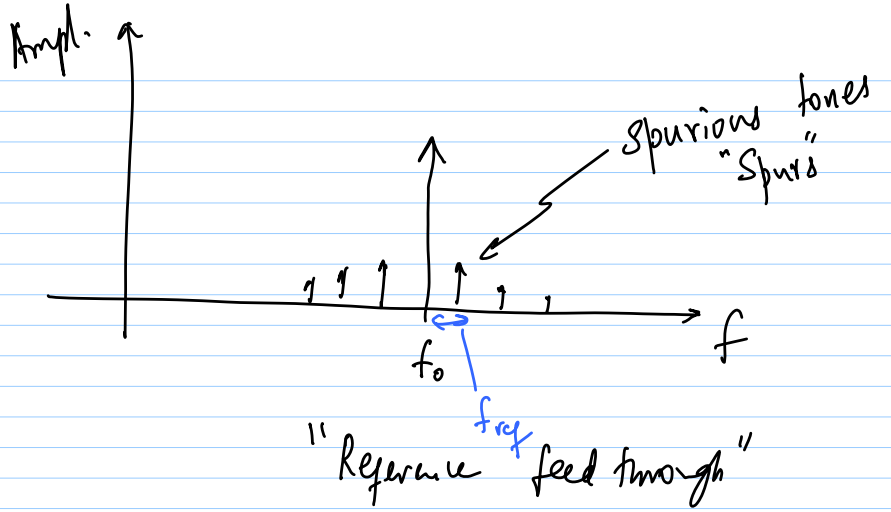
f_o will follow

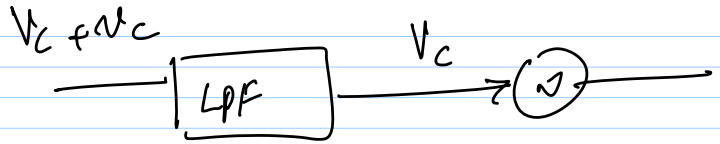




$$f_o = f_{free} + K_{VCO} \cdot V_c$$

$$\cos(2\pi f_o t)$$





↳ affects ω_{3dB}

Slows down PLL

Stability

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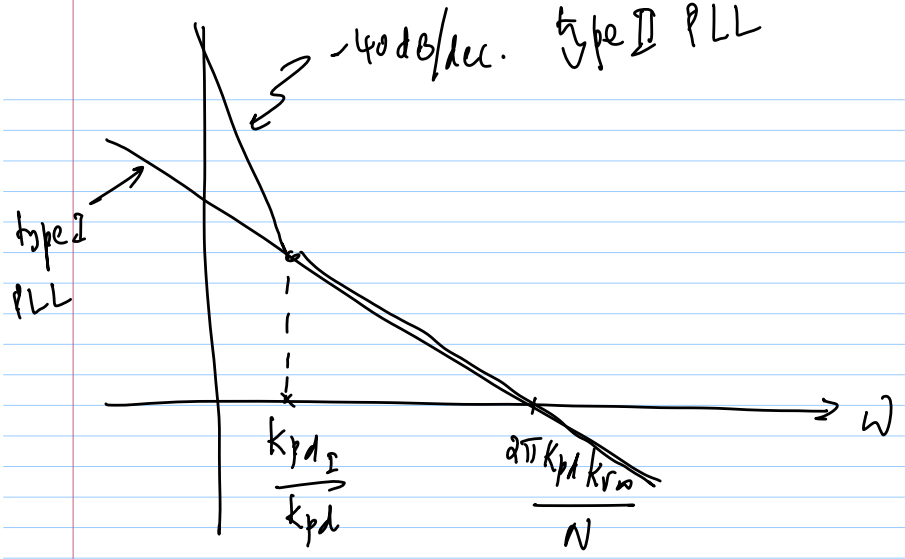
ref. feedthrough $\longleftrightarrow$ BW of PLL

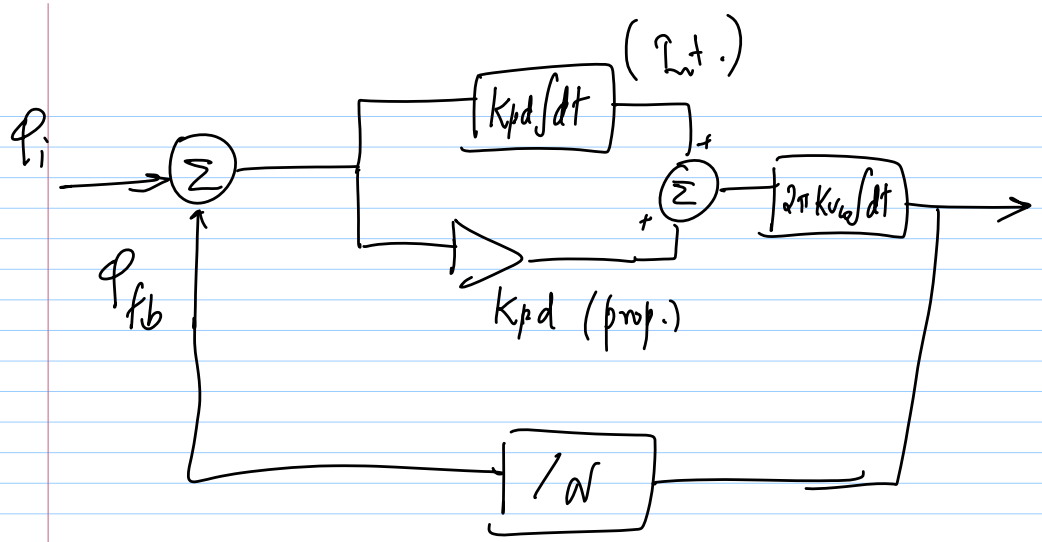
↑ f_{3dB} ⇒ ref. feedthrough gets worse



$$L(s) = \frac{2\pi K_{pd_I} K_{VCO}}{N s^2}\left[1 + \frac{K_{pd}}{K_{pd_I}} \cdot s\right]$$

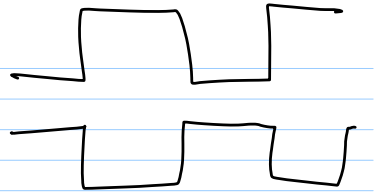
$$\frac{\varphi_{out}}{\varphi_{in}}(s) = N \cdot \frac{\left(1 + \frac{K_{pd}}{K_{pd_I}} \cdot s\right)}{s^2 \cdot \frac{N}{2\pi K_{pd_I} K_{VCO}} + s\frac{K_{pd}}{K_{pd_I}} + 1}$$

$$\omega_n = \sqrt{\frac{2\pi K_{pd_I} K_{VCO}}{N}} \quad ; \quad Q = \frac{\sqrt{N K_{pd_I} / 2\pi K_{VCO}}}{K_{pd}}$$

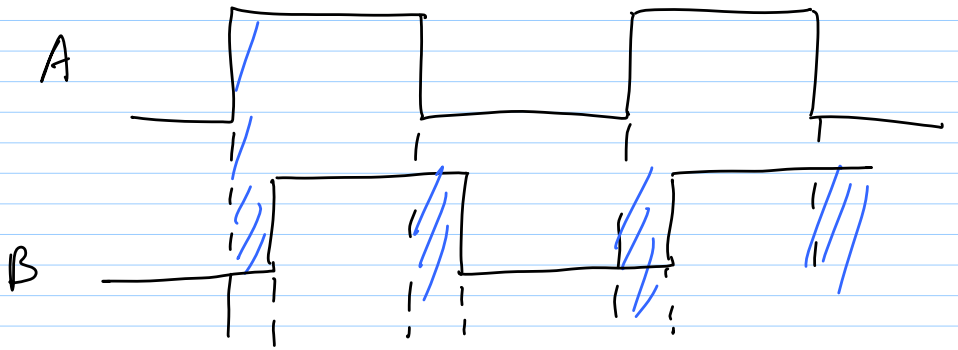


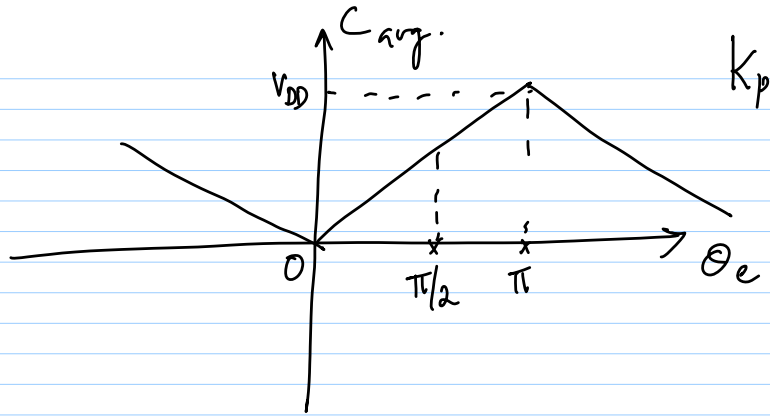
PD

1) Mult. type PD



2) XOR type PD





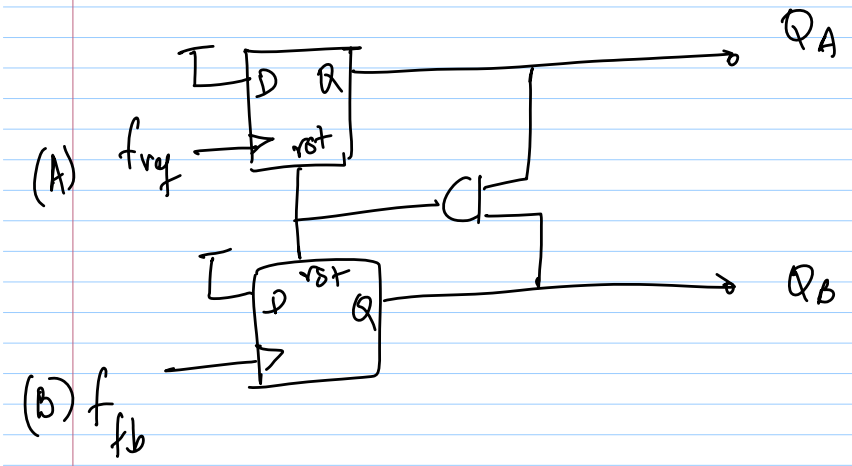
$$K_{pd} = \frac{V_{DD}}{\pi}$$

disadv.

a) monotonic over only certain ranges

b) operation is a function of duty cycle

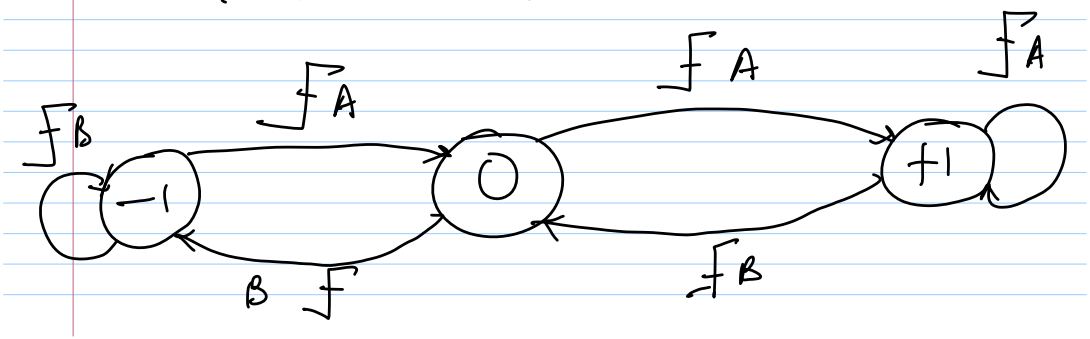
3) Tristate PFD

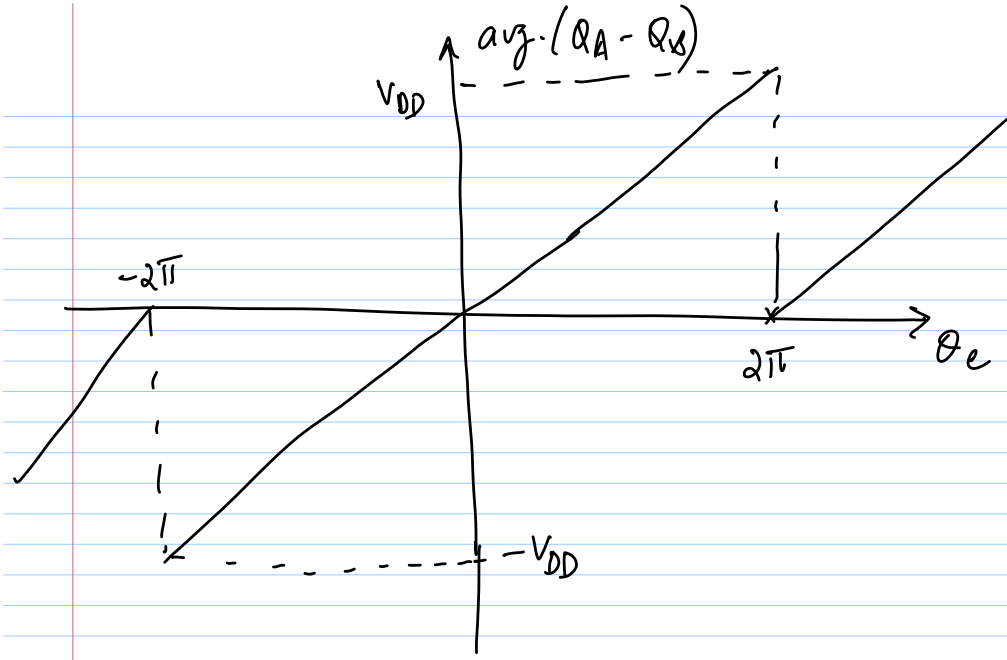


Q_A	Q_B	State
0	0	0
0	1	−1
1	0	+1
1	1	prohibited (reset)

$\theta_e = 0$

$\Rightarrow avg.(Q_A - Q_B) = 0$





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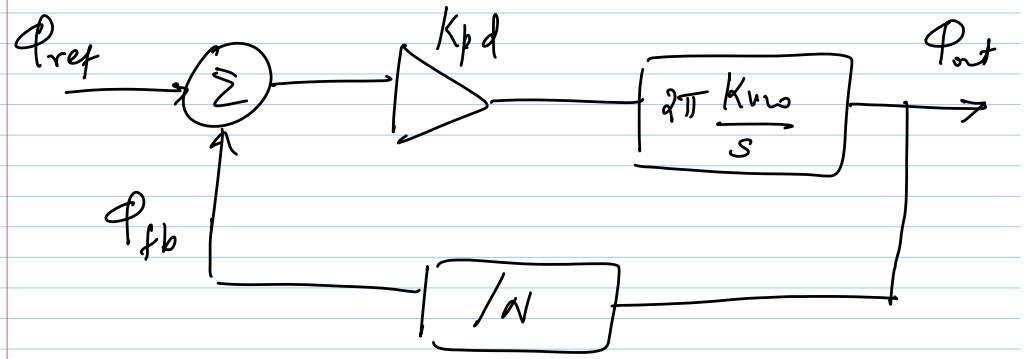
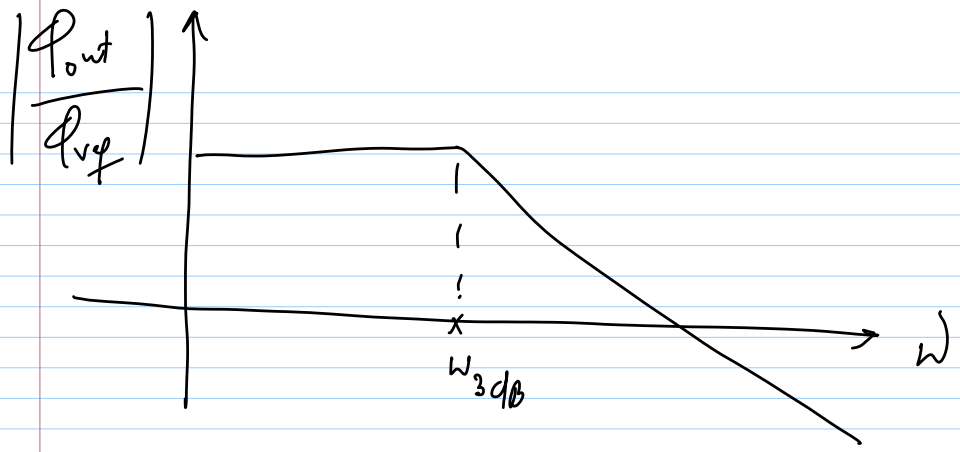
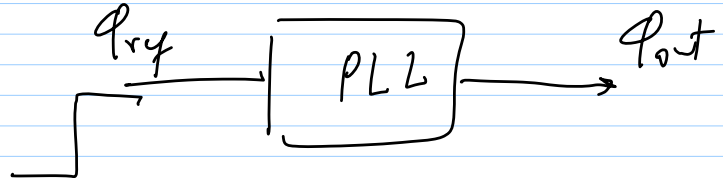
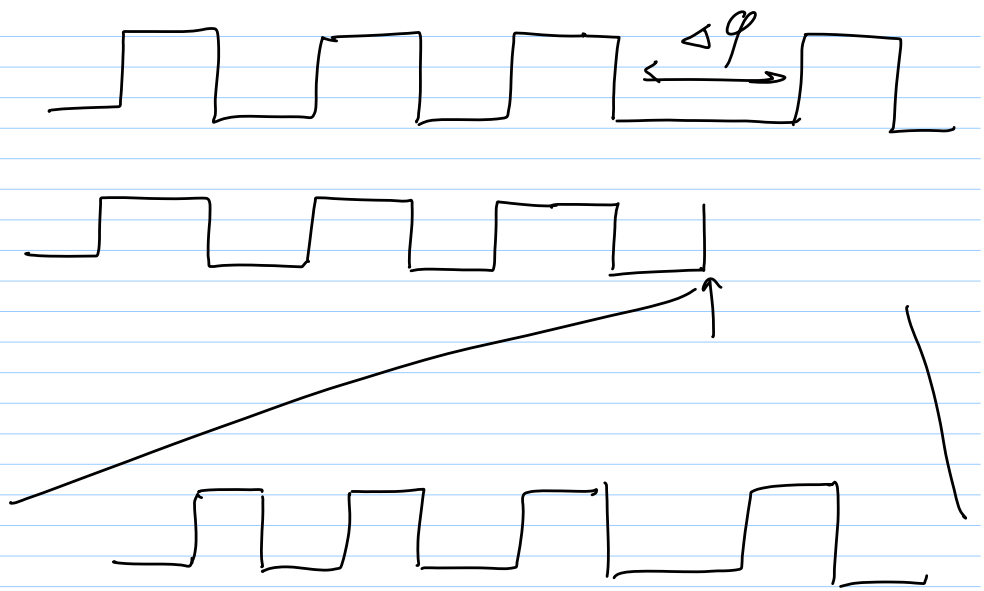
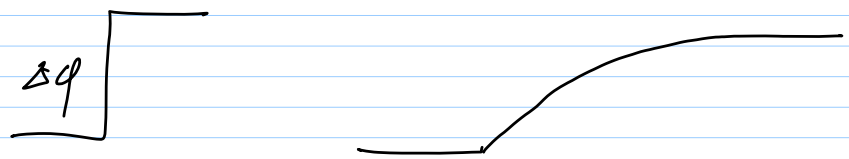


$$\frac{\varphi_{out}}{\varphi_{ref}}(s) = N \frac{1}{1 + \frac{Ns}{2\pi K_{pd} K_{VCO}}}$$

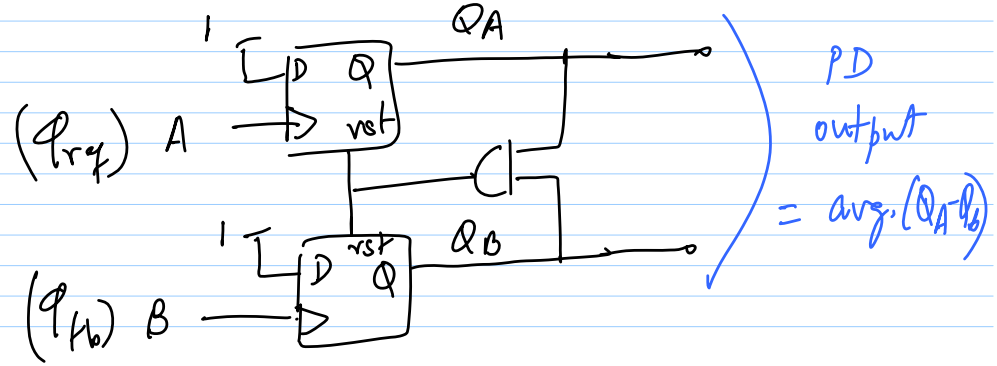


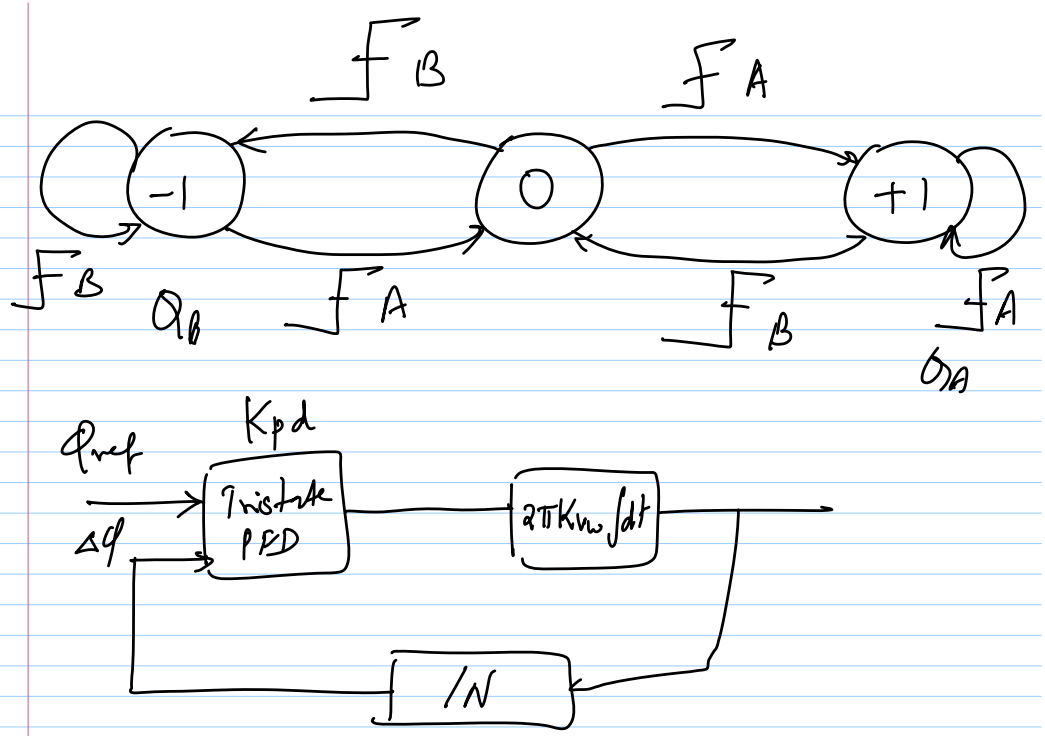






2) Ref feedthrough





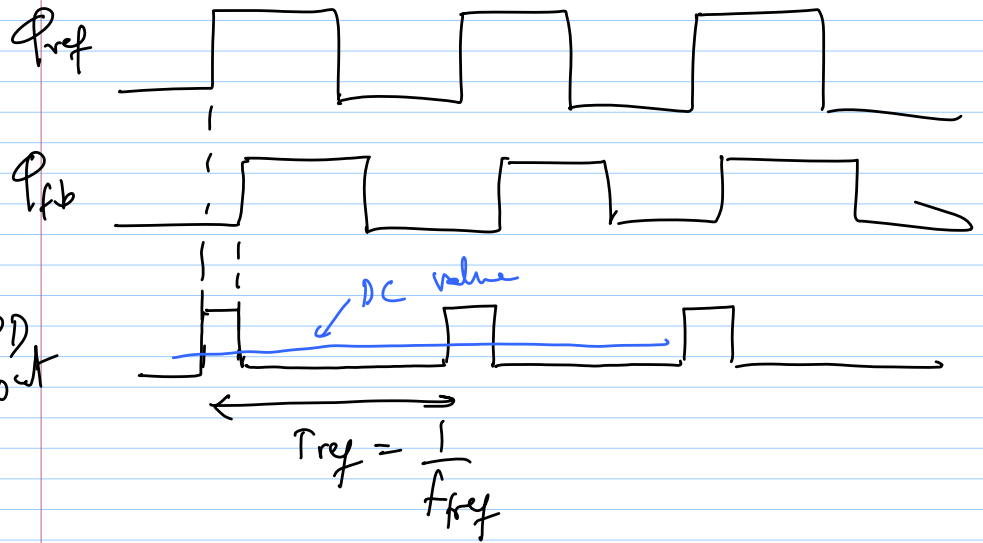
$$N f_{ref} = f_{out}$$

$$f_{out} = f_{free} + K_{VCO} \cdot V_C$$

in steady state

$$V_C = \frac{N f_{ref} - f_{free}}{K_{VCO}}$$

$$\Delta\phi = \frac{N f_{ref} - f_{free}}{K_{pd} K_{VCO}}$$



$$V_C = V_{C0} + v_c(t)$$

$$V_C(f) \longrightarrow f_{ref},\ 2f_{ref},\ \ldots$$

* Consider 1 term @ freq

$$V_{out}(t) = \cos\left[2\pi N f_{ref} t + b_1 \sin(2\pi f_{ref} t)\right]$$

assume b_1 is small

$$f_{out} \doteq f_{free} + K_{VCO} \cdot V_C$$

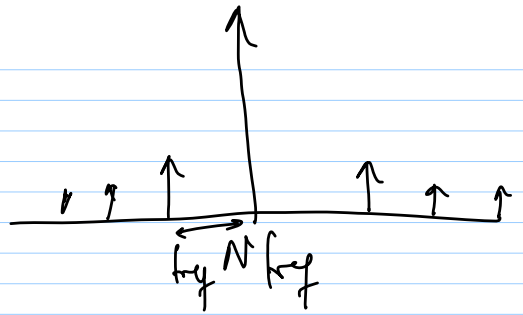
$$= f_{free} + K_{VCO} \cdot V_{C0} + K_{VCO} \cdot v_c(t)$$

$$V_{out}(t) = \cos(2\pi N f_{req} t)\cos(b_1 \sin(2\pi f_{req} t)) - \sin(2\pi N f_{req} t)\sin(b_1 \sin(2\pi f_{req} t))$$

If b_1 is small

$$V_{out}(t) = \cos(2\pi N f_{req} t) - b_1 \sin(2\pi N f_{req} t)\sin(2\pi f_{req} t)$$

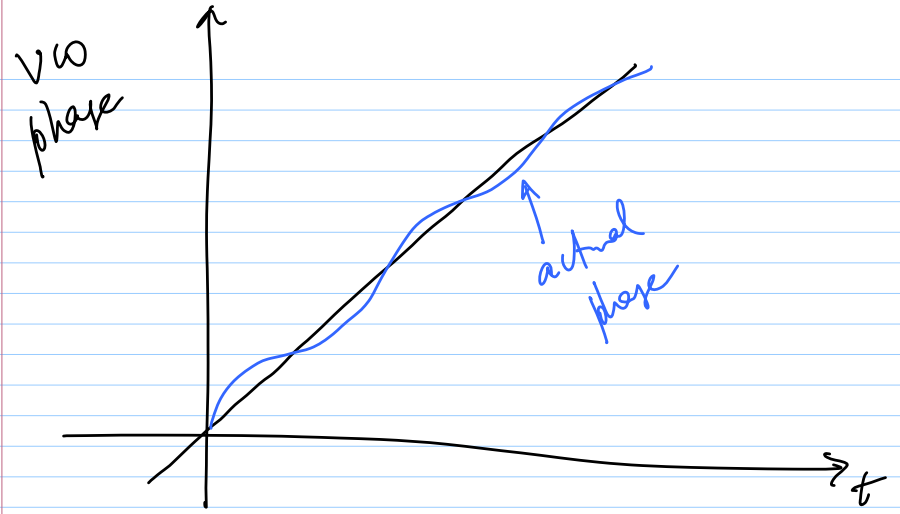
$$= \cos(2\pi N f_{req} t) - \frac{b_1}{2}\cos(2\pi(N \pm 1) f_{req} t)$$

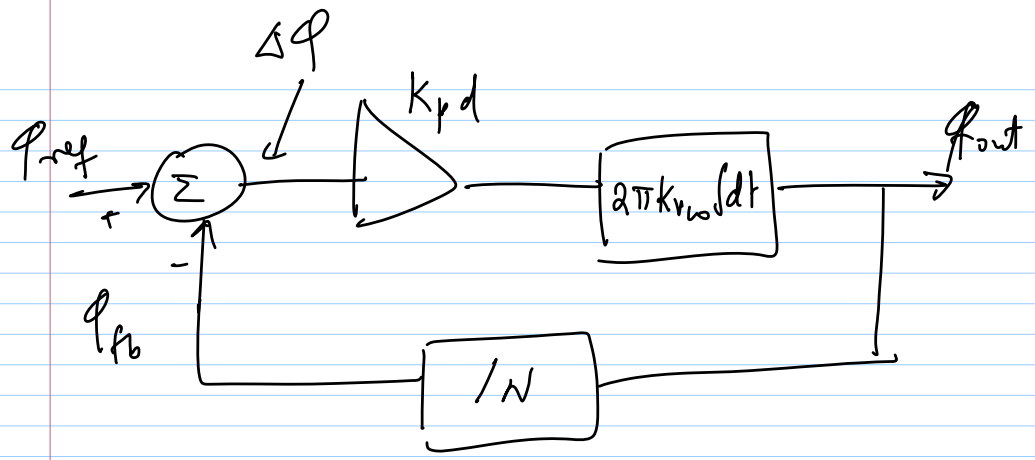


o/p of VCO is no longer periodic @ $N f_{req}$

$$f_{out} = f_{free} + K_{VCO} \cdot V_{C_0} + K_{VCO} v_c(t)$$

$$V_{out}(t) = \cos\left[2\pi f_{free} t + K_{VCO} \int v_c(t) dt\right]$$

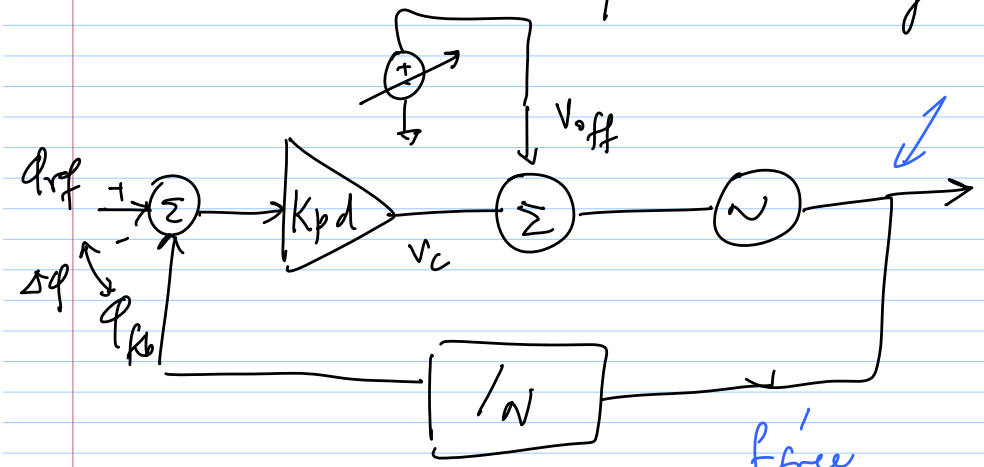




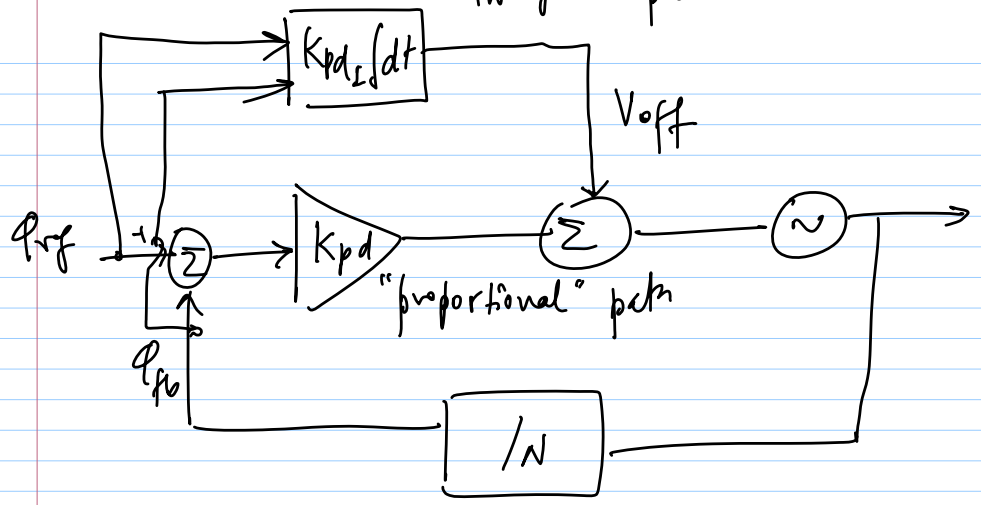
$$\Delta\varphi = \frac{N f_{ref} - f_{free}}{K_{pd}\ K_{vco}}$$

$\Delta\varphi = 0$ when $N f_{ref} = f_{free}$

We want $\Delta\varphi = 0$ always



$$f_{out} = (f_{free} + K_{vco} \cdot V_{off}) + K_{vco} \cdot V_c$$



in steady state: $V_{off} = \frac{f_{out} - f_{free}}{K_{pd}\ K_{vco}}$

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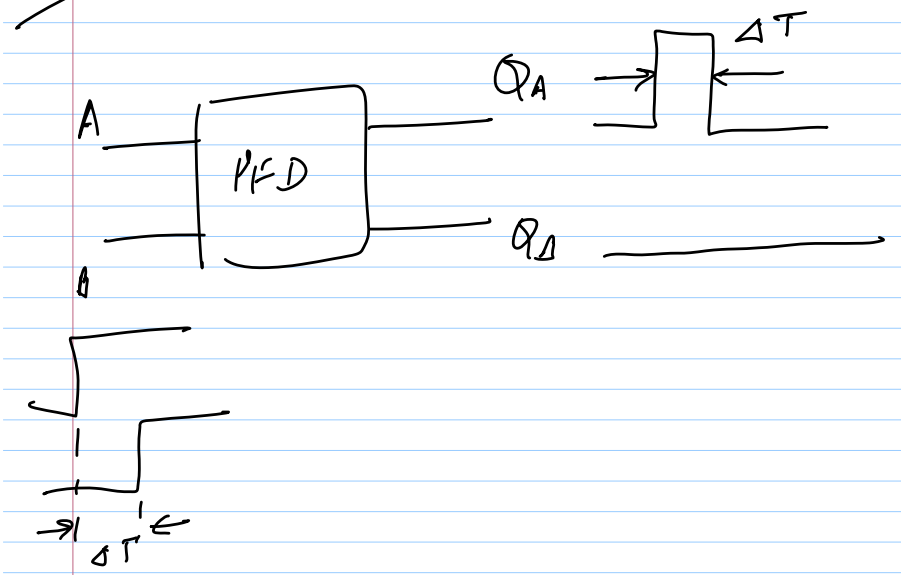
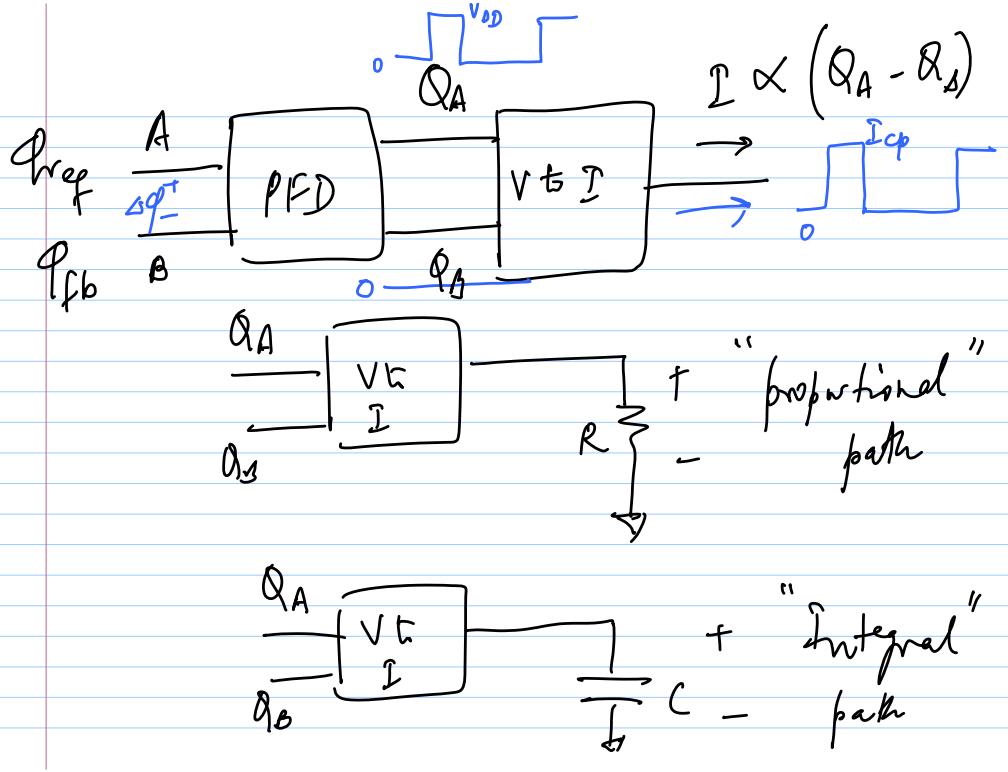
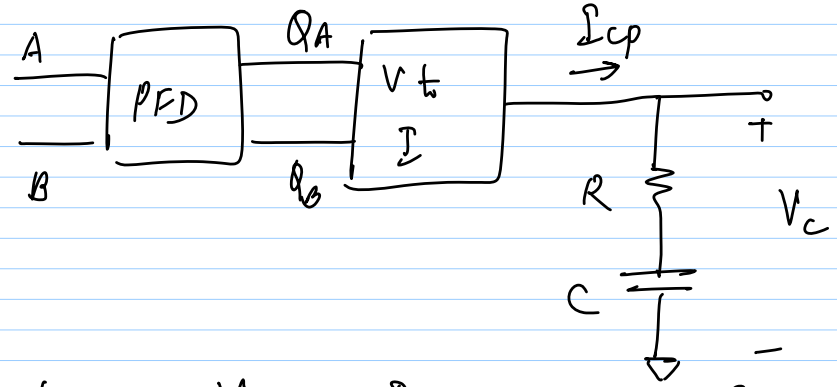
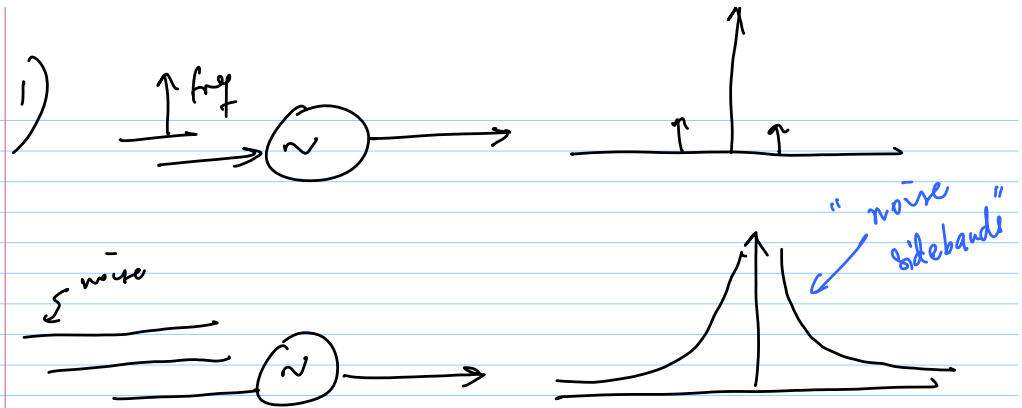






$$K_{pd} = \frac{V_{DD}}{2\pi} \cdot \frac{I_{cp}}{V_{DD}} \cdot R = \frac{I_{cp} R}{2\pi}$$

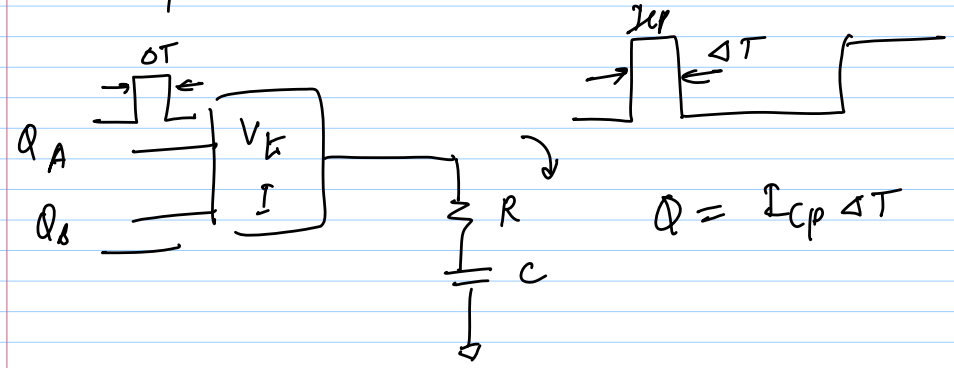
$$K_{pd_I} = \frac{I_{cp}}{2\pi C}$$



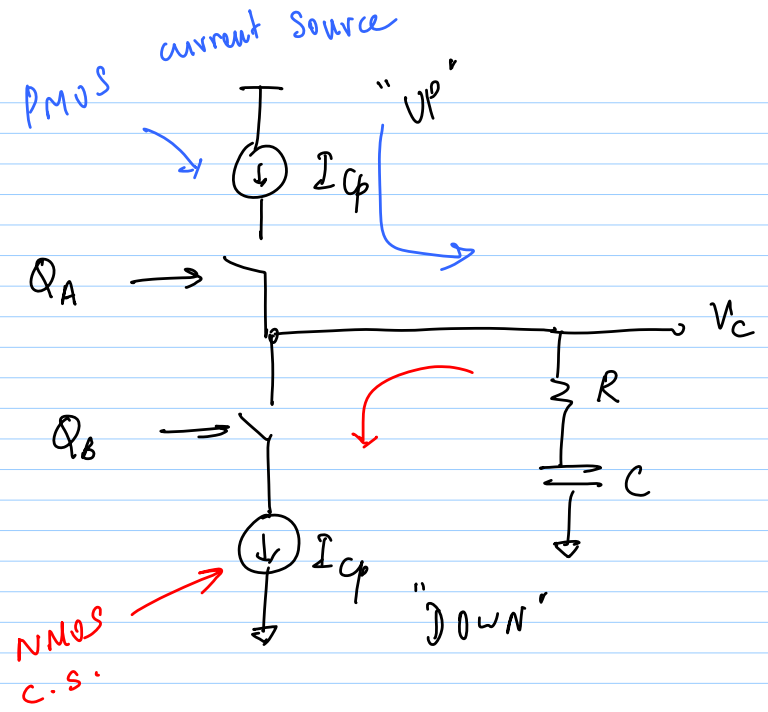
* Noise → R
  → I_{cp}

* Area → C

I_{cp} → "Charge Pump"



$$Q = I_{cp} \Delta T$$



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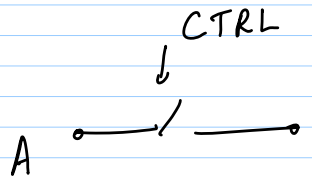
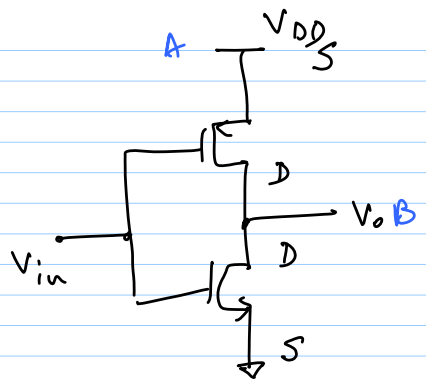


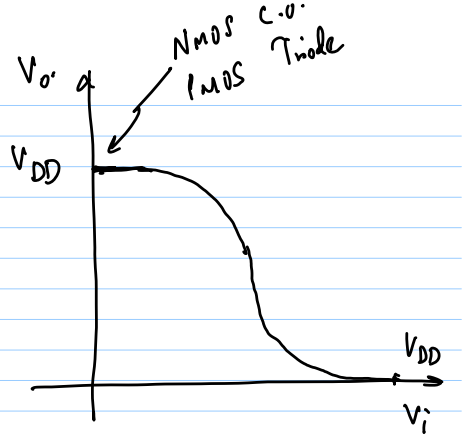
V_A = small (e.g. $0 - V_{DD}/2$)

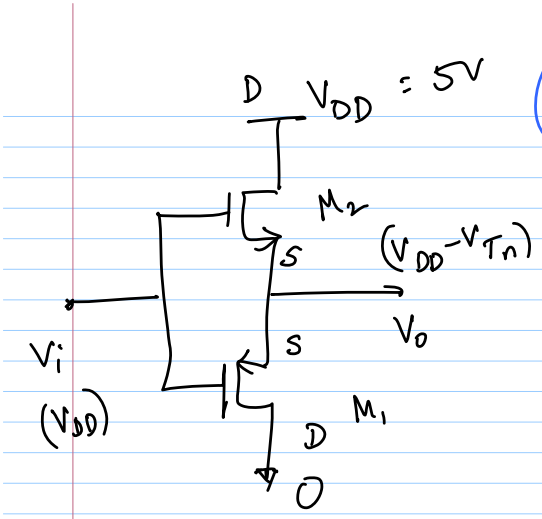
↳ NMOS switch

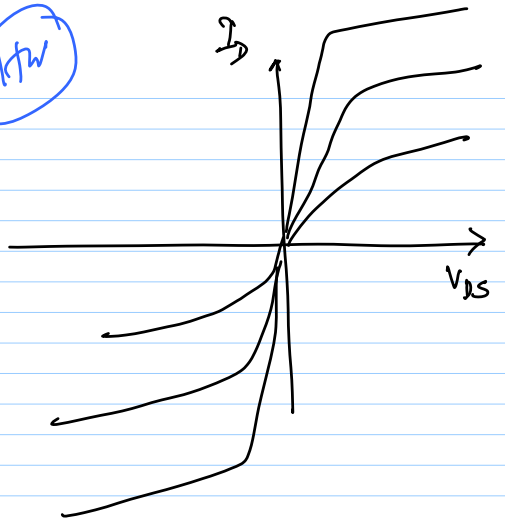
V_A = large (e.g. $V_{DD}/2 - V_{DD}$)

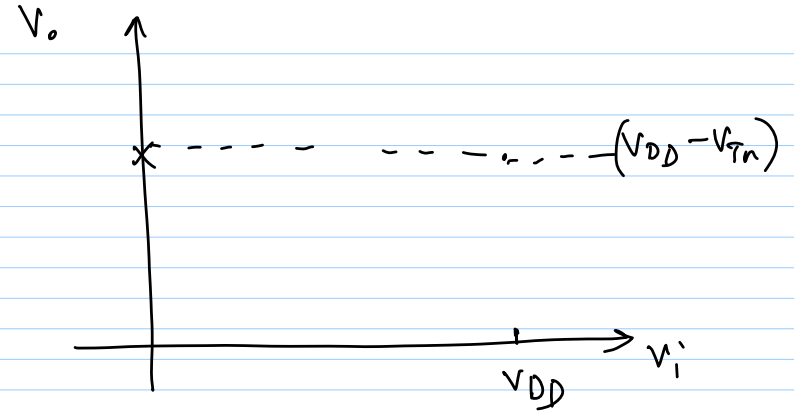
↳ PMOS switch

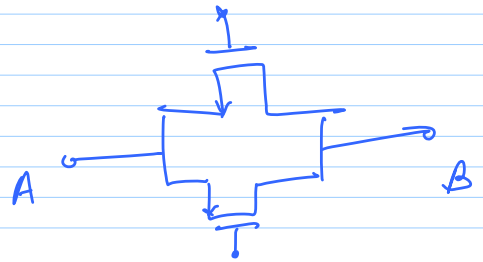


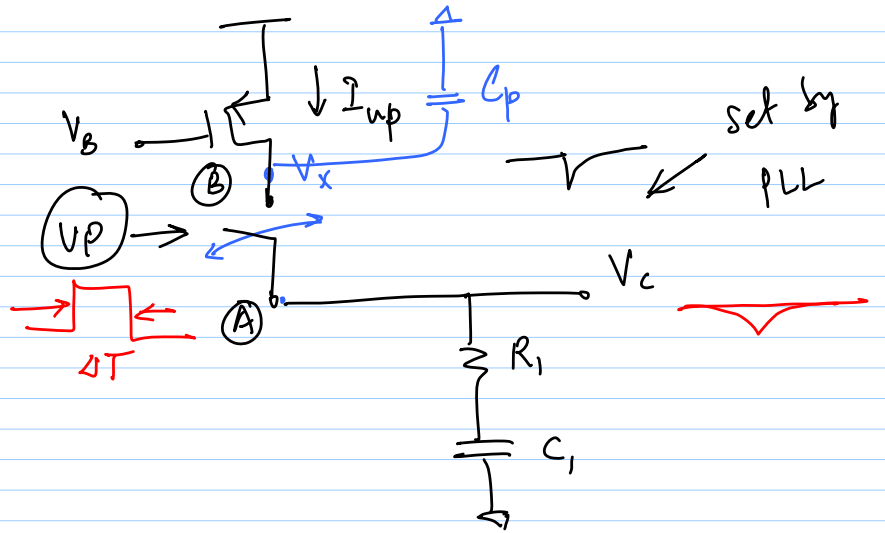


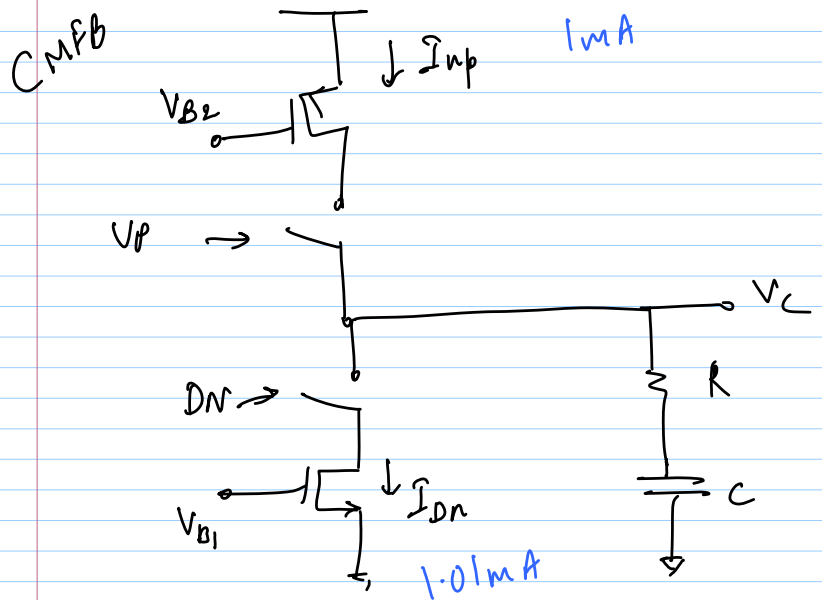


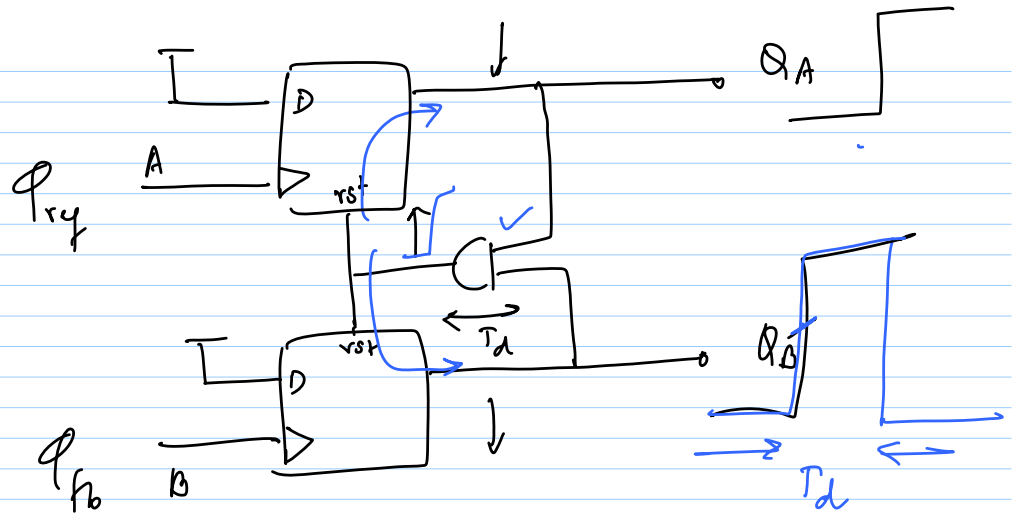


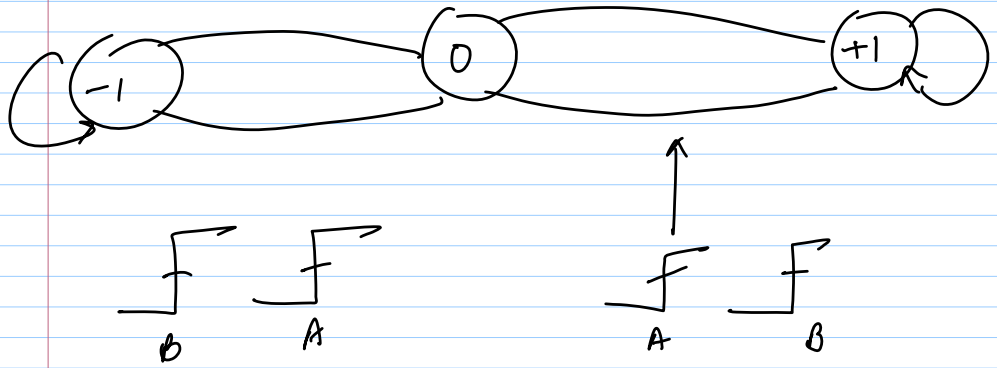

V_o
$(V_{DD}-V_{Tn})$
V_{DD}
V_i

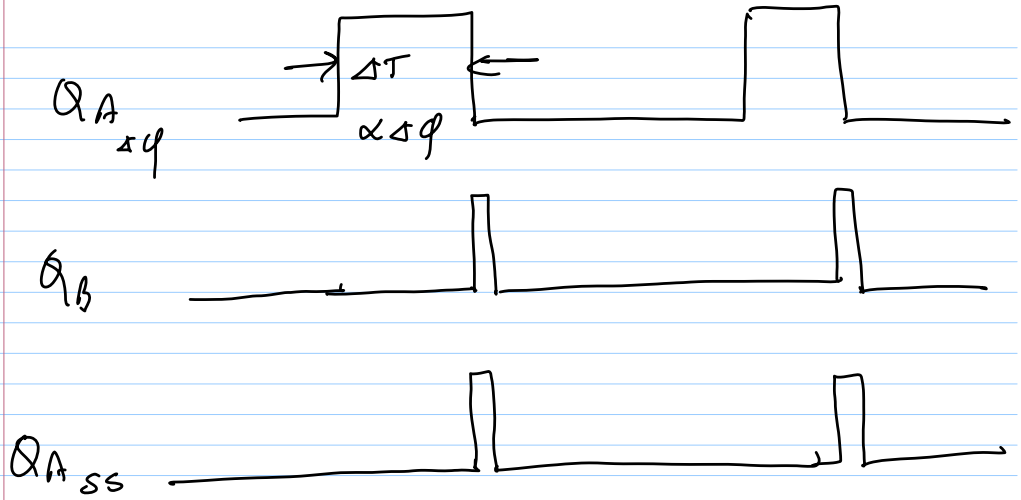

A
B
R_{on}


V_B
I_{up}
C_p
B
V_x
set by PLL
VP
V_c
A
UT
R_1
C_1


CMFB
I_{up}
1mA
V_{B2}
VP
V_c
DN
R
I_{DN}
C
V_{B1}
1.01mA


Q_A
D
A
ϕ_{rq}
rst
T_d
rst
D
Q_B
ϕ_{fb}
B
T_d





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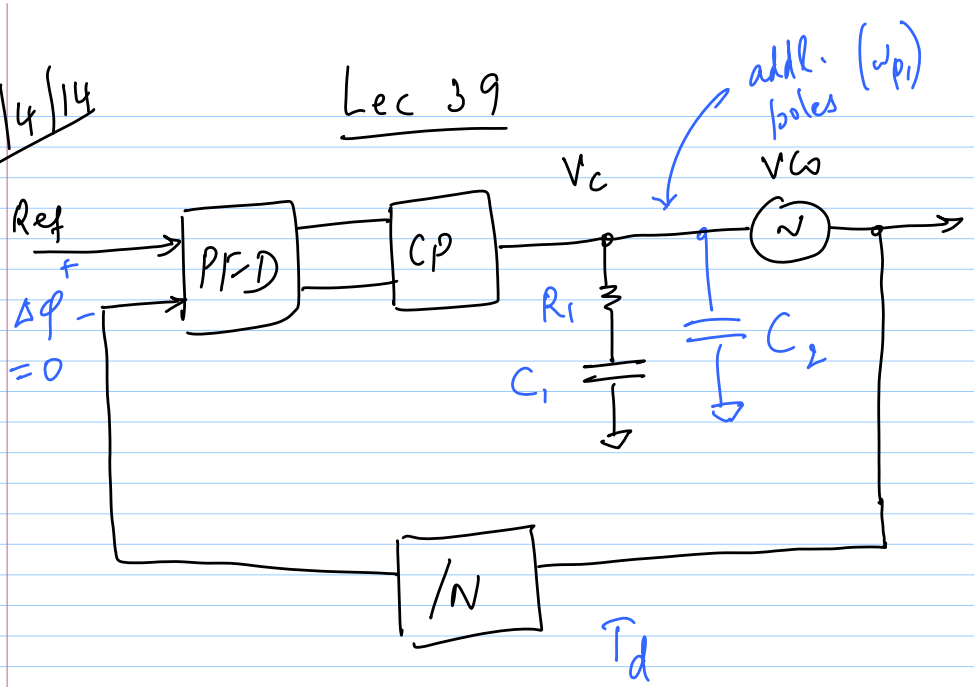
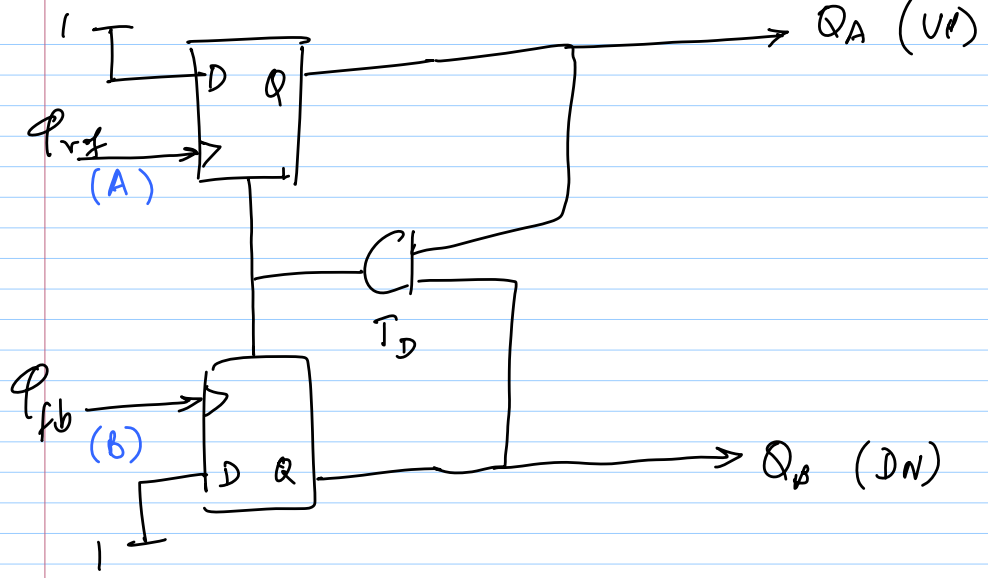
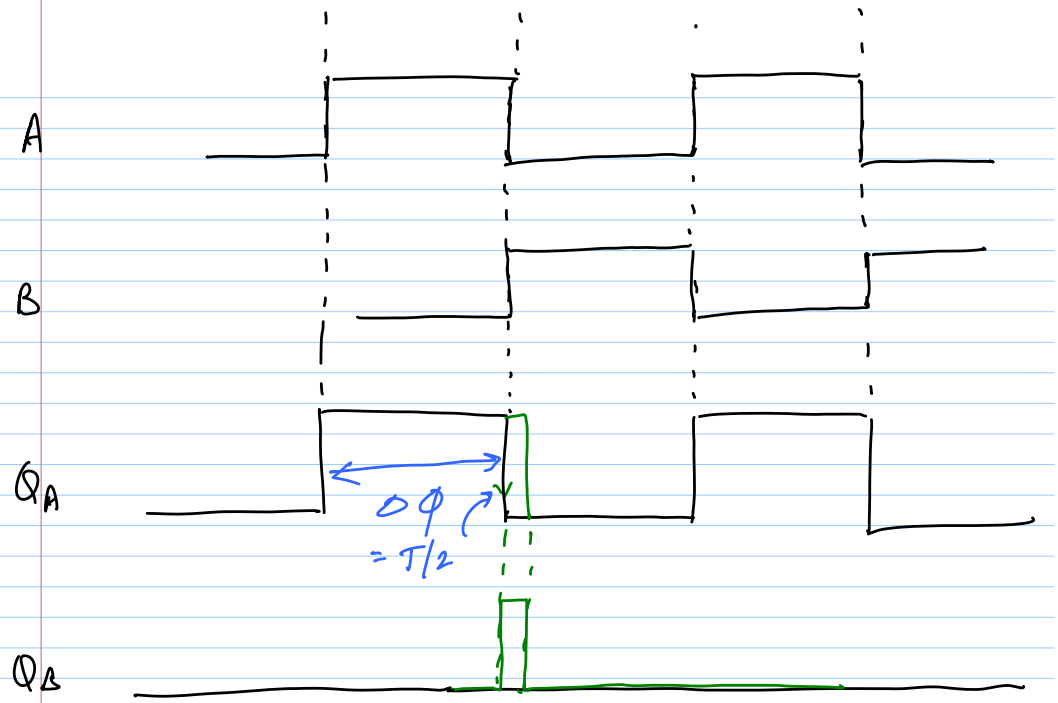
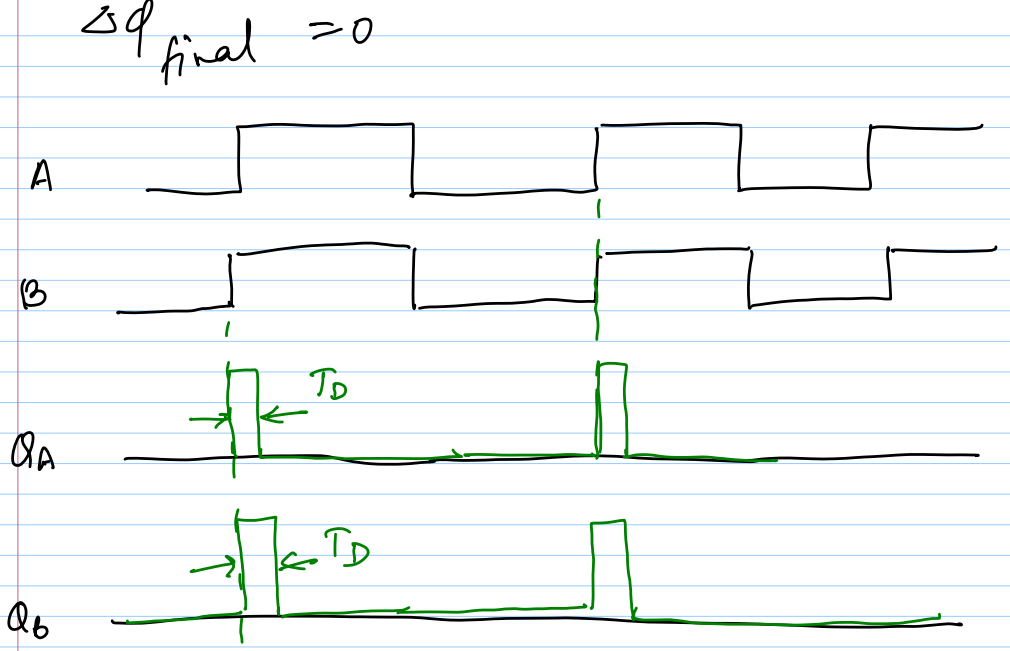
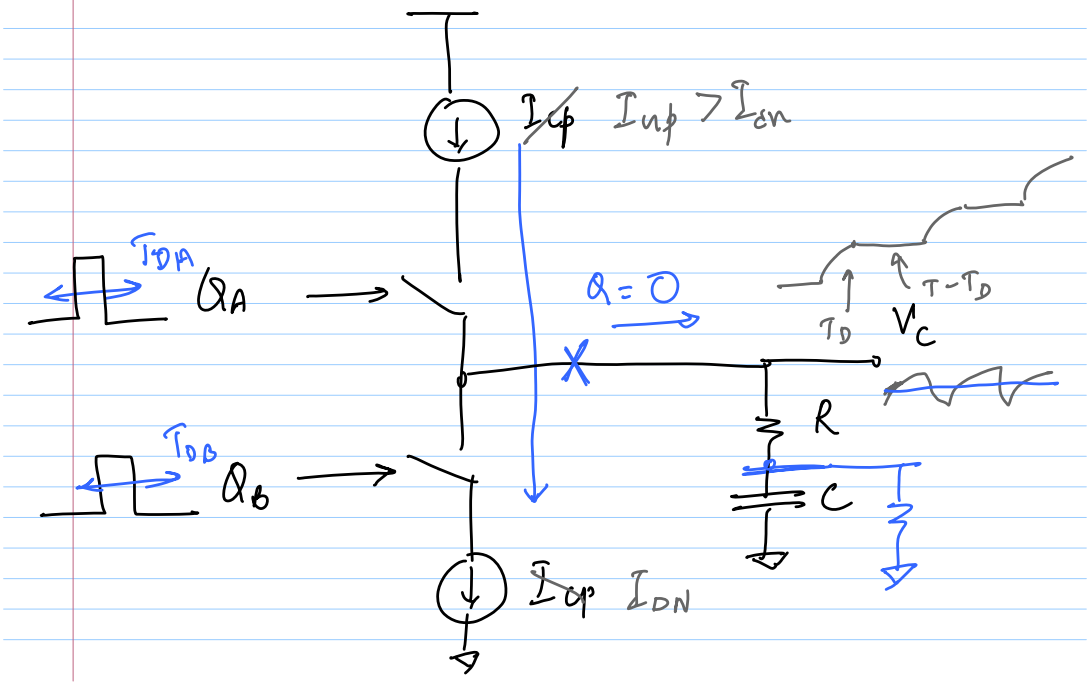


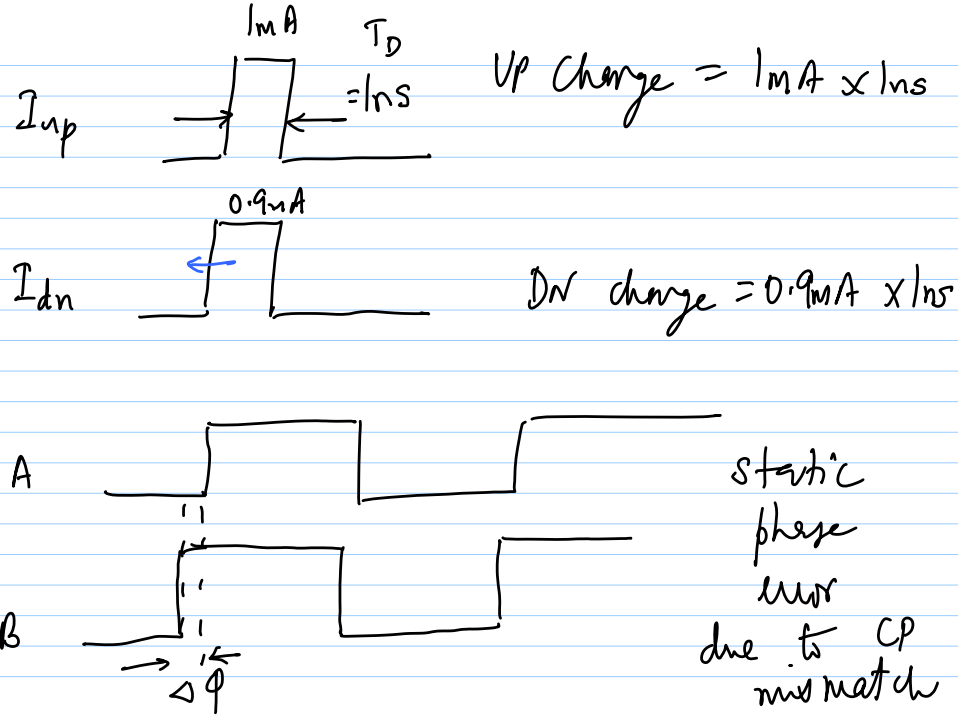


$Q_A = Q_B = 1$ ✗

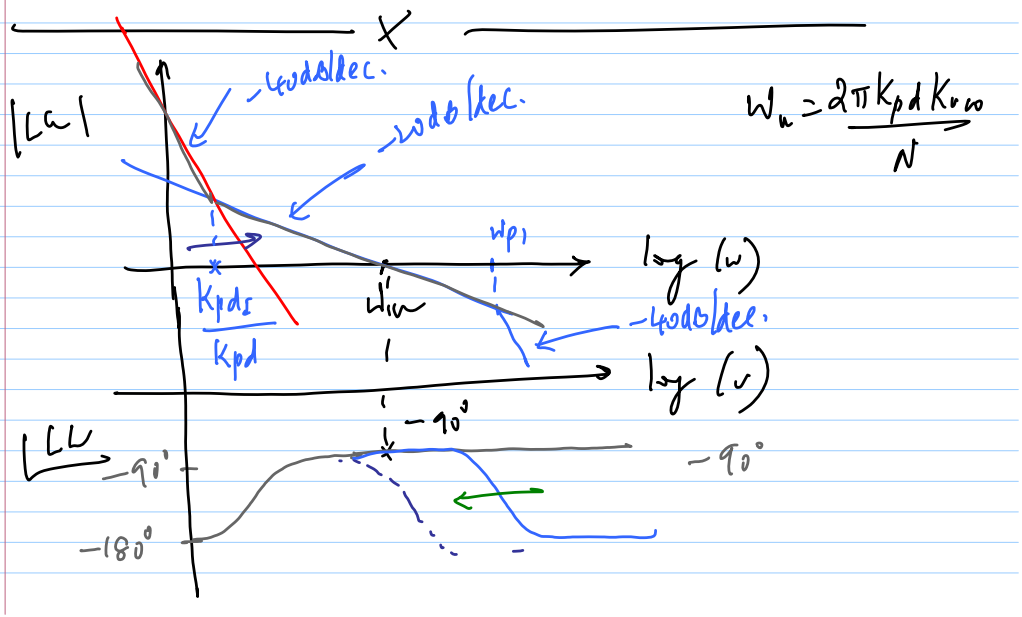

A
B
Q_A
Q_B
$\Delta\varphi$
$= T/2$

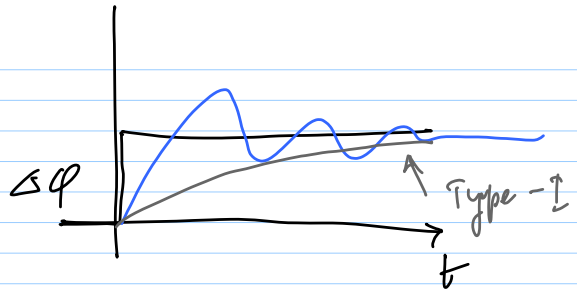

$\Delta\varphi_{final} = 0$
A
B
Q_A
Q_B
T_D
T_D

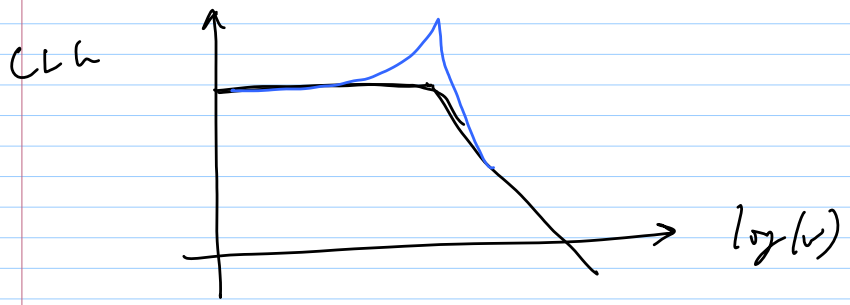

$I_{up} > I_{dn}$
T_{DA}
Q_A
$Q = 0$
T_{DB}
Q_B
T_D
$T - T_D$
V_C
R
C
I_{DN}


1mA
T_D
$= 1ns$
I_{up}
Up charge = 1mA x 1ns
0.9mA
I_{dn}
Dn charge = 0.9mA x 1ns
A
B
$\Delta\varphi$
Static phase error due to CP mismatch

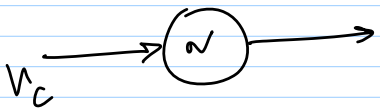
* Use CMFB to set $I_{up} = I_{dn}$





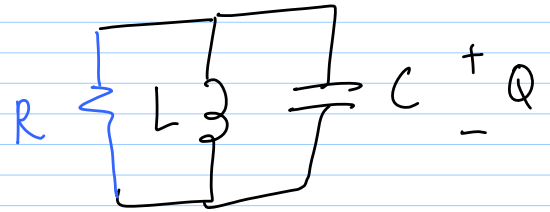


VCOs



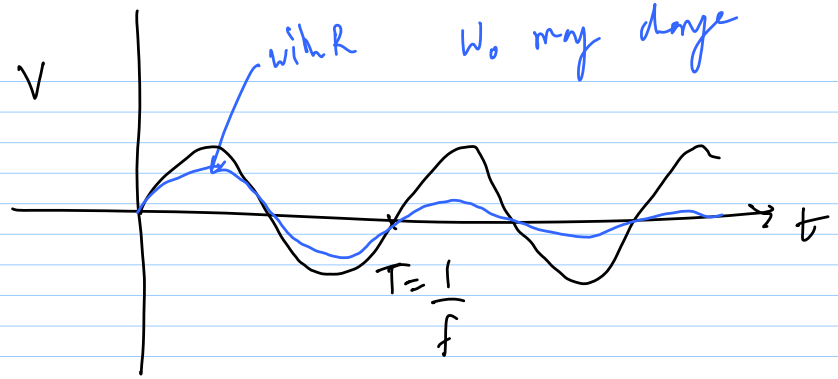
$$f_{vco} = f_{free} + K_{vco} \cdot v_c$$

LC Oscillator



$$f = \frac{1}{2\pi\sqrt{LC}}$$

↑ resonant freq.



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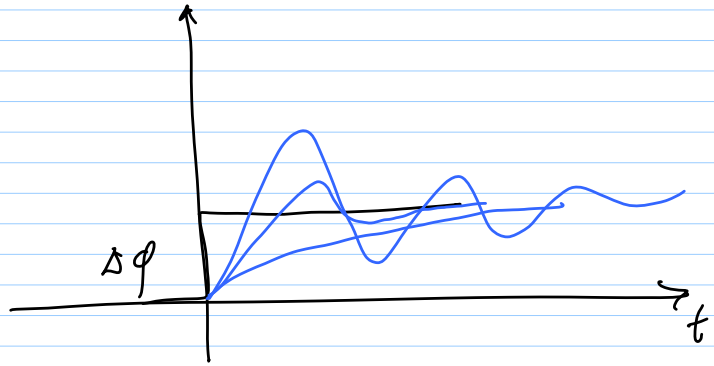
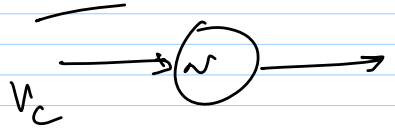
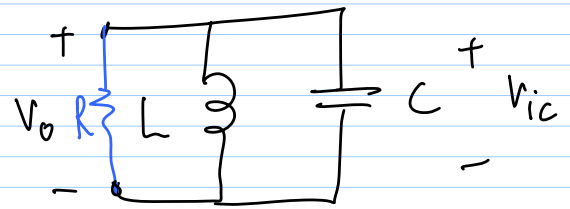


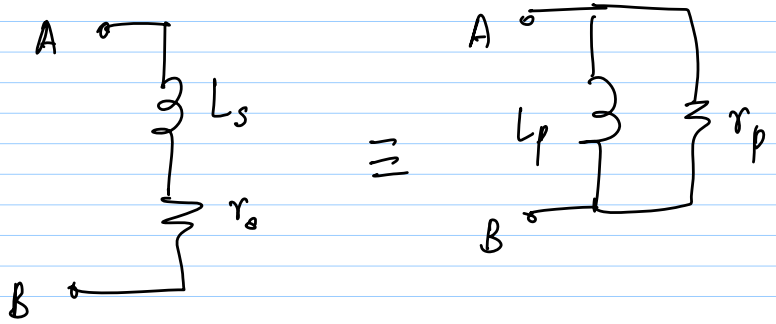
VCO

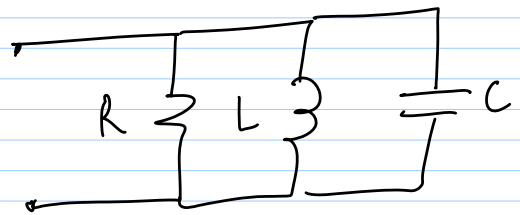


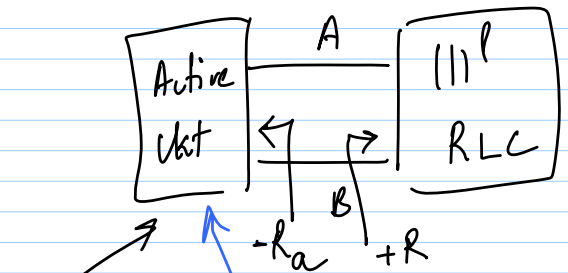
$$f_{VCO} = f_{free} + K_{VCO} \cdot V_C$$



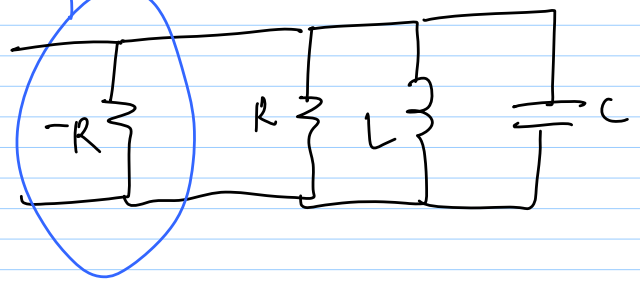
$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

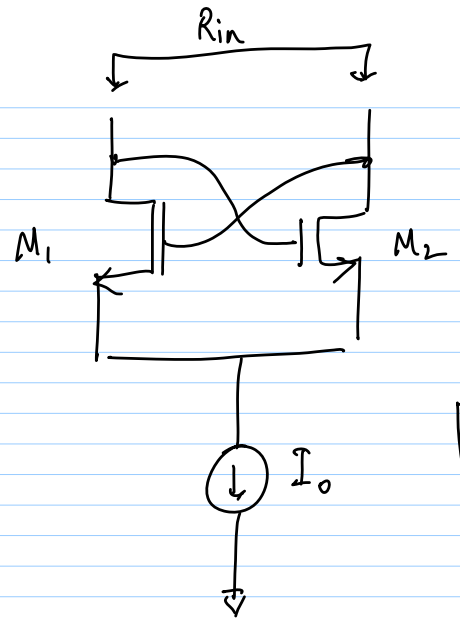






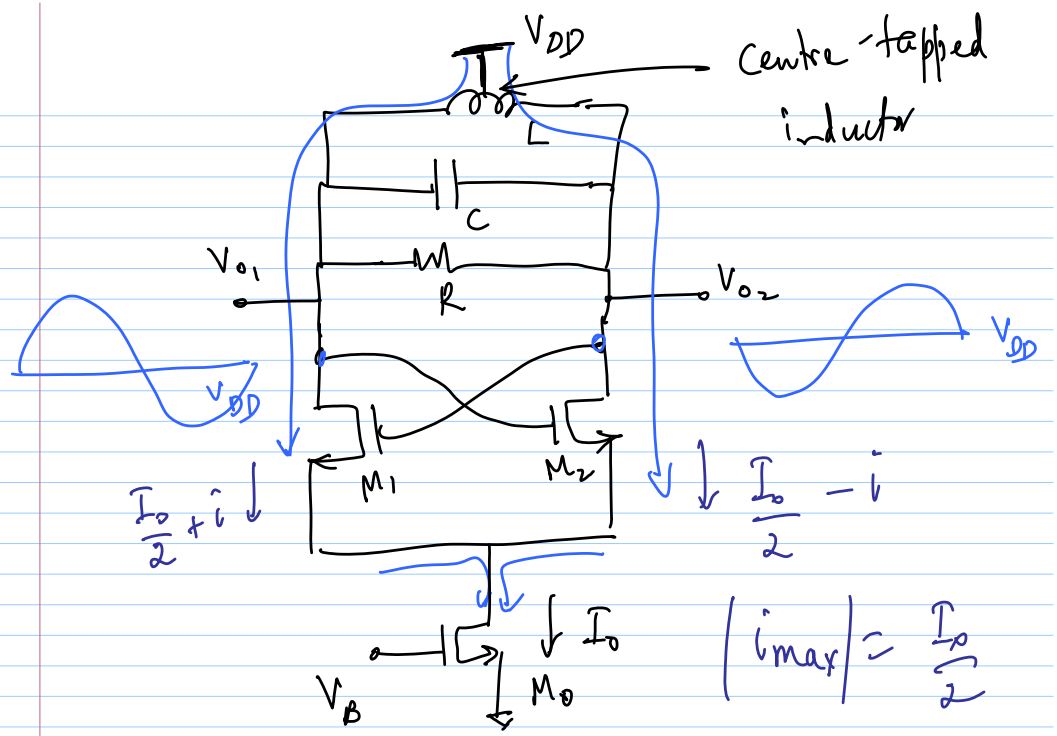
Energy Restorer

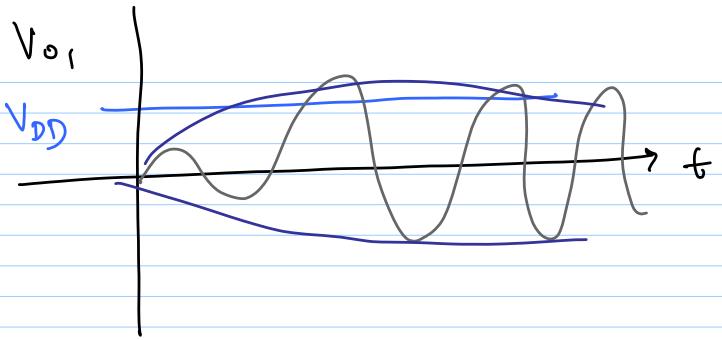




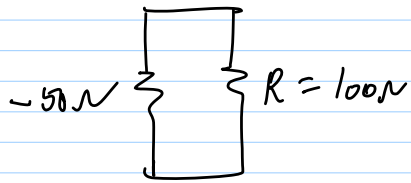
$$R_{in} = -\frac{2}{g_m}$$

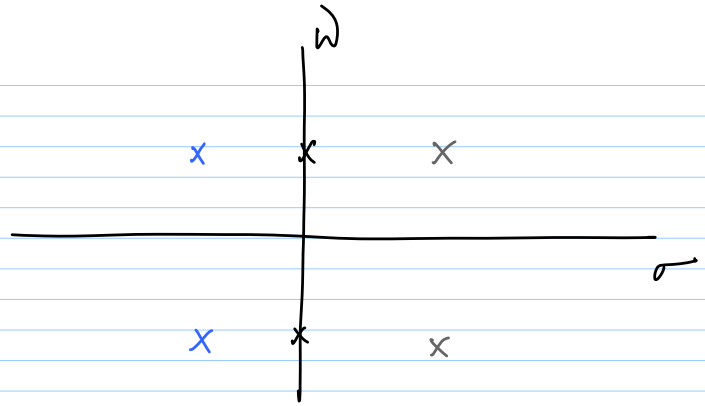
$$-\frac{2}{g_m} = -R$$





$R_a < R$





$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$

tuning: 1) rev. biased diode

2) MOS varactor

V.C. cap