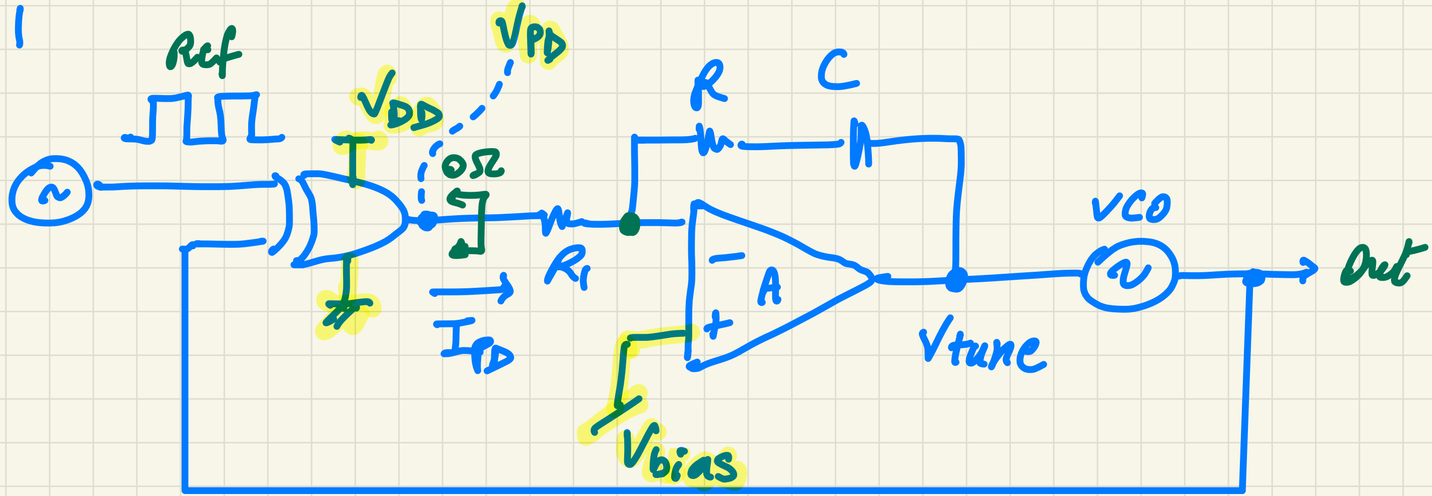
RF Circuit Design

T2

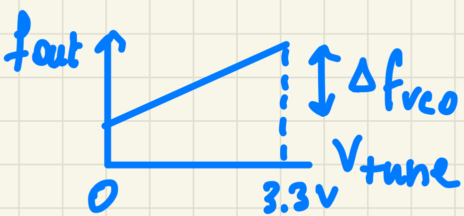
T2.1



$V_{DD} = 3.3\,V$

$f_{ref} = 200\,KHz$

$A \to \infty$



a. $V_{bias} = 1.65V = V_{DD}/2$

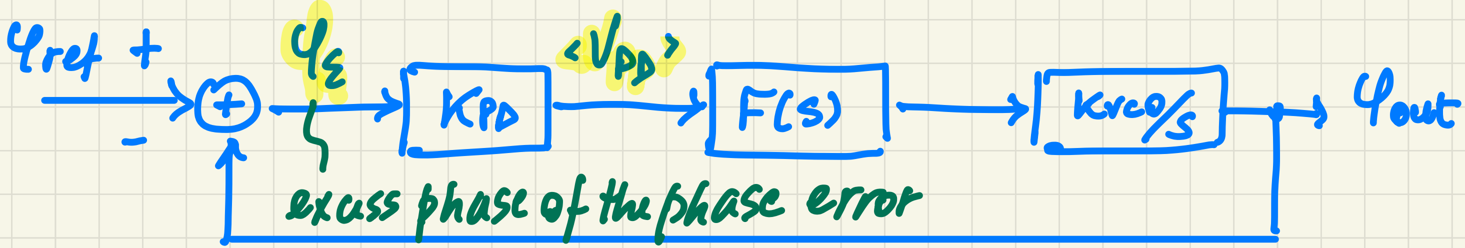
unknown R_1, R, C, K_{vco}

i. $I_{PD\,max} = 1\,mA$

ii. $\Delta f_{vco} = 50\,KHz$

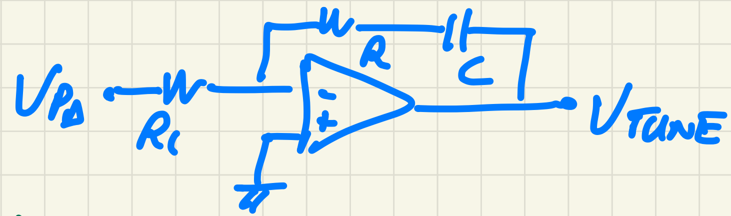
iii. $\varphi_m = 60\,deg$

iv. $f_u = 1\,KHz$

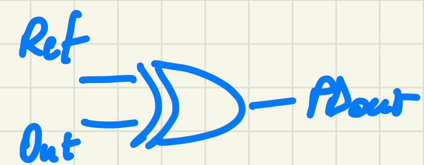


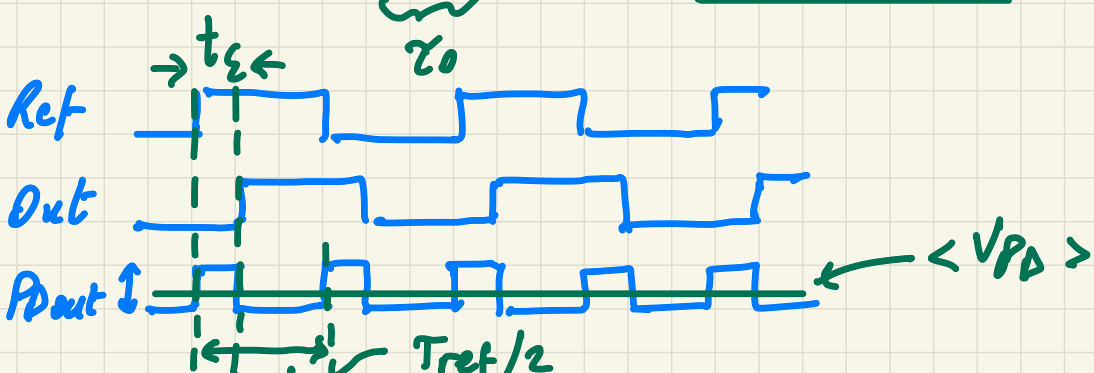
linear "CT" equivalent model

$$F(s) = \frac{R + 1/sC}{R_1} = \frac{1 + s\overbrace{RC}^{\tau_z}}{s\underbrace{R_1 C}_{\tau_0}}$$



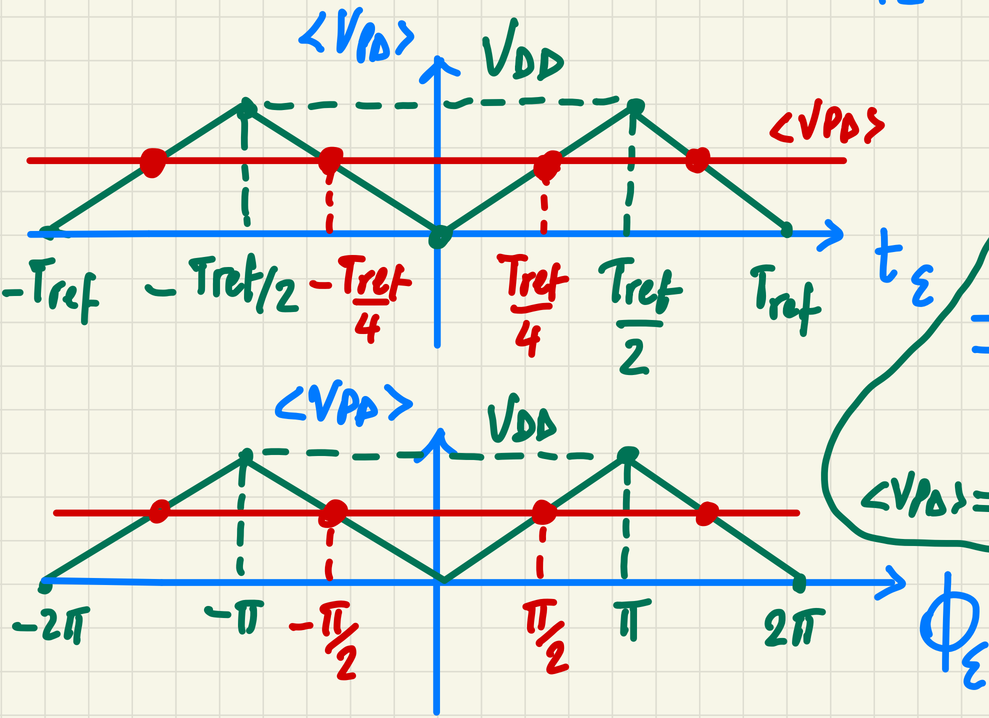
$$\underline{\varphi_\varepsilon = \omega_{ref} \cdot t_\varepsilon}$$

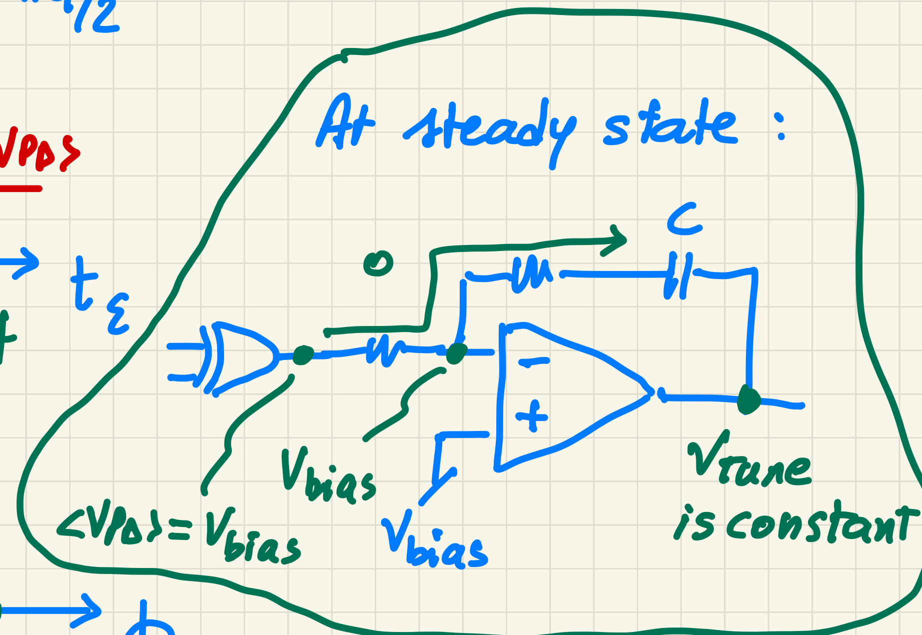




Ref	Out	PDout
0	0	0
0	1	1
1	0	1
1	1	0

$$\langle V_{PD} \rangle = D \cdot V_{DD} = \frac{t_\varepsilon}{T_{ref}/2} \cdot V_{DD} = \frac{2}{T_{ref}} \cdot V_{DD} \cdot t_\varepsilon$$



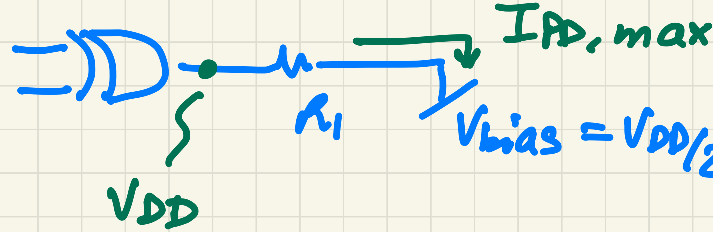


$$\Rightarrow K_{PD} = \frac{\langle V_{PD} \rangle}{\phi_\varepsilon} = \frac{V_{DD}}{\pi}$$

$$V_{bias} = V_{DD}/2$$

$$\Rightarrow \langle V_{PD} \rangle = V_{DD}/2$$

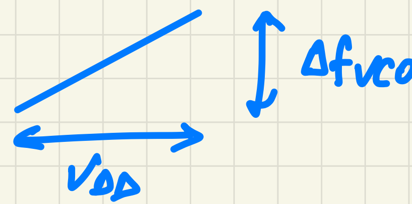
i. $I_{PD max} = 1mA$



$V_{PD,max} = V_{DD}$

$I_{PD,max} = \dfrac{V_{DD} - V_{DD}/2}{R_1} = 1\,mA$; $R_1 = \dfrac{1.65V}{1mA} = 1.65k\Omega$

ii. $\Delta f_{vco} = 50\,kHz$



$K_{vco} \triangleq \dfrac{\partial \omega_{out}}{\partial V_{TUNE}}$

$K_{vco} = \dfrac{2\pi \cdot 50k}{3.3} = 95.2\,\dfrac{krad}{s \cdot V}$

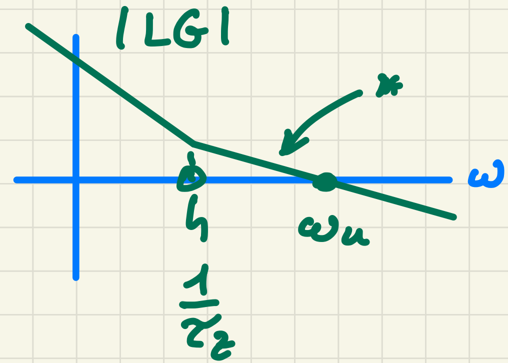
iii. iv. $\varphi_m = 60\,deg$ $f_u = 1kHz$

$LG(s) = K_{PD}\dfrac{K_{VCO}}{s}F(s) = K_{PD} \cdot K_{VCO}\,\dfrac{1}{s} \cdot \dfrac{1 + s\tau_z}{s\tau_0}$

$\tau_z = RC$ $\tau_0 = R_1 C$

" TYPE-II PLL "

• $|LG(\omega_u)| = 1$;



(1) $$\frac{K_{PD}\cdot K_{VCO}}{\omega_u^2\cdot\tau_0}\cdot\sqrt{1+\omega_u^2\tau_z^2} = 1$$

* Asymptotic approx. $LG(j\omega) \approx \frac{K_{PD}K_{VCO}}{j\omega}\cdot\frac{\tau_z}{\tau_0}$

• $$\varphi_m = \cancel{180°} - \cancel{90°} - \cancel{90°} + \arctan\left(\frac{\omega_u}{\omega_z}\right) = 60 \text{ deg}$$

(2) $$\omega_z = \frac{\omega_u}{\tan(60)} = \frac{\omega_u}{\sqrt{3}}$$

$\tau_z = RC$

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

(1) $$\tau_0 = \frac{K_{PD}\,K_{VCO}}{\omega_u^2}\cdot\sqrt{1+\frac{\cancel{\omega_u^2}}{\cancel{\omega_u^2}}\cdot 3} = \frac{K_{PD}K_{VCO}}{\omega_u^2}\cdot 2 =$$

$$= \frac{\cancel{V_{DD}}}{\cancel{\pi}}\cdot\frac{2\cancel{\pi}\cdot\Delta f_{VCO}}{\cancel{V_{DD}}}\cdot\frac{2}{(2\pi\cdot 10^3)^2} = \frac{4\cdot 50k}{(2\pi)^2\cdot 10^6} = 5.07 \text{ ms}$$

$$C = \frac{\tau_0}{R_1} = \frac{5.07\text{ ms}}{1.65\text{ k}\Omega} = 3.07\,\mu F$$

(with asyntotic approx. $2.66\,\mu F$)

$$R = \frac{\tau_z}{C} = \frac{1}{\frac{\omega_a}{\sqrt{3}}\cdot C} = \frac{\sqrt{3}}{2\pi\cdot 10^3\cdot 3.07\cdot 10^{-6}} = 89.8\,\Omega$$

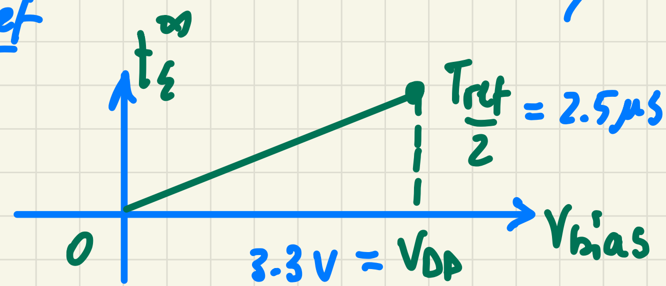
(with asymtotic approx. $103.7\,\Omega$)

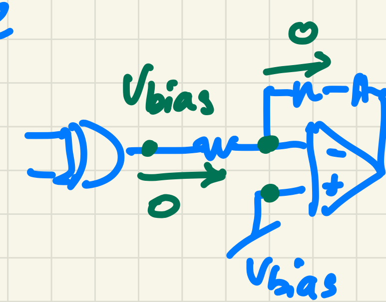
b) Static time error t_ε vs. V_{bias}

$$\langle V_{PD}\rangle = V_{DD}\cdot\frac{t_\varepsilon}{T_{ref}/2} = V_{bias}$$

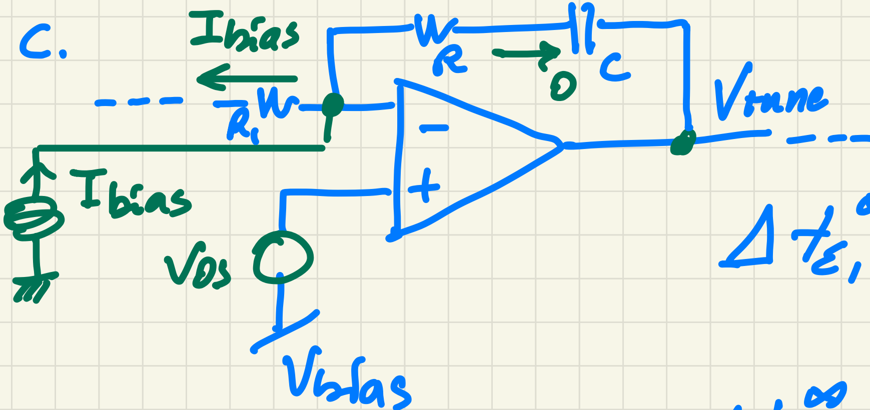
at steady state

$$t_\varepsilon^{\infty} = \frac{V_{bias}}{V_{DD}}\cdot\frac{T_{ref}}{2}$$





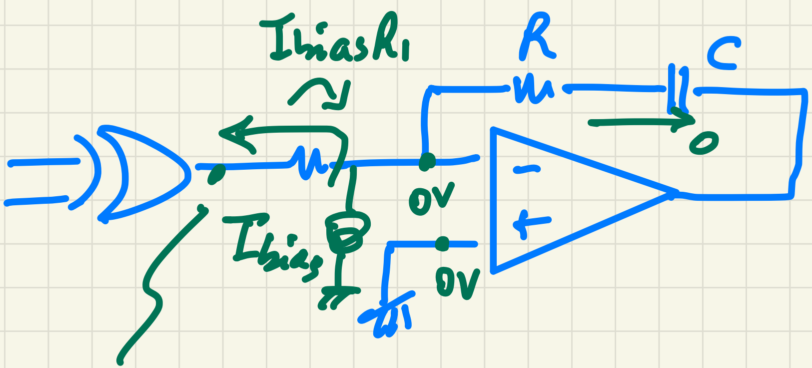
C.



$$t_{\varepsilon}^{\infty} = ?$$

$$\Delta t_{\varepsilon_1}^{\infty} = \frac{V_{OS}}{V_{DD}} \cdot \frac{T_{ref}}{2}$$

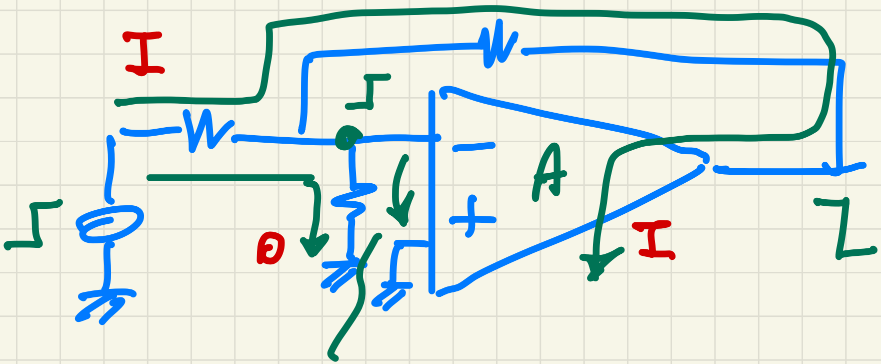
$$\Delta t_{\varepsilon_2}^{\infty} = \frac{-I_{bias}R_1}{V_{DD}} \cdot \frac{T_{ref}}{2}$$



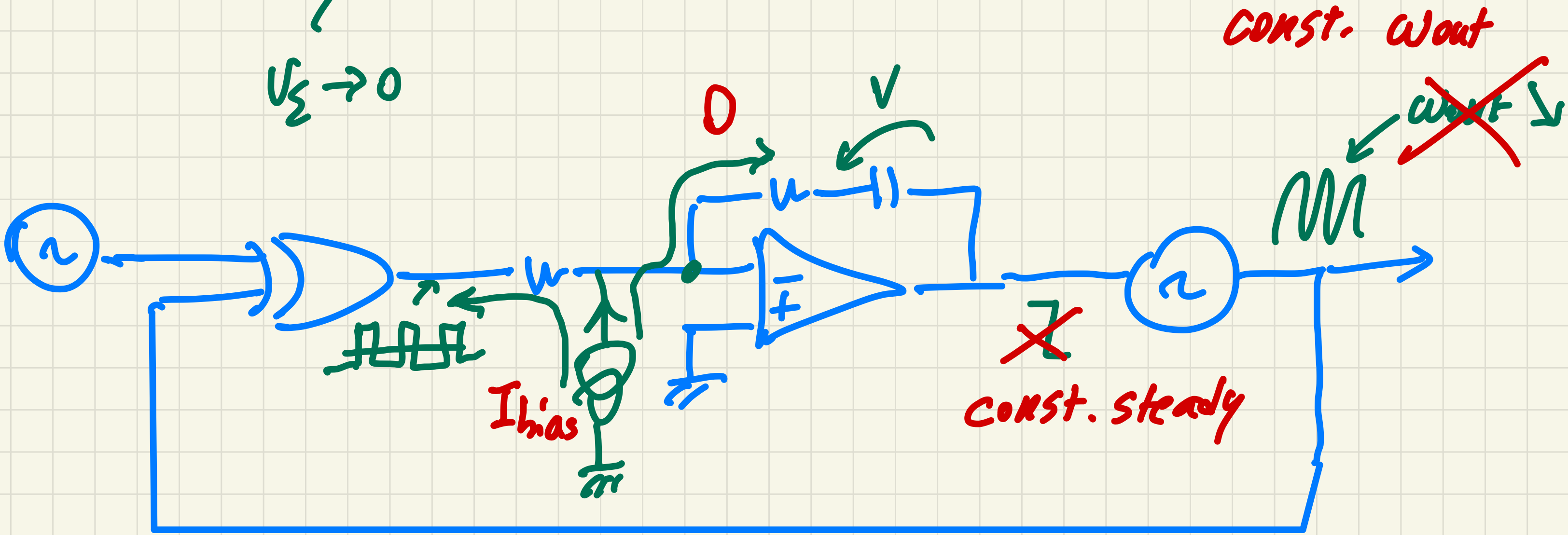
$\langle V_{PD} \rangle = -I_{bias}R_1$

Superposition principle

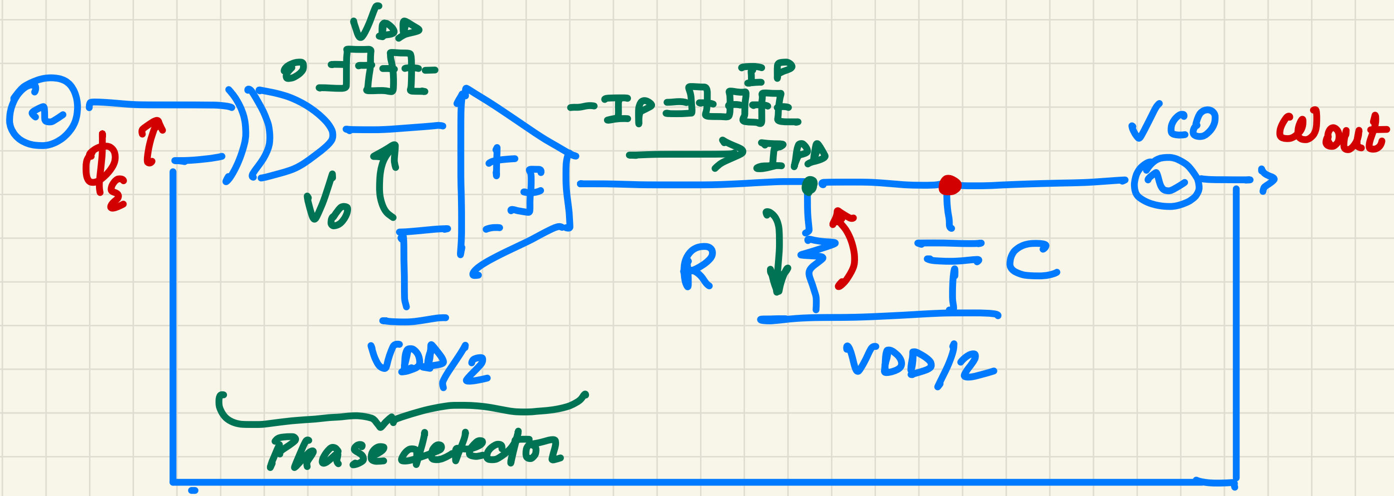
Feedback amplifier analogy



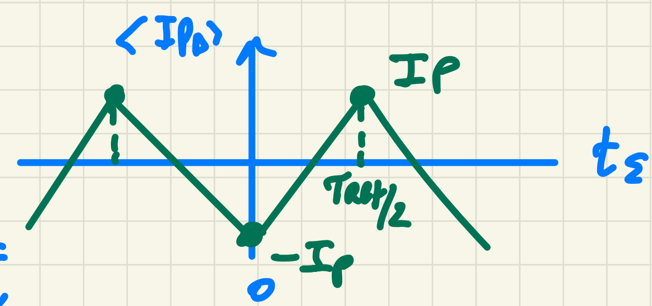
$V_\Sigma \to 0$



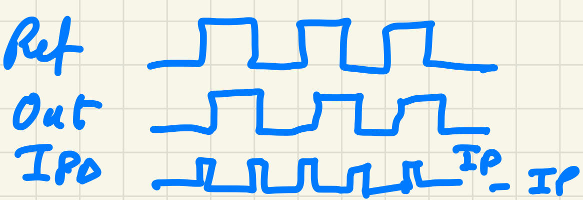
T.2.2



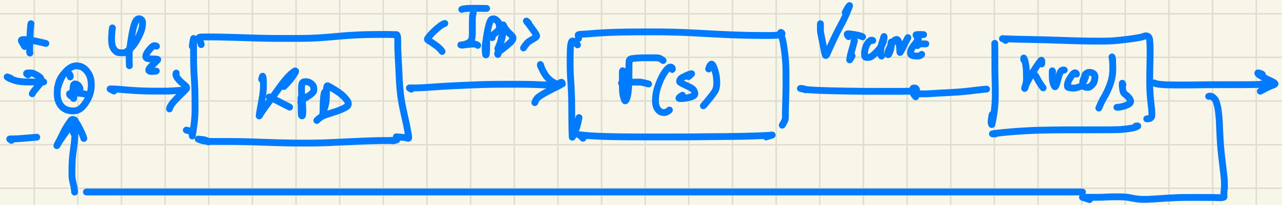
$V_0 > 0$ $I_{PD} = +I_P$
$V_0 < 0$ $I_{PD} = -I_P$ } Charge pump



• Equivalent model of PD:

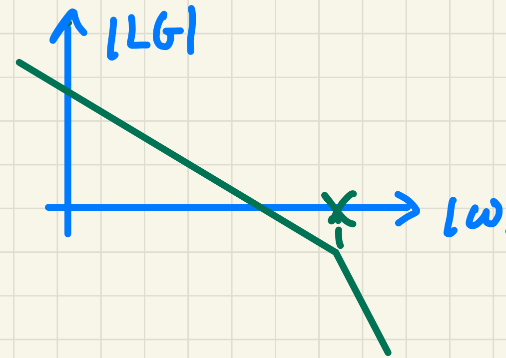


$\langle I_{PD} \rangle = 2I_P \cdot D =$
$= 2I_P \; t_\varepsilon / T_{REF}/2$

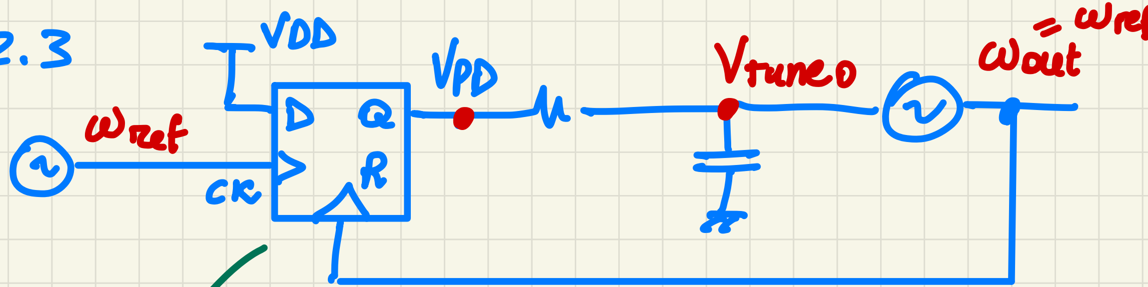


$$K_{PD} = \frac{\langle I_{PD} \rangle}{\varphi_\varepsilon} = \frac{2 I_P}{\pi} \Leftarrow \langle I_{PD} \rangle = 2 I_P \cdot \frac{\varphi_\varepsilon}{\pi}$$

$$F(s) = R \parallel \frac{1}{sC} = \frac{R}{1 + s\underbrace{RC}_{\tau_p}}$$



T2.3



D-type flip flop

- Bias point

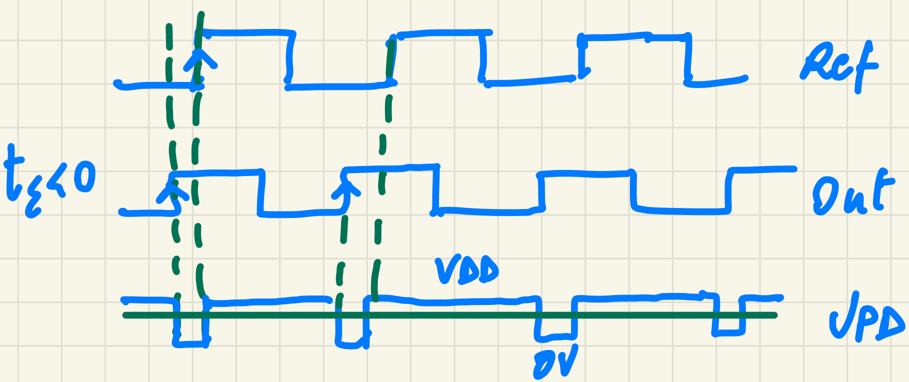
$\langle V_{PD} \rangle = V_{tune0}$

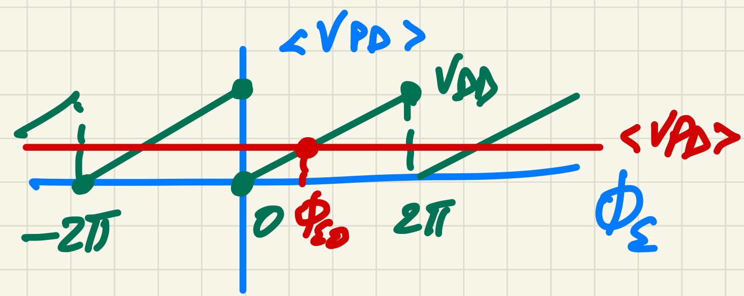
- Equivalent model

CK ↗ : Q → D = "1"

R ↗ : Q → "0"

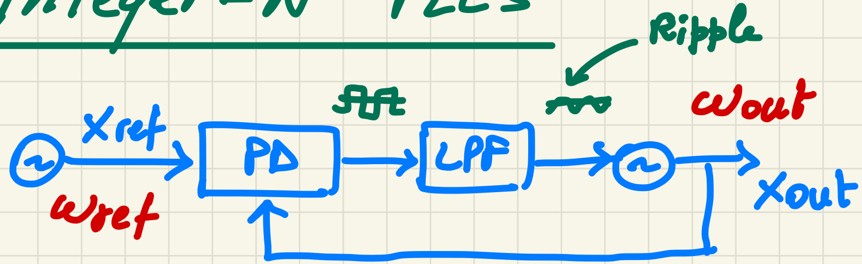
otherwise : Q is constant





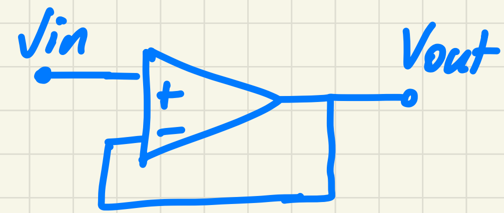
$$K_{PD} = \frac{V_{DD}}{2\pi}$$

Integer-N PLLs

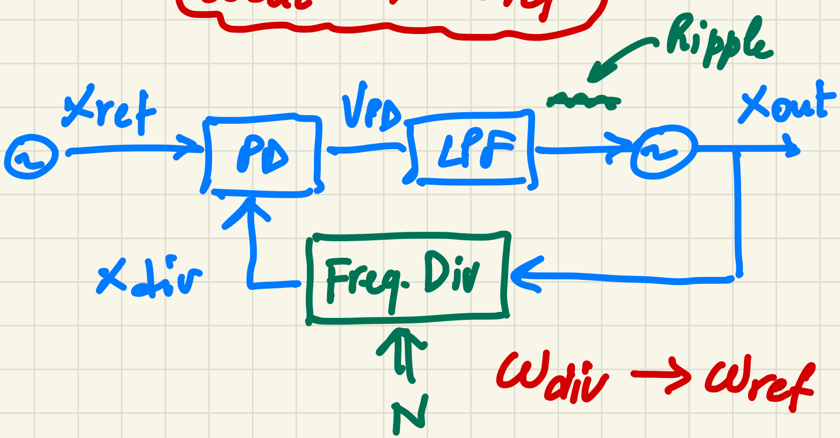


frequency follower

$\omega_{out} \rightarrow \omega_{ref}$

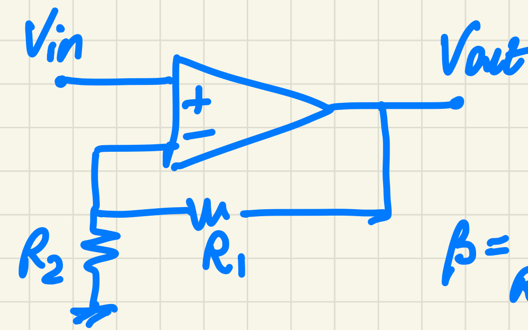


voltage follower



$\omega_{div} \rightarrow \omega_{ref}$

frequency multiplifier

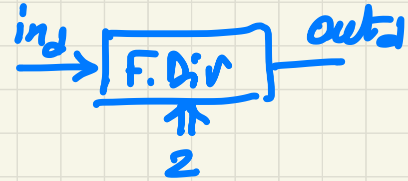


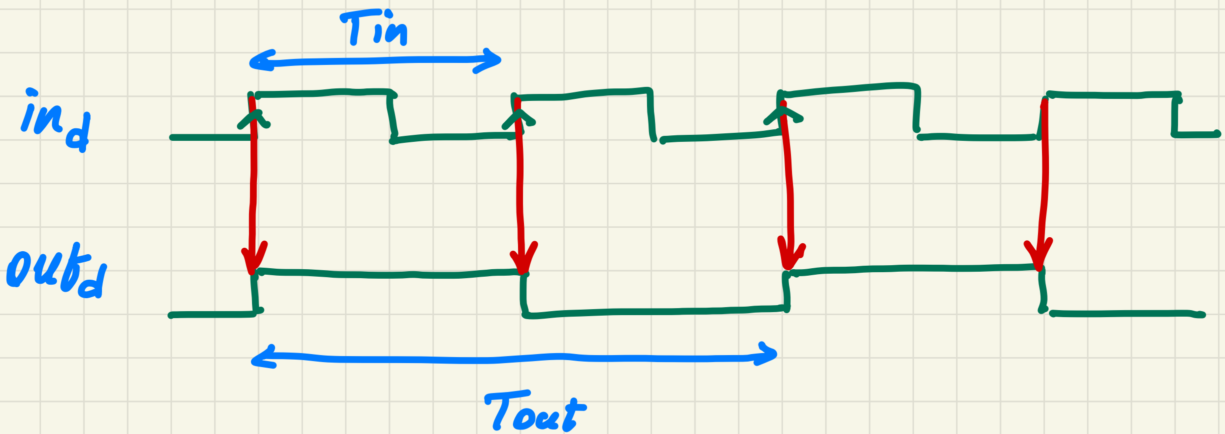
$$\beta = \frac{R_2}{R_1 + R_2}$$

Voltage amplifier

$$V_{out}/V_{in} = \frac{1}{\beta}$$

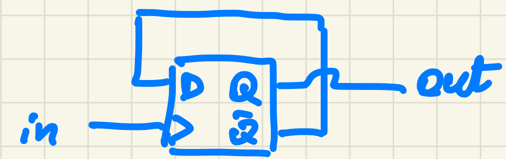
e.g. Frequency divider by $N = 2$



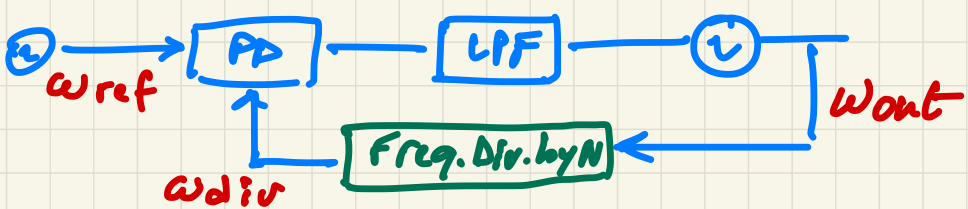


$$T_{out_d} = 2 \cdot T_{in_d}$$

Modulo-2 counter (MSB output)



In gen. modulo N-counter as freq. div. by N



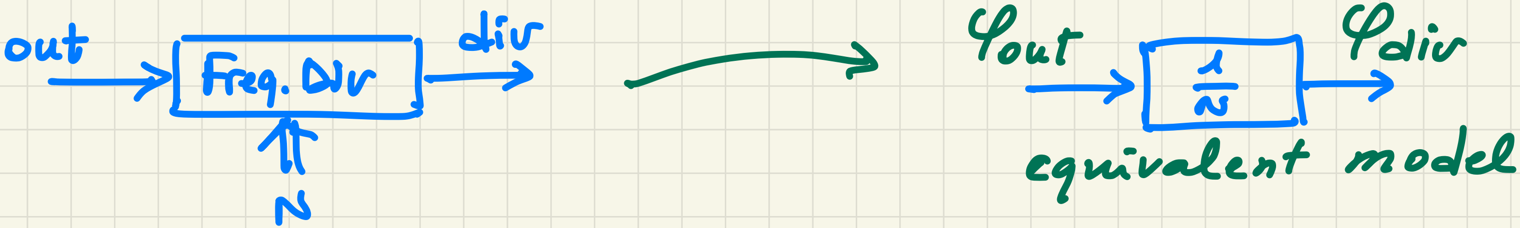
$$T_{div} = N \cdot T_{out}$$

$$\Downarrow$$

$$\omega_{div} = \frac{\omega_{out}}{N} \to \omega_{ref} \Rightarrow$$

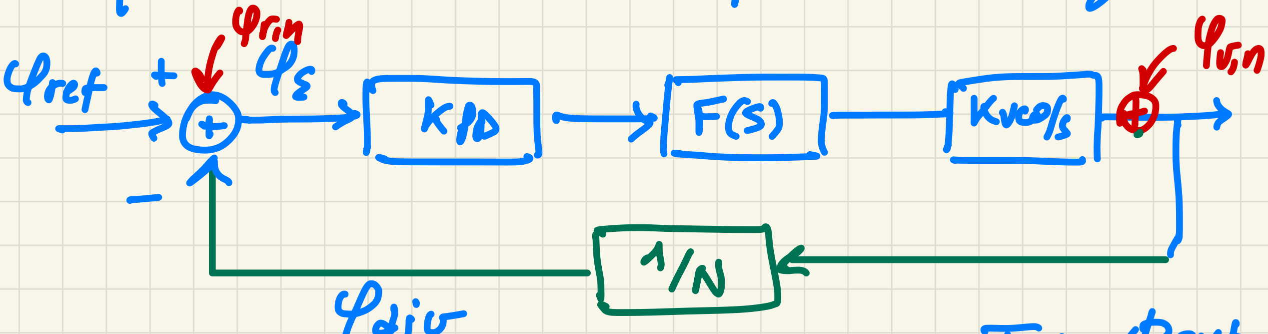
$\omega_{out} \downarrow N\omega_{ref}$

- Equivalent model of the frequency divider



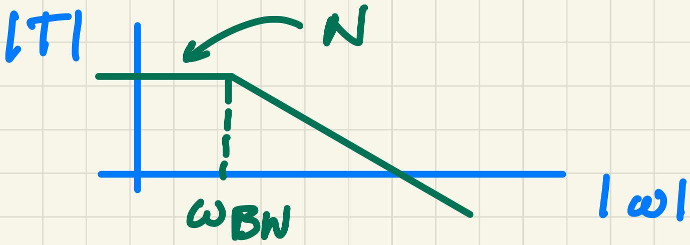
$$\omega_{div} = \frac{\omega_{out}}{N} \Rightarrow \varphi_{div} = \frac{\varphi_{out}}{N}$$

- Equivalent model of an integer-N PLL:



$$LG(s) = K_{PD} \cdot \frac{K_{VCO}}{s} \cdot F(s) \cdot \frac{1}{N}$$

$$T(s) = \frac{\Phi_{out}}{\Phi_{ref}} = \frac{\overbrace{N \cdot LG(s)}^{\text{Forward gain}}}{1 + LG(s)}$$

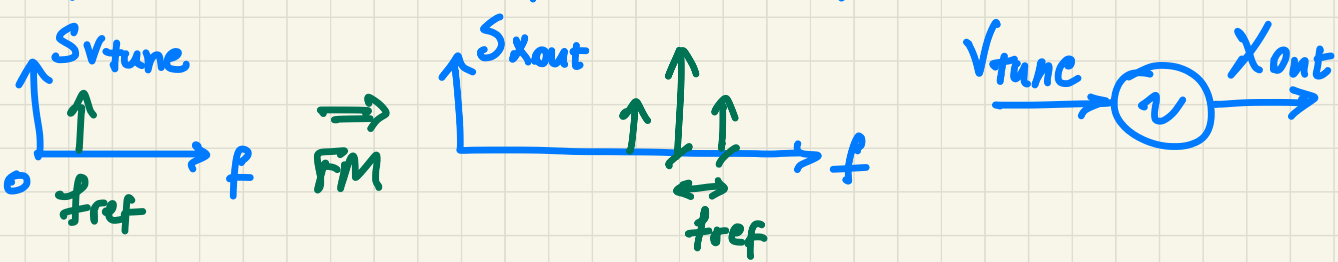


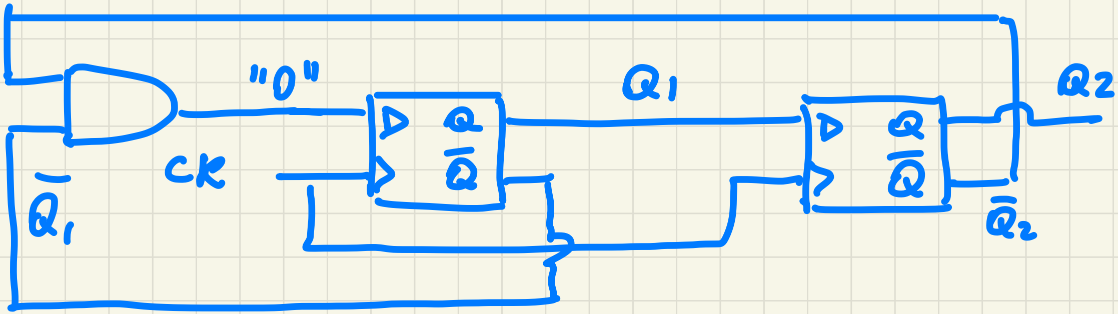
Int-N PLLs amplify the ref. phase noise by N^2 (within PLL BW)

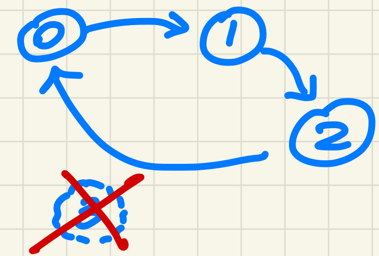
Phase Noise :

$$S_{\varphi_{out}} = S_{\varphi_{rn}} \cdot \underbrace{|T(f)|^2}_{\text{(LPF) } N^2 \text{ within } f_{BW}} + S_{\varphi_{vn}} \cdot \underbrace{\left|\frac{1}{1+LG(f)}\right|^2}_{\text{(HPF) gain 1 outside } f_{BW}}$$

Ripple and Reference Spur







Synchronous Divider by 3