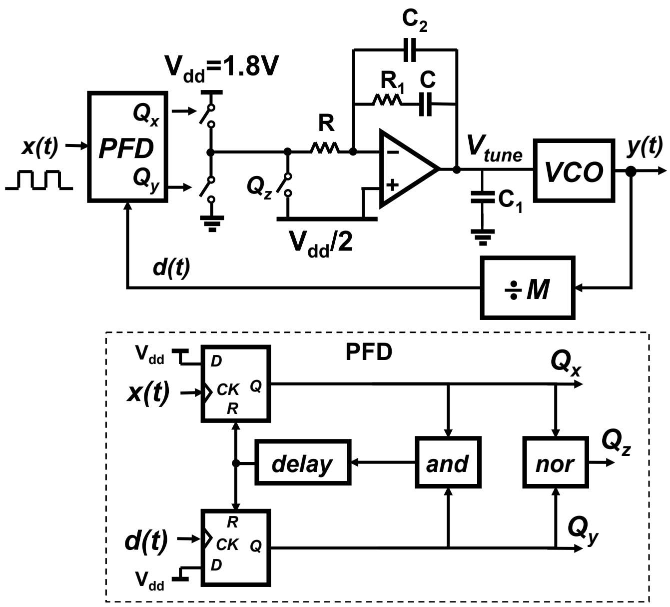
RF Circuit Design

T4

Tutorial T4

T4.1 The PLL in the figure embeds the PFD in the inset, where the block "delay" introduces a delay of 0.5 ns. The switches have infinite resistance (when off) and 10 Ω (when on). The reference clock $x(t)$ has 50 MHz frequency. The frequency-division factor is $M = 55$ and the VCO frequency varies in the range between 2650 and 2850 MHz, sweeping the V_{tune} from 0 to $V_{dd} = 1.8$ V. Let the capacitors be $C_1 = 100$ pF and the resistor $R_1 = 100$ Ω.



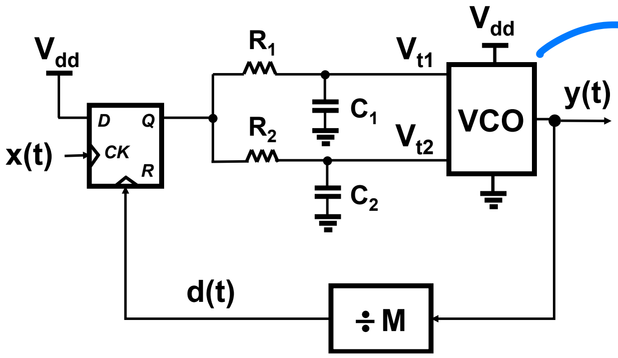
a. Assuming an ideal Op-Amp (with infinite gain and bandwidth), set the value of R and C to get two complex dominant (closed-loop) poles at 100 kHz located at 45 degree on the Gauss plane.
b. If the resistance of the switch driven by Q_X is 15 Ω (when on), set the minimum value of C_2, to get the level of the spur at 50 MHz in the spectrum of $y(t)$ lower than -80 dBc.
c. Assuming all the switches with resistance 10 Ω (when on), but an offset voltage of 100 mV for the Op-Amp, can the loop lock? If yes, what is the value of the output frequency, the delay between $x(t)$ and $d(t)$ at steady state, the reference-spur level?

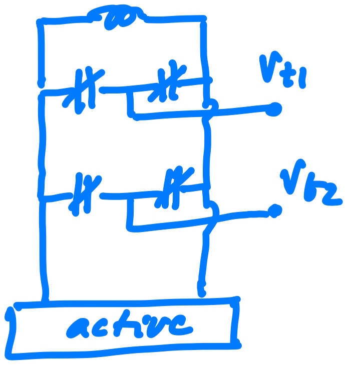
[Solution: a. R = 195 Ω, C = 22.5 nF; b. I_{OS} = -0.92 mA, t_e = 105 ps, C_2 = 154 pF; c. I_L = 0.49 mA, t_ϵ = 2.2 ns, SFDR = -32.8 dBc]

$\bullet\ R_1C_1 = 300\,ns = \tau_1 \Rightarrow f_1 \cong 531\,kHz$

$\bullet\ R_2C_2 = 1.2\,ms = \tau_2 \Rightarrow f_2 \cong 133\,Hz$

T4.2. Let $V_{dd} = 1.8V$, $R_1 = 1\ k\Omega$, $C_1 = 300$ pF, $R_2 = 10\ k\Omega$, $C_2 = 120$ nF, $x(t)$ a 10-MHz periodic signal and $M = 135$. The D flip-flop has rails 0 and V_{dd}, and synchronous reset (clock samples data even when reset is "1"). The VCO has two tuning voltages V_{t1} and V_{t2}, which varies linearly VCO frequency, and a free-running frequency of $f_{fr} = 1200$ MHz at $V_{t1} = V_{t2} = 0$.





a. After deriving the continuous-time phase model of the system, compute the VCO tuning frequency ranges through control voltages V_{t1} and V_{t2} (when varied from 0 to V_{dd}) to set the unity-gain bandwidth of loop gain equal to 100 kHz and phase margin equal to 60 degrees.

b. What is the value of V_{t1} and V_{t2} at steady state? Calculate the delay relationship between $x(t)$ and $d(t)$ in seconds at steady state.

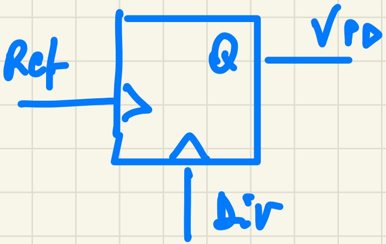
c. Do you expect any reference spur? If so, compute the level of the spurious tone in the spectrum of $y(t)$ in dBc.

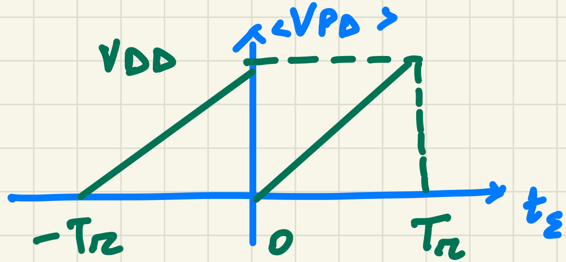
τ_ε

[Solutions: a. τ = 4.65 μs, Δf_{VCO1} = 80 MHz, Δf_{VCO2} = 22.0 GHz; b. $V_{t1} = V_{t2}$ = 12.2 mV, t_ϵ = 0.68 ns; c. SFDR = -50 dBc]

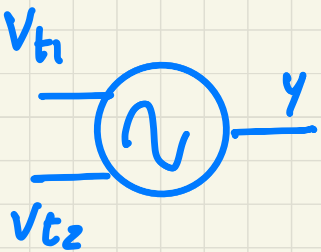
$$K_{VCO_1} = 2\pi \frac{\Delta f_{VCO1}}{V_{DD}}$$

$$K_{VCO_2} = 2\pi \frac{\Delta f_{VCO2}}{V_{DD}}$$





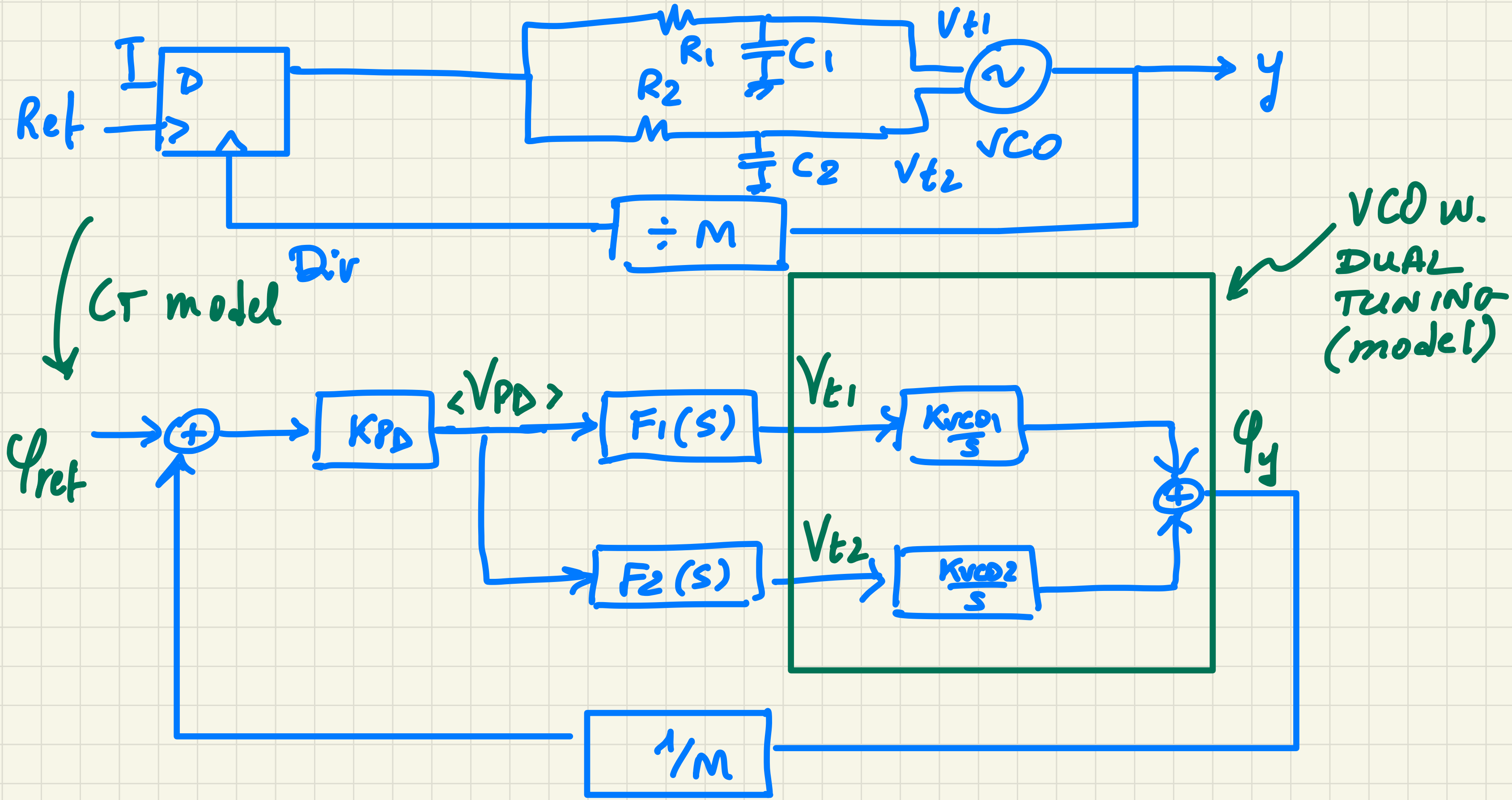
$$K_{PD} = \frac{V_{PD}}{\varphi_\varepsilon} = \frac{V_{DD}}{2\pi}$$



$$\omega_{out} = \omega_{fr} + K_{vco_1} \cdot V_{t_1} + K_{vco_2} \cdot V_{t_2}$$

$$\Downarrow \mathcal{L}$$

$$\varphi_{out} = \frac{K_{vco_1}}{s} V_{t_1} + \frac{K_{vco_2}}{s} V_{t_2}$$



$$F_1(s) = \frac{1}{1 + sR_1C_1} \qquad F_2(s) = \frac{1}{1 + sR_2C_2}$$

$$LG(s) = K_{PD} \cdot \frac{1}{s} \cdot \frac{1}{N} \cdot \left[\frac{K_{VCO1}}{1 + s \underbrace{R_1 C_1}_{\tau_1}} + \frac{K_{VCO2}}{1 + s \underbrace{R_2 C_2}_{\tau_2}} \right] =$$

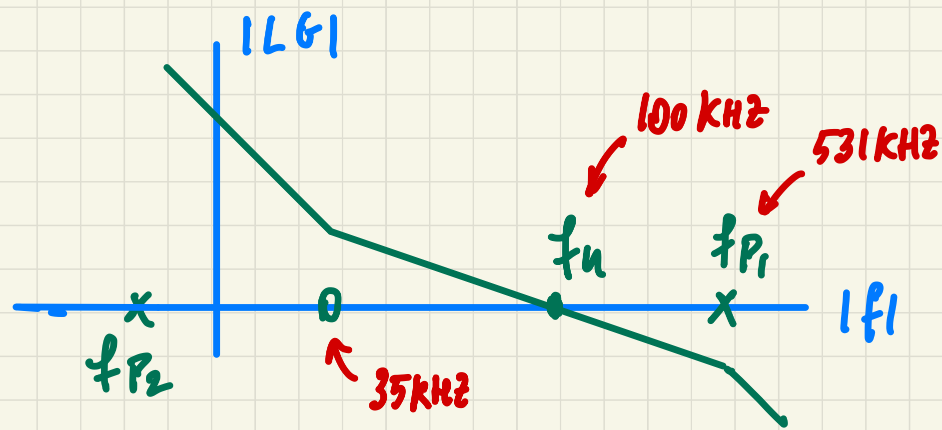
$$= \frac{K_{PD}}{N} \cdot \frac{1}{s} \cdot \frac{K_{VCO1}(1+sR_2C_2) + K_{VCO2}(1+sR_1C_1)}{(1+sR_1C_1)(1+sR_2C_2)} =$$

$$= \frac{K_{PD}}{N} \cdot \frac{K_{VCO1}+K_{VCO2}}{s} \cdot \frac{1 + s \cdot \overbrace{\frac{K_{VCO1}\tau_2 + K_{VCO2}\tau_1}{K_{VCO1}+K_{VCO2}}}^{\tau_z}}{(1+s\tau_1)(1+s\tau_2)}$$

3rd order - type I - PLL
zero comes from the
two paths in parallel

$f_{P_2} \simeq 133$ Hz

$f_{P_1} \simeq 531$ KHz



$$s \approx j\omega_u$$

$$LG(s) \cong \frac{K_{PD}}{N} \cdot \frac{K_{VCO1}+K_{VCO2}}{s} \cdot \frac{\cancel{1}+s\tau_z}{(1+\cancel{s\tau_1})\cdot(\cancel{1}+s\tau_2)}$$

$$\omega_u \gg \omega_{p_2} \Rightarrow s\tau_2 \gg 1$$

$$\omega_u \ll \omega_{p_1} \Rightarrow s\tau_1 \ll 1$$

$$\omega_u \gg \omega_z \Rightarrow s\tau_z \gg 1$$

$$1 = |LG(j\omega_u)| = \frac{K_{PD}\cancel{(K_{VCO1}+K_{VCO2})}}{N} \cdot \frac{1}{\omega_u} \cdot \frac{K_{VCO1}\tau_z + K_{VCO2}\tau_1}{\tau_2\cancel{(K_{VCO1}+K_{VCO2})}}$$

$$\Rightarrow \quad \omega_u = \frac{K_{PD}}{N}(K_{VCO1}+K_{VCO2}) \cdot \frac{\omega_{p_2}}{\omega_z} = 2\pi \cdot 100k$$

$$\varphi_m \cong \operatorname{atan}\left(\frac{\omega_u}{\omega_z}\right) - \operatorname{atan}\left(\frac{\omega_u}{\omega_{p1}}\right) = 60^\circ \Rightarrow \omega_z = 2\pi \cdot 35\ \frac{krad}{s}$$

- <u>TYPE</u> - n : <u>n poles in the origin</u> in the loop gain

- <u>ORDER</u> - m : <u>m poles in the system</u> (loop gain or transfer functions)