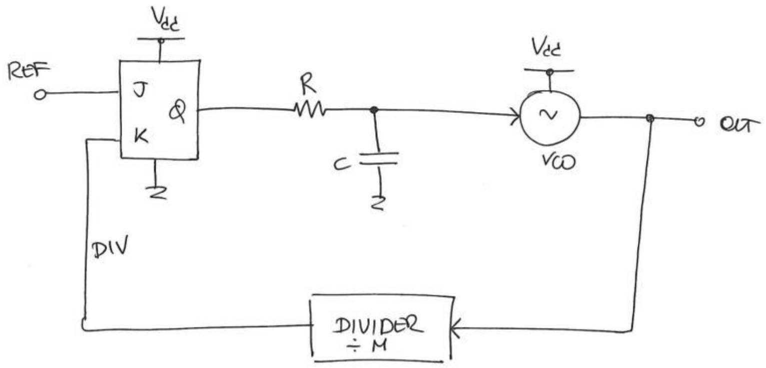
RF Circuit Design **Prof. Salvatore Levantino**

Available time: 75 minutes May 2nd, 2018

Mid-term Test

Exercise 1

In the PLL in figure, the JK latch (a.k.a. “level-triggered” flip-flop) has CMOS levels 0V and V_{DD} = 1.2V, zero output impedance, and truth table shown below. Let the REF signal be a squarewave with frequency f_{ref} = 10 MHz, the frequency-division factor M = 100, and let the VCO have free-running frequency 957MHz and linear tuning range over input voltage between 0V and V_{DD}.



J	K	Q_{n+1}
0	0	Q_n
0	1	0
1	0	1
1	1	$\overline{Q_n}$

a) Calculate and plot the **voltage-vs-phase characteristic of the JK latch** and calculate its **gain**.

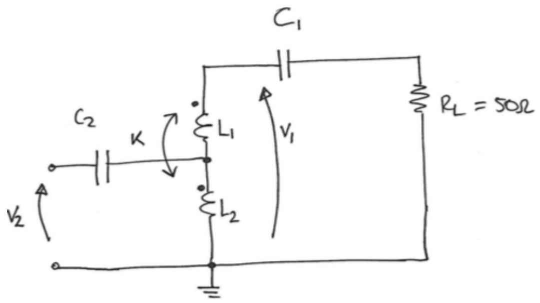
b) Set the **value of *R*, *C*, and VCO tuning range** to get (i) closed-loop poles at 100kHz, (ii) maximally flat PLL input-output frequency response, (iii) contribution of R thermal noise to the output phase noise $\mathcal{L}$ equal to -146dBc/Hz at 1MHz offset.

c) Calculate the **time delay (in seconds)** between two positive edges of REF and DIV signals at steady state, and the **level of the reference spur** in the output spectrum (in dBc).

[Sol: a) PD gain = 0.19 V/rad; b) R = 11 kΩ, C = 100 pF, TR = 44.3 MHz; c) Delay = 96 ns; Spur at 10MHz offset = -54 dBc]

Exercise 2

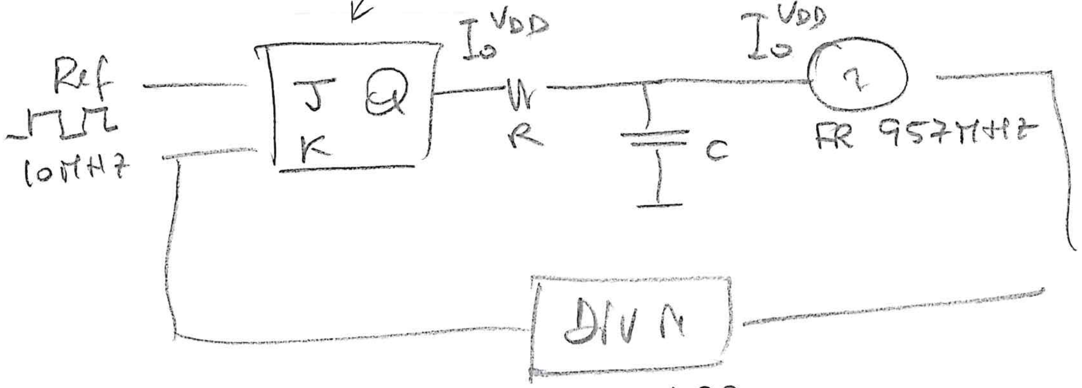
The circuit in figure is used to transform the impedance R_L = 50Ω. Given C_1 = 1pF, L_1 = 0.8nH, find **the values of L_2, k, C_2** to have an input impedance of Z_{in} = 5Ω + j0Ω at 5GHz frequency.



[Sol: L_2 = 317pH, k = 0.43, C_2 = 3.78pF]

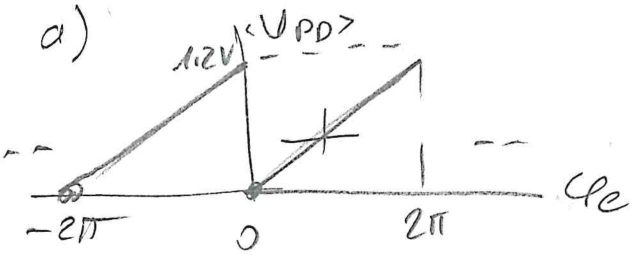
EX:

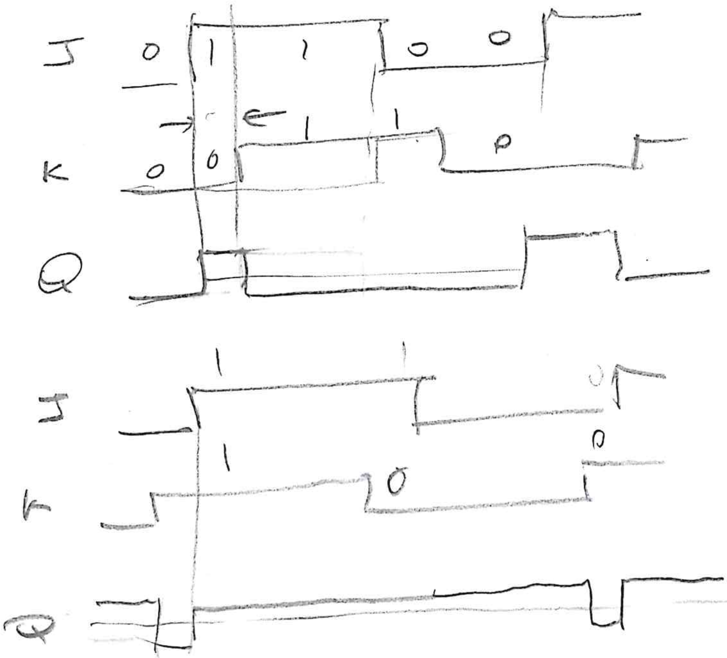
JK level-triggered FF $0, V_{DD} = 1.2V$



JK	Q_{n+1}
00	Q_n
01	0
10	1
11	$\overline{Q_n}$

a)

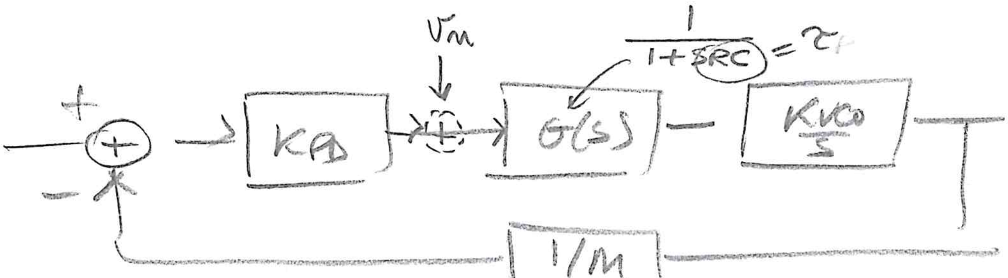




Gain $K_{PD} = \dfrac{V_{DD}}{2\pi} =$

$= \dfrac{1.2}{6.28} = 0.19 \dfrac{V}{rad}$

b)



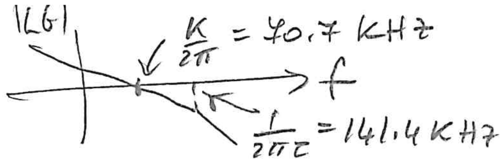
$$LG = \underbrace{K_{PD} \cdot \frac{K_{VCO}}{s} \cdot \frac{1}{M}}_{K} \cdot \frac{1}{1+s\tau}$$

$1 + LG = 0 \quad ; \quad s^2 \left(\frac{\tau}{K}\right) + \frac{s}{K} + 1 = 0$

$\frac{\tau}{K} = \frac{1}{\omega_p^2} \qquad \frac{1}{K} = \frac{2\xi}{\omega_p}$

$\omega_p = \sqrt{\frac{K}{\tau}}$

$\xi = \dfrac{1}{2\sqrt{K\tau}} \overset{(ii)}{=} \dfrac{\sqrt{2}}{2} \Rightarrow K = \dfrac{1}{2\tau} \Rightarrow \omega_p = \sqrt{2} \cdot K$



(i) $f_P = \frac{\sqrt{2}}{2\pi}\cdot\frac{K_{PD}\,K_{VCO}}{M} = 100K$

$\Rightarrow K_{VCO} = \frac{\overbrace{2\pi\cdot 100K\cdot 100}^{10^7}}{0.19\cdot\sqrt{2}} = 23.37\cdot 10^7\ \frac{rad}{Vs}$

$K_{VCO} = 2\pi\cdot\frac{TR}{V_{DD}} \Rightarrow TR = \frac{K_{VCO}}{2\pi}\cdot V_{DD} =$

$= \frac{23.37\cdot 10^7}{6.28}\cdot 1.2 =$

$= \underline{\underline{44.66\ MHz}}$

(ii) $\tau = \frac{1}{2K} =$

$= \frac{1}{2\cdot 444K} =$

$= 1.126\mu$

$\downarrow$

$141.4K$

(iii) $\frac{\varphi_{out}}{v_n}(s) = \frac{G(s)\cdot K_{VCO}/s}{1 + LG(s)}$

at $f = 1MHz$: $\left|\frac{\varphi_{out}}{v_n}(f)\right| \approx \frac{|G(f)|\,K_{VCO}}{2\pi f} =$

$= \sqrt{\frac{1}{1+(2\pi f\tau)^2}}\ \frac{K_{VCO}}{2\pi f}$

$\mathcal{L} = \frac{S_{\varphi out}}{2} = \frac{1}{2}\left|\frac{\varphi_{out}}{v_n}\right|^2\cdot S_{vn} =$

$= \frac{1}{2}\cdot\frac{1}{1+(\underbrace{2\pi f\tau}_{7})^2}\cdot\left(\frac{K_{VCO}}{2\pi f}\right)^2\cdot 4KTR =$

$= \frac{1}{2}\cdot\frac{1}{51}\cdot\left(\frac{23.37\cdot 10^7}{6.28\cdot 10^6}\right)^2\ 16\cdot 10^{-21}\cdot R = 10^{-14.6}$

$R = \frac{10^{-14.6}}{10^{-21}}\ \frac{2\cdot 51}{16}\cdot\frac{1}{1385} = \underline{\underline{11.56\ K\Omega}}$

$10^{+6.4}$

$\Downarrow$

$C = \frac{1.126\mu}{11.56K} = \underline{\underline{97.4p}}$

c) Delay

$f_{out} = M\cdot f_{ref} = 1GHz$

$\Delta f = f_{out} - f_{fr} = 1000 - 957 = 43MHz$

$V_{tune} = \frac{2\pi\cdot\Delta f}{K_{VCO}} = 1.155V$

$$\varphi_\varepsilon = \frac{V_{tune}}{K_{PD}} = \frac{1.155}{0.19} = 6.079 \text{ rad}$$

$$t_\varepsilon = \frac{\varphi_\varepsilon}{2\pi}\cdot T_R = \frac{6.079}{6.28}\cdot 100 \text{ ns} = \underline{96.8 \text{ ns}}$$

V_{DD} $\qquad \frac{6.079}{6.28} = 96.8\%$

$$\Rightarrow \underbrace{\frac{2}{\pi}\cdot\Delta\cdot \sin \pi D}_{78 \text{ mV}} = V_{PD}$$

$$\mathcal{L}_{SPUR} = \frac{S_{\varphi out}}{2} = \frac{\Delta\varphi^2/2}{2} =$$

$$= \frac{1}{4}\cdot\frac{K_{VCO}^2}{(2\pi f_{SPUR})^2}\cdot |G|^2 \cdot V_{PD}^2 =$$

$$= \frac{1}{4}\cdot\left(\frac{23.37\cdot\cancel{10^7}}{6.28\cdot\cancel{10^7}}\right)^2\cdot\left(\frac{1}{2\pi\cdot 10^7\cdot 1.126\cdot 10^{-6}}\right)^2\cdot(78\,m)^2 =$$

$$= \left(\frac{1}{2}\cdot 3.72\cdot 0.014\cdot 0.078\right)^2$$

$$\Rightarrow 20\log_{10}(0.002) = -53.75 \text{ dBc}$$