Electrical Engineering Department

Communications Circuits

Homework 9

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On-chip inductors

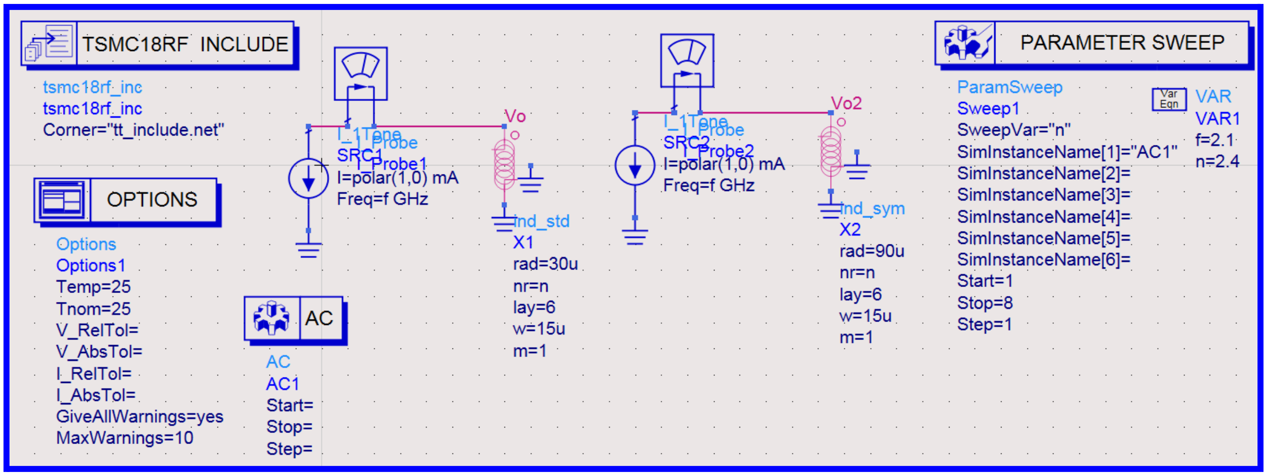

Figure 1 - circuit for evaluating STD (left) and SYM (right) inductors

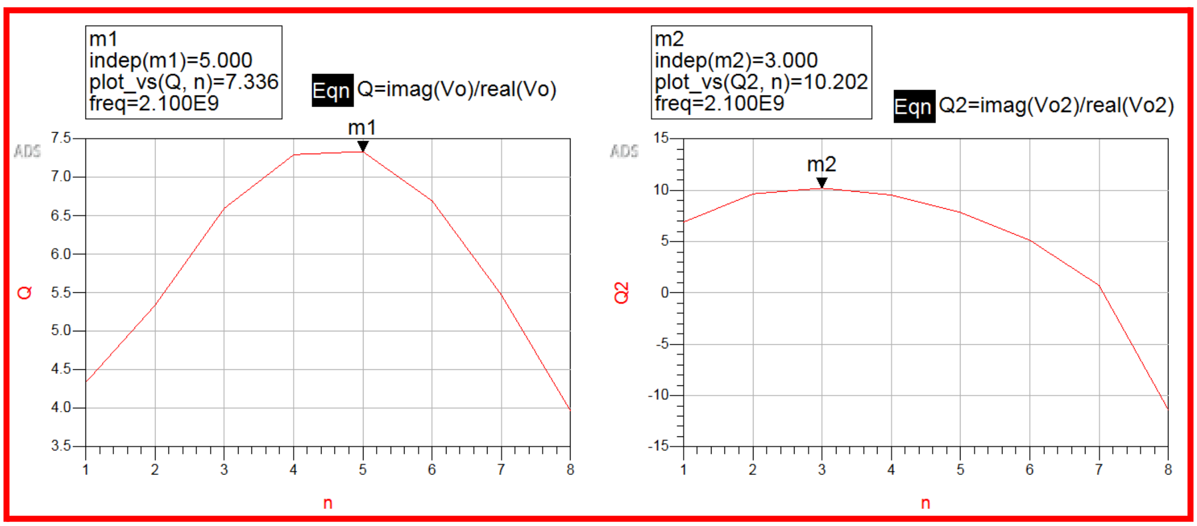

Figure 2 - quality factor vs number of turns for STD (left) and SYM (right) inductor

As evident, the optimum number of turns for a STD inductor is 5 which yields a quality factor of 7.3, and for a SYM inductor 3 turns leads to the maximum quality factor of 10.2.

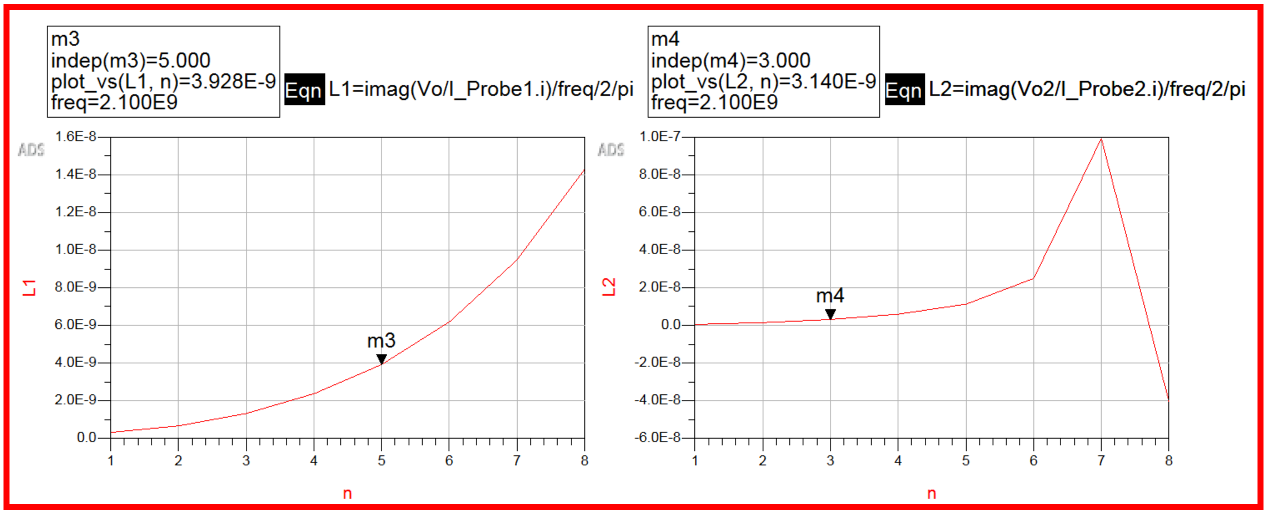

Figure 3 - the size of the inductor for the optimum n

Variable capacitor or varactor

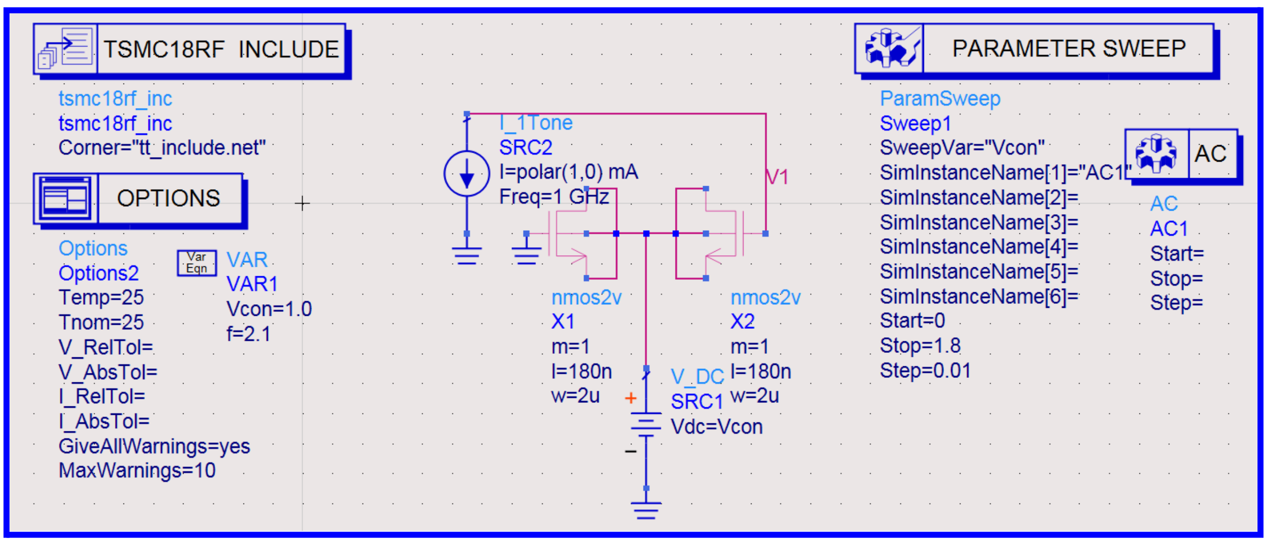

Figure 4 - the circuit for evaluating a varactor

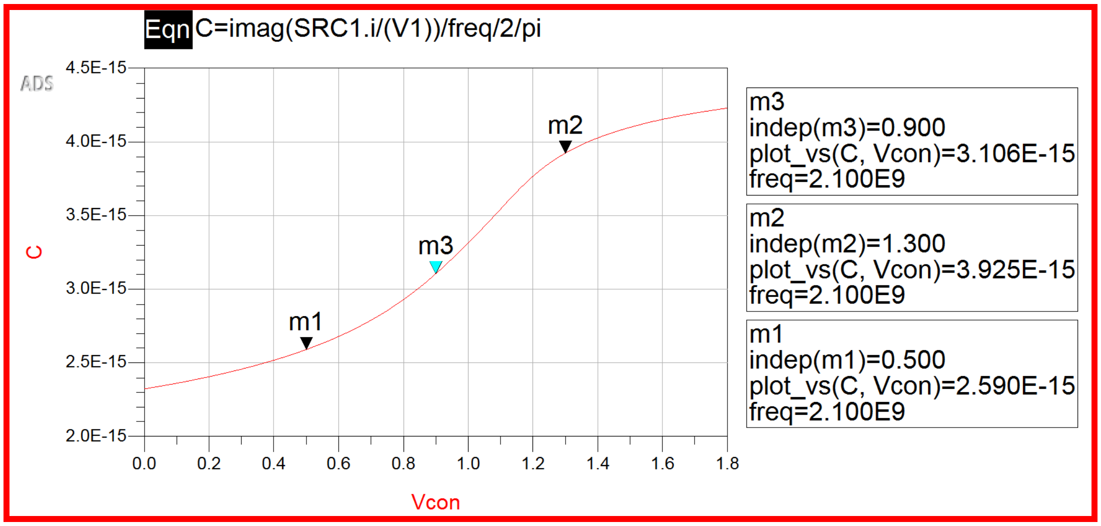

Figure 5 - capacitance of the varactor vs. the control voltage

Using the above diagram, the linear region of the varactor could be estimated to be from 0.5V to 1.3V. The capacitance of the varactor in the middle of this region is 3.1pF.

Design of the oscillator

1. Width of M3: as the maximum current passing through the supply voltage is 2mA, disregarding the bias currency source, each of M1 and M2 can pass 1mA which means M3 must multiply the bias current by 40 so that when halved, 1mA can pass through each oscillating transistor.
2. g_m of M1 and M2: as the circuit should have a minimum area, the width of M1 and M2 could be set at a minimum of 2um. However, while the minimized width decreases the capacitance of the transistor, it also demands a large overdrive voltage that limits the output swing. With a reasonable width of 20um, using typical technology parameters, $g_{m1,2} = \sqrt{2\mu_n C_{ox} W/L I_D} = 7.45mS.$
3. Parallel and series resistance of L to guarantee oscillation: the oscillation condition in cross-coupled oscillators is $(g_m R_p)^2 > 1$ which means $R_p > \frac{1}{g_m} = 134\Omega.$

   The series resistance is equal to $\frac{L\omega}{Q} = \frac{(L\omega)^2}{R_p}$ at a center frequency of 2.1GHz. This requires $QL = 10$ which could be achieved by a STD inductor with 5 turns.

4. Center frequency by tuning L and C: first the parasitic capacitances at the drain of M1 are calculated using $C_{ox} = 9\frac{F}{\mu m^2}$, $C_{ov} = 0.2\frac{F}{\mu m}$, $C_j = 1.2\frac{F}{\mu m^2}$, $E = 0.54\mu m$:

   $C_{GS2} = \frac{2}{3}C_{ox}WL + C_{ov}W = 25.6fF$, $C_{GD2} = C_{ov}W = 4fF$
   $C_{DB1} = EWC_j = 13fF$

   The resonance frequency is: $f_0 = \frac{1}{2\pi\sqrt{LC_{eq}}}$, $C_{eq} = C_{DB1} + C_{GS2} + 4C_{GD2} + 2C_{var}$ which is $C_{eq} = 54.56fF + 2C_{var}$. So without any extra capacitances, the center frequency would be 11.8GHz which means an additional capacitance of 880fF is necessary to bring the center frequency back to 2.1GHz. After simulation, this capacitance was found to be 660fF.

5. Choose the inductor: already done in step 3.

6. Choose the varactor transistor width: the desired frequency range is 2050 to 2150 MHz which requires the overall capacitance to be in the range of (1395, 1534)fF. After subtracting the parasitic capacitances and dividing the result by 2, the capacitance of the passive capacitor and the varactor needs to be in the range of (670, 740)fF. The varactor needs to provide a 70fF range in its linear region which is achievable by a width of 400um. The passive capacitance needs to be scaled accordingly. The linear region of this capacitor would be between 0.7 and 1.2 V as evident below:

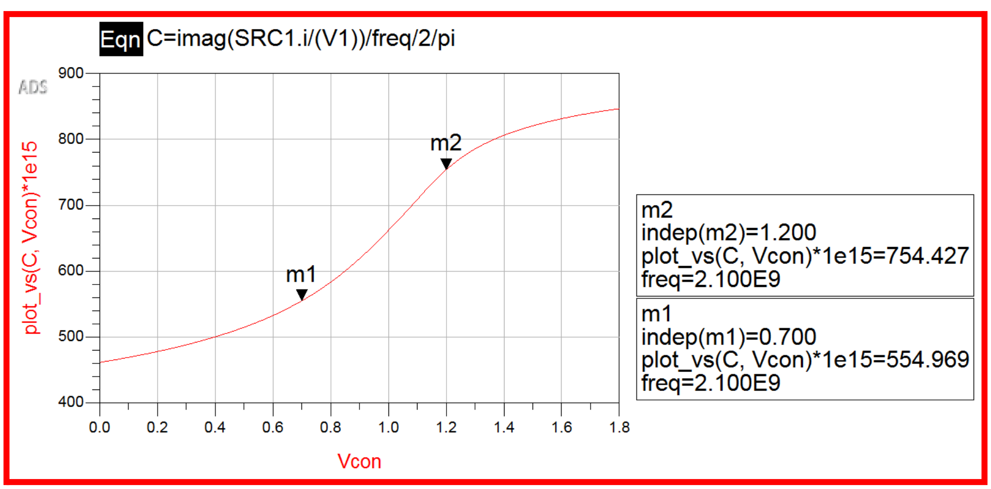

Figure 6 - varactor linear region

7. VCO gain: after fine-tuning the capacitors, the VCO gain was: $\frac{2.15-2.05}{1.2-0.7} = 200\frac{MHz}{V}$.

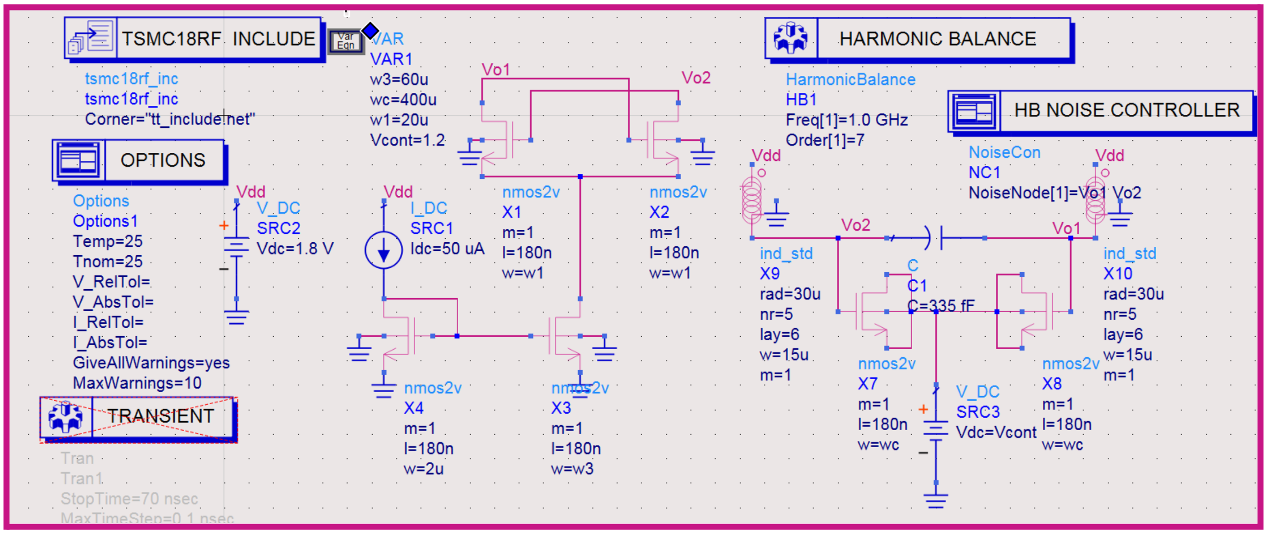

Figure 7 - final circuit

8. DC simulation and comparison with theory: the DC current in M3 was much higher than expected so the width of M3 had to be lowered to 60um to achieve the 2mA current desired. The g_m from simulation after correcting the width of M3 was close to the theoretical results:

index	Gm*1000	Id*1000
1	7.163	0.928
2	7.163	0.928
3	18.034	1.855
4	0.532	0.050
5	0.000	0.000
6	0.000	0.000

Figure 8 - DC simulation results

9. Transient simulation and the frequency requirements: the transient waveform for a control voltage of 1.3V is shown below. The frequency of oscillation for each control voltage value was determined using HB simulation.

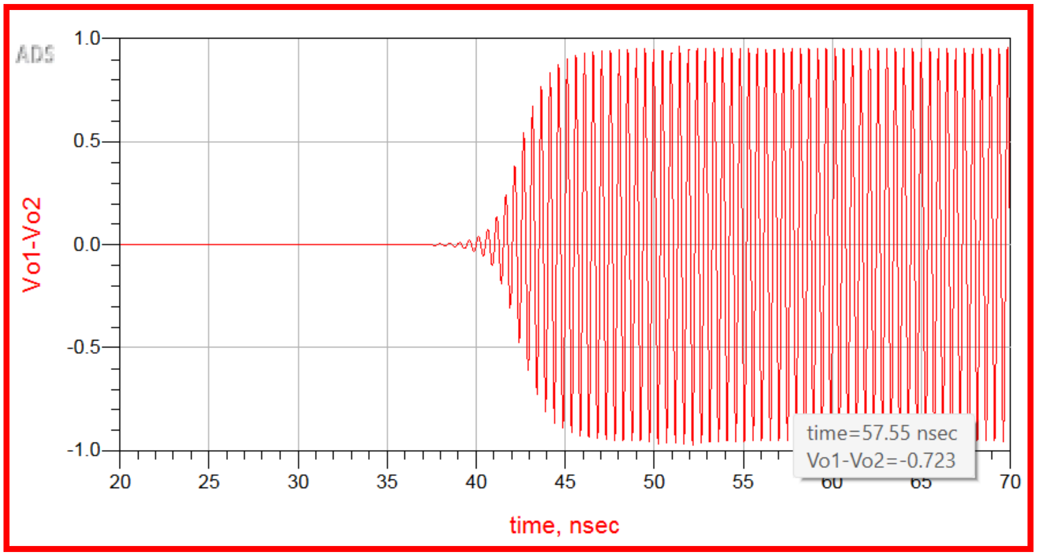

Figure 9 - transient waveform

harmindex	HB.freq
0	0.0000 Hz
1	2.051 GHz
2	4.101 GHz
3	6.152 GHz
4	8.202 GHz
5	10.25 GHz

harmindex	HB.freq
0	0.0000 Hz
1	2.099 GHz
2	4.198 GHz
3	6.296 GHz
4	8.395 GHz
5	10.49 GHz

harmindex	HB.freq
0	0.0000 Hz
1	2.150 GHz
2	4.301 GHz
3	6.451 GHz
4	8.601 GHz
5	10.75 GHz

Figure 10 - frequency of oscillation with a control voltage of 0.76V, 1V, and 1.16V

10. Phase noise:

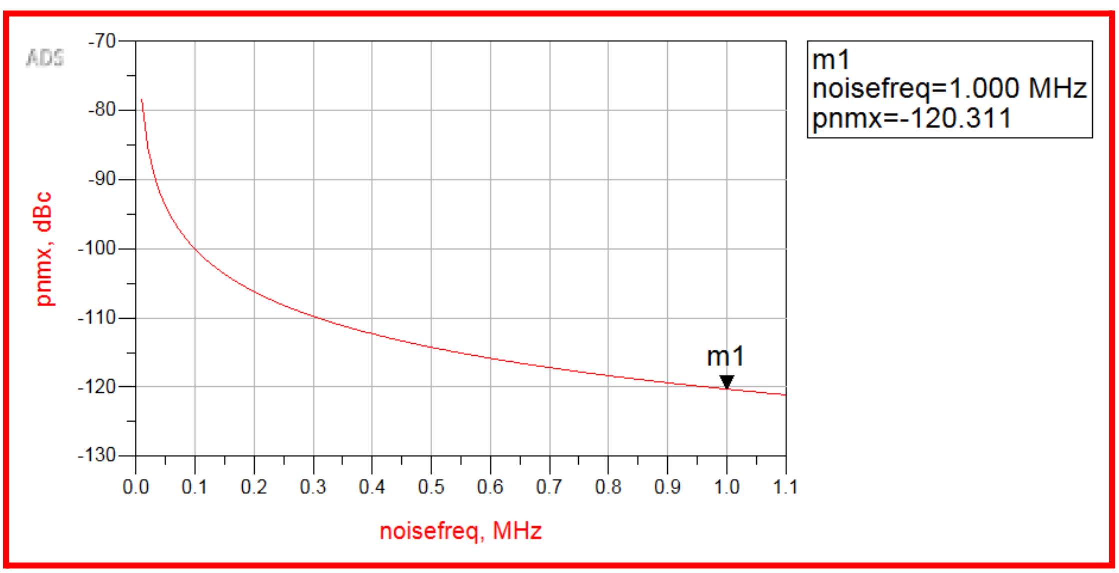

Figure 11 - phase noise

As evident, the phase noise meets the requirements stated in the worksheet.