
1.5 GHz Oscillator Design

RF Circuit Design
Salvatore Levantino
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Differential CMOS LC Oscillator

Parameters

$$V_T = 0.35V$$

$$\mu_n C_{ox} = 120 \mu A/V^2$$

$$\mu_p C_{ox} = 60 \mu A/V^2$$

Requirements

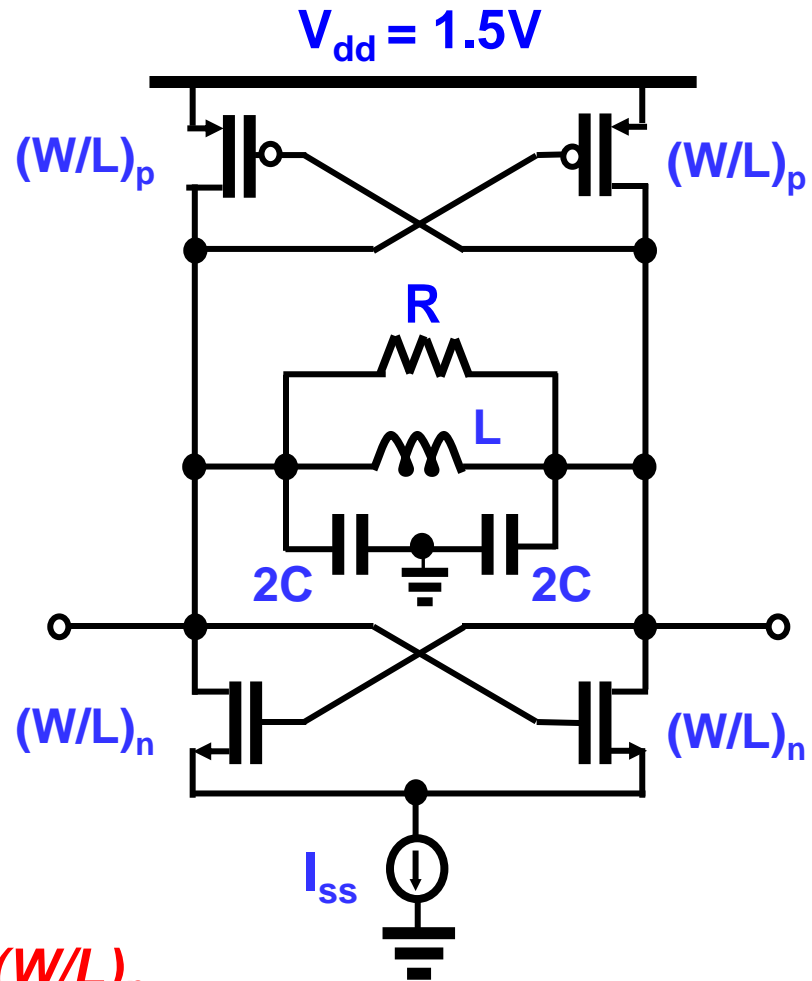
$f_0 = 1.5\text{GHz}$

Q = 20

$$I_{ss} = 3\text{mA}$$

EGF = 5

Maximize the FoM



Derive values of R , L , C , $(W/L)_n$, $(W/L)_p$

Oscillator Phase Noise and Figure of Merit

$$\mathcal{L}(\Delta\omega) = \frac{S_v(\omega_0 + \Delta\omega)}{S_v(\omega_0)} = \frac{\frac{1}{2} \frac{4K_b T}{R} \frac{1}{(2\mathbf{C}\Delta\omega)^2} F_a}{\frac{1}{2} A_0^2} = \frac{K_b T R F_a}{Q^2 A_0^2} \left(\frac{\omega_0}{\Delta\omega} \right)^2 = \boxed{\frac{K_b T F_a}{Q^2 2\eta P_{diss}} \left(\frac{\omega_0}{\Delta\omega} \right)^2}$$

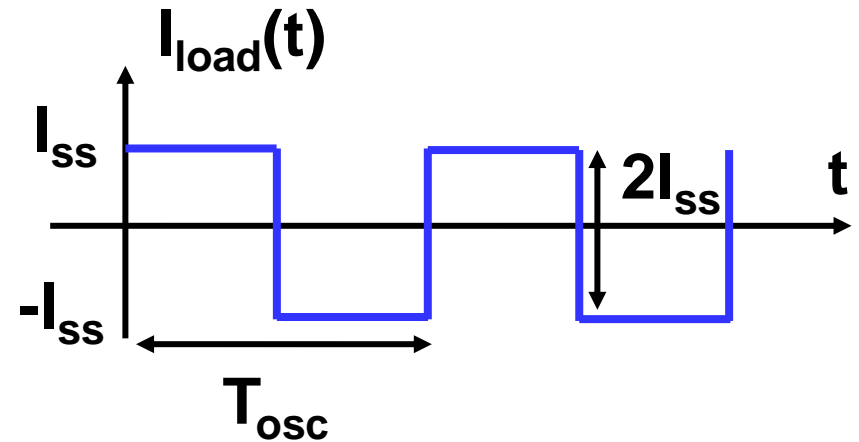
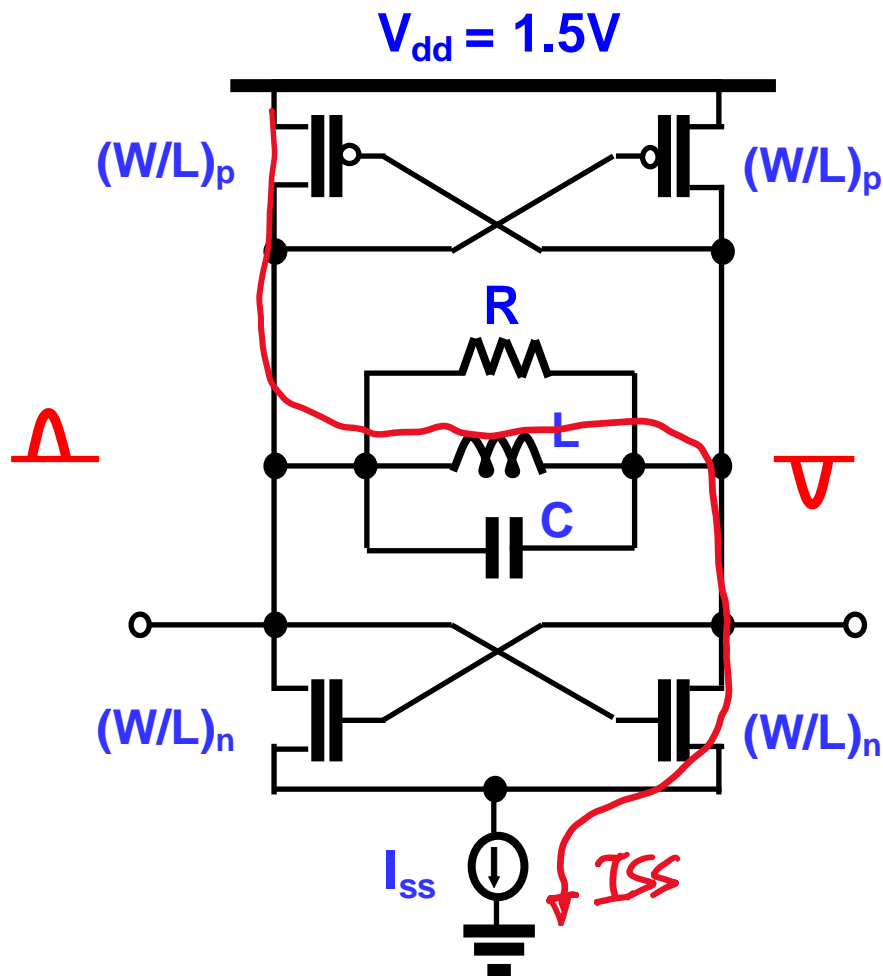
$$\mathbf{C} = Q/(\omega_0 R)$$

$$\eta = \frac{P_{out}}{P_{diss}} = \frac{\frac{A_0^2}{2R}}{V_{dd} I_{ss}} = \frac{2A_0^2}{\pi A_0 V_{dd}} \propto \boxed{\frac{A_0}{V_{dd}}} \quad A_0 = \frac{4}{\pi} I_{ss} R$$

$$FoM = \frac{1}{\mathcal{L}(\Delta\omega) P_{diss,mW}} \left(\frac{\omega_0}{\Delta\omega} \right)^2 = 10^{-3} \frac{2\eta Q^2}{K T F_a} \boxed{\propto \eta}$$

To maximize the FoM, A_0 has to be maximized

Oscillation Amplitude

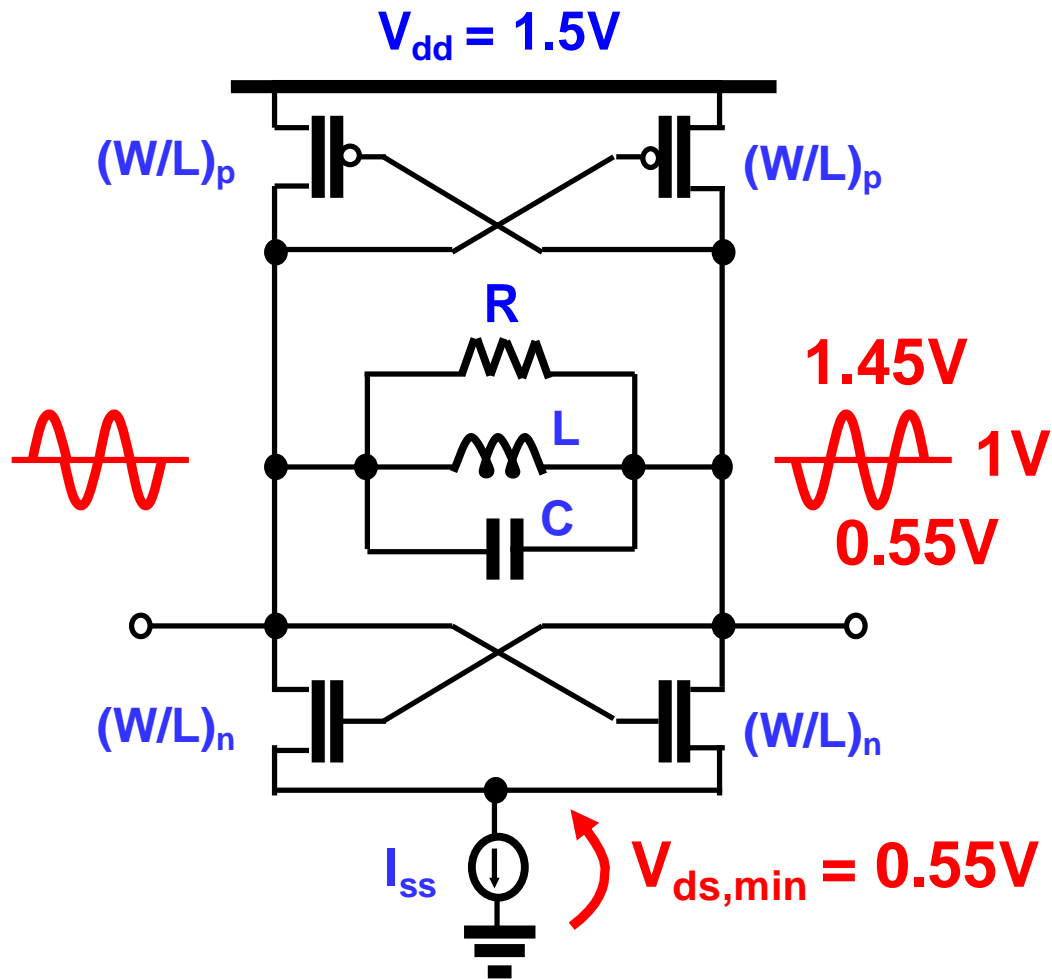


$$I_1 = \frac{2}{\pi} 2I_{ss} \quad I_{load}(t) \text{ 1st harmonic}$$

Oscillation Amplitude:

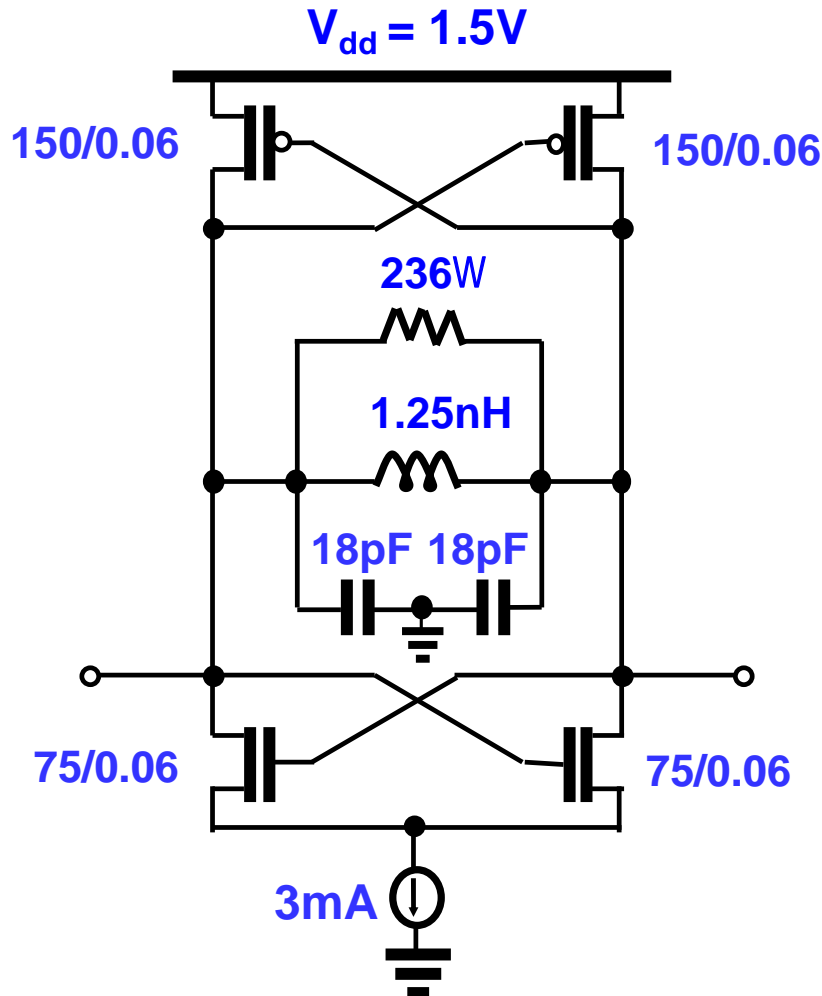
$$A_0 = I_1 R = \frac{4}{\pi} I_{ss} R$$

Maximizing the Amplitude



$$A_{0,max} = 0.9V$$

Deriving the component values



$$A_0 = 0.9V = \frac{4}{\pi} \cdot I_0 R \rightarrow R \approx 236\Omega$$

$$Q = 20 = \frac{R}{\omega_0 L} \rightarrow L \approx 1.25nH$$

$$f_0 = 1.5GHz = \frac{1}{2\pi\sqrt{LC}} \rightarrow C \approx 9pF$$

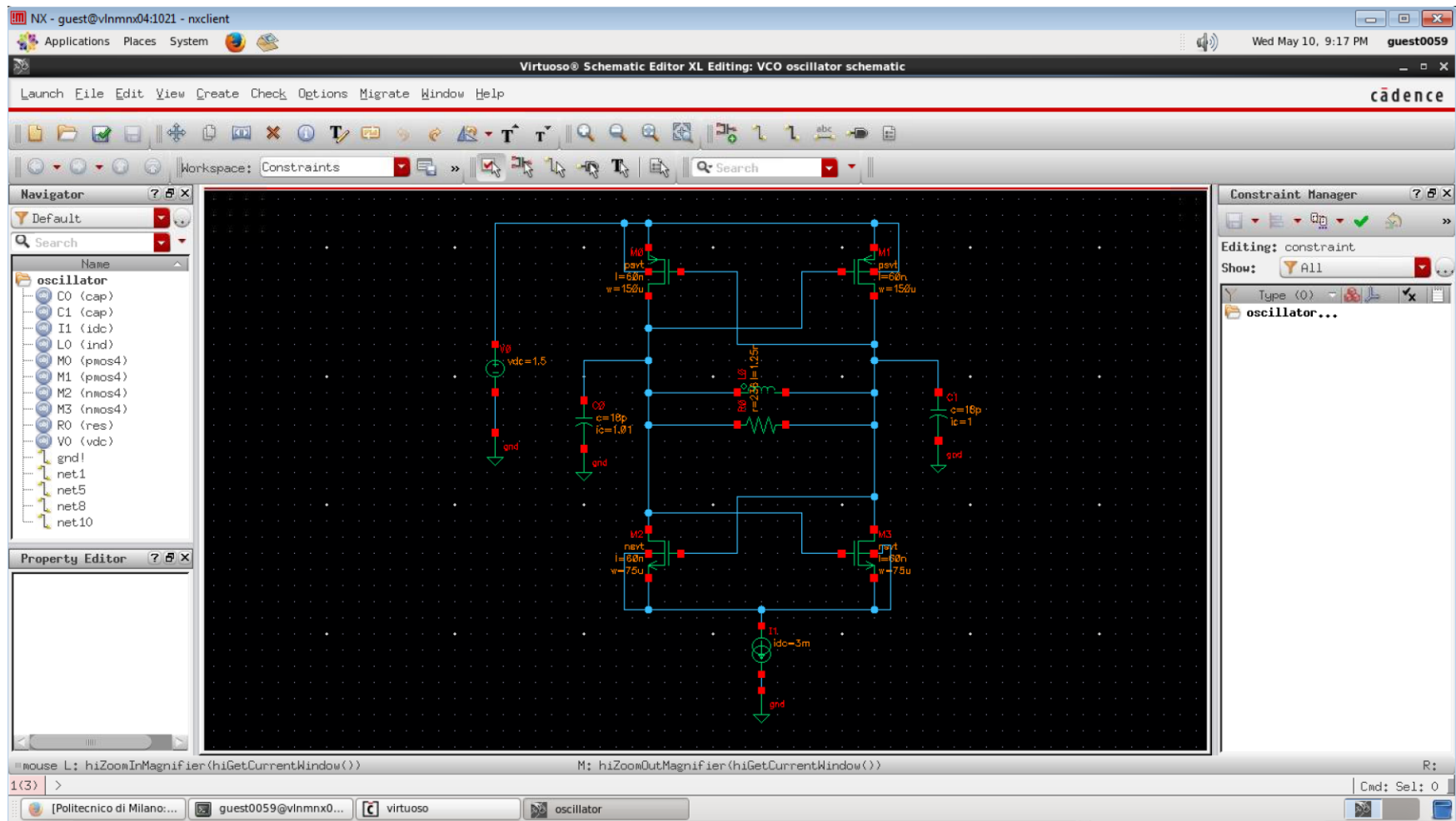
$$g_m R = 5 \rightarrow \left(\frac{W}{L}\right)_n = 1250 = \left(\frac{75\mu m}{60nm}\right)$$

Try using a spreadsheet to play around with the values

Cadence Simulation

- Start virtual desktop: *NX Client*
- Applications ► Terminal ► *virtuoso.sh*
- File ► New ► Library (do not need process)
- File ► New ► Cellview (schematic – schematic XL)
- “i” to add instances
- Use devices from “*analogLib*” library (*res, cap, ind, nmos4, pmos4, vdc, gnd, idc*)
- Use model name *nsvt* and *psvt* for *nmos4* and *pmos4*, respectively

Draw Schematic



Model File

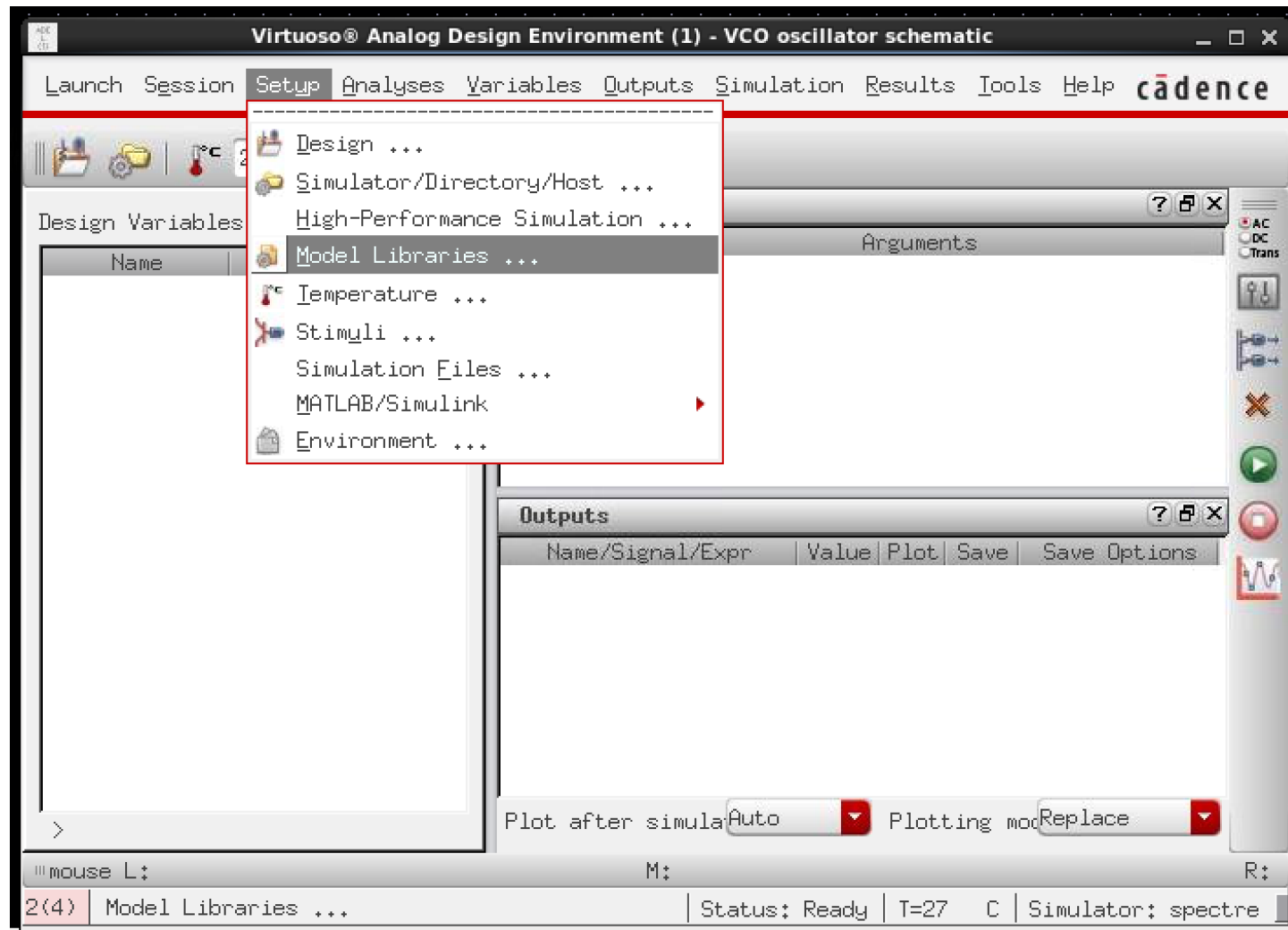
- Create a text file:

“models.scs”

```
simulator lang=spectre  
model nsvt mos1 type=n vto=0.35 kp=120e-6 lambda=5e-2 \  
cgso=2e-10 cgdo=2e-10 cgbo=2e-10  
model psvt mos1 type=p vto=-0.35 kp=60e-6 lambda=5e-2 \  
cgso=2e-10 cgdo=2e-10 cgbo=2e-10
```

- Open ADE L
- Menu Setup ► Model Libraries (path to your model.scs file)

Model Library



1) DC Analysis

- From ADE L tool
- Menu *Analysis*: dc
- Menu *Results* ► Print Operating Point
 - $g_m \approx 21.5 \text{ mA/V}$
 - $c_{gs,n} \approx 15 \text{ fF}$, $c_{gs,p} \approx 15 \text{ fF}$



2) Transient Analysis

Choosing Analyses -- Virtuoso® Analog Design Environment (1 X)

Analysis ☒ tran ☐ dc ☐ ac ☐ noise
☐ xf ☐ sens ☐ dcmatch ☐ stb
☐ pz ☐ sp ☐ envlp ☐ pss
☐ pac ☐ pstb ☐ pnoise ☐ pxf
☐ psp ☐ qpss ☐ qpac ☐ qpnoise
☐ qpxf ☐ qpssp ☐ hb ☐ hbac
☐ hbnoise

Transient Analysis

Stop Time

Accuracy Defaults (errpreset)
☒ conservative ☐ moderate ☐ liberal

☐ Transient Noise

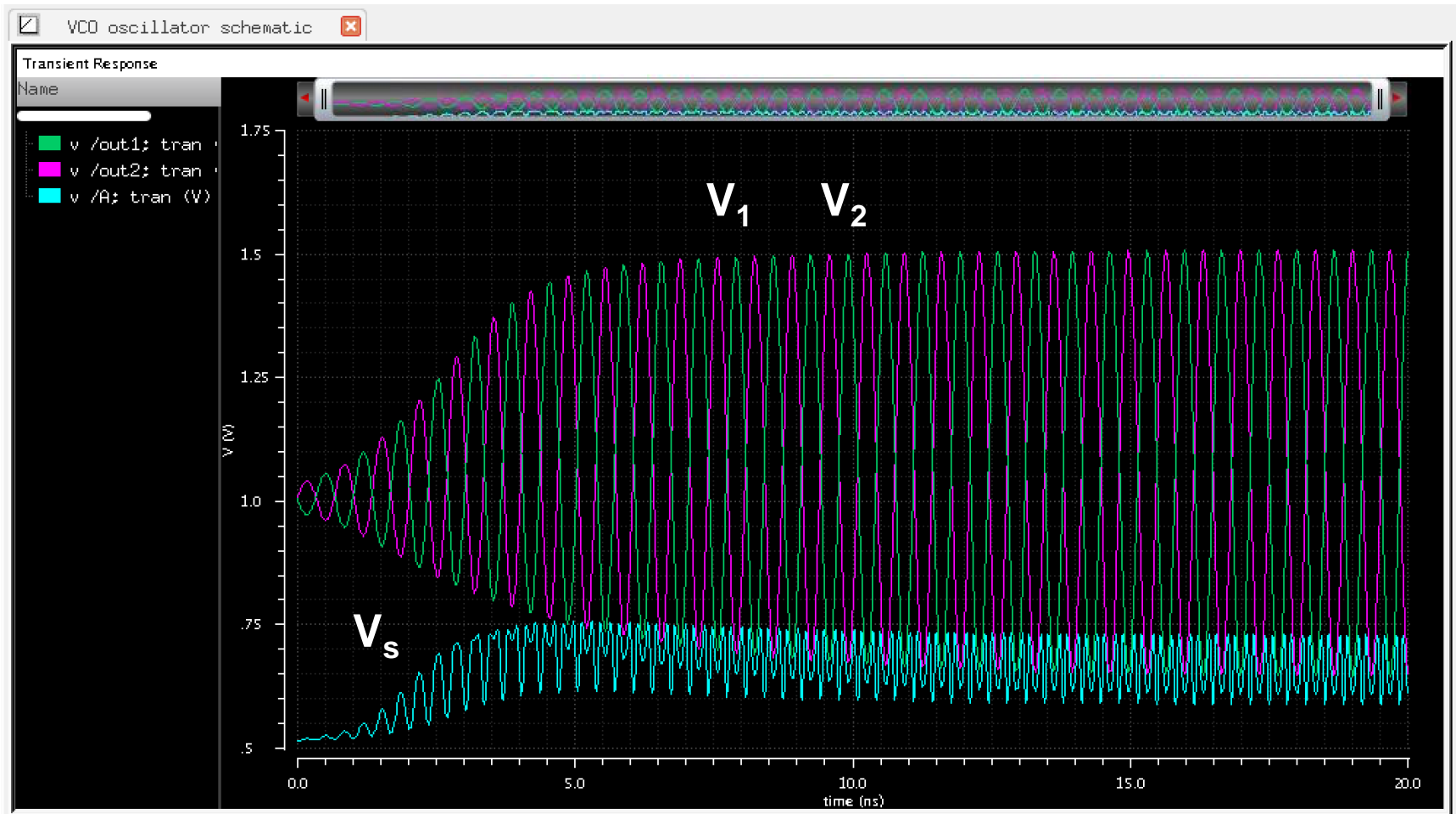
☐ Dynamic Parameter

Enabled ☒

Options...

OK Cancel Defaults Apply Help

Result of Transient Analysis



Set initial conditions!

3) Periodic Steady State

Choosing Analyses -- Virtuoso® Analog Design Environment (1) X

Analysis ☐ tran ☐ dc ☐ ac ☐ noise
☐ xf ☐ sens ☐ dcmatch ☐ stb
☐ pz ☐ sp ☐ envlp ☒ pss
☐ pac ☐ pstb ☐ pnoise ☐ pxf
☐ psp ☐ qpss ☐ qpac ☐ qpnoise
☐ qpxf ☐ qpssp ☐ hb ☐ hbac
☐ hbnoise

Periodic Steady State Analysis

Engine ☒ Shooting ☐ Harmonic Balance

Fundamental Tones

#	Name	Expr	Value	Signal	SrcId
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Large

☒ Beat Frequency ☐ Beat Period

1.5G Auto Calculate ☐

Output harmonics
Number of harmonics

Accuracy Defaults (errpreset)
☒ conservative ☐ moderate ☐ liberal
Additional Time for Stabilization
Save Initial Transient Results (save) ☐ no ☐ yes

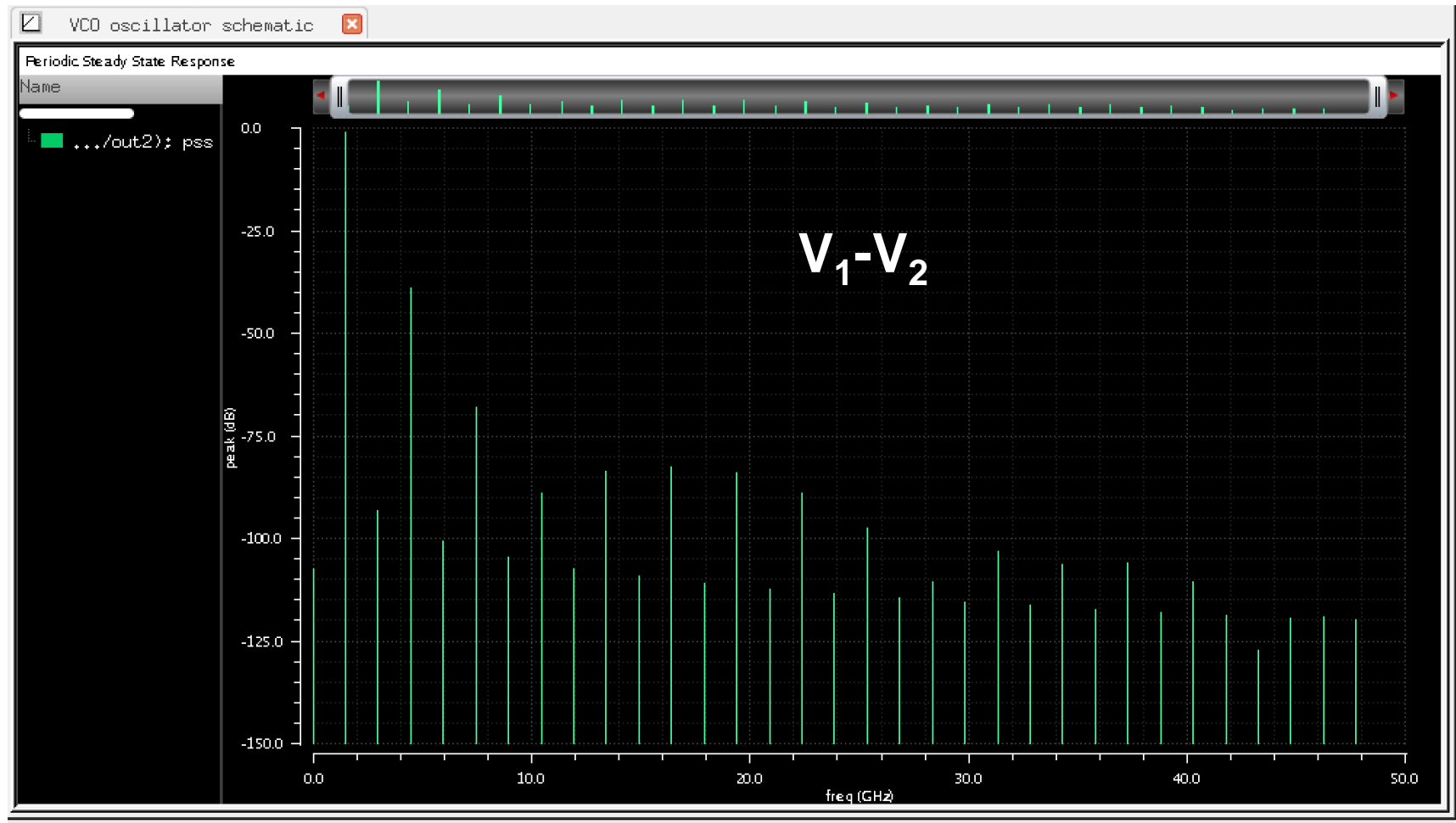
Oscillator ☒ Oscillator node
Reference node
Osc initial condition ☒ default ☐ linear

Sweep ☐
New Initial Value For Each Point (restart) ☐ no ☐ yes

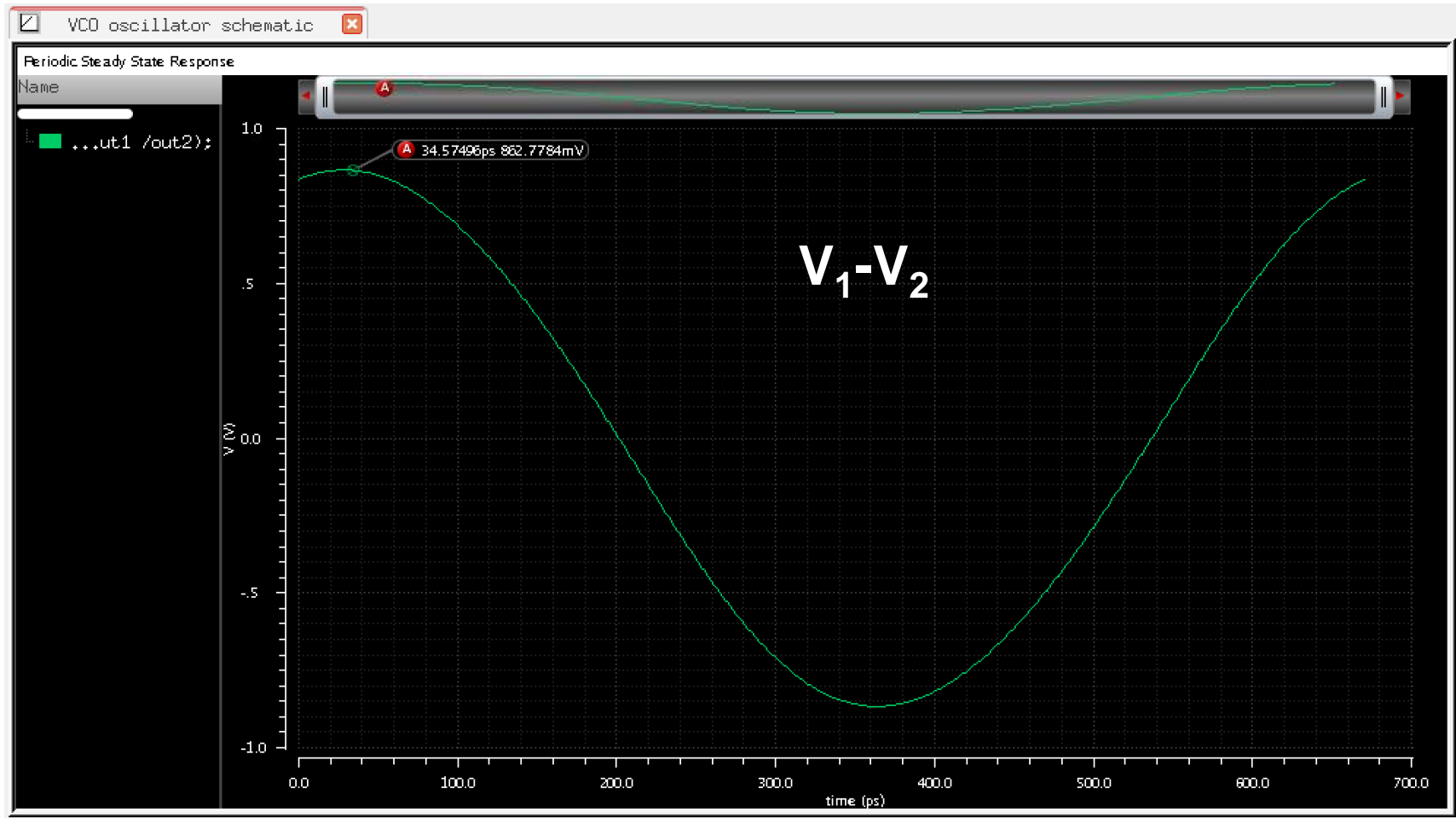
Loadpull ☐

Enabled ☒

Result of PSS Analysis (frequency domain)



Result of PSS Analysis (time domain)



- $A_0 = 0.89V$

4) Periodic Noise (PNOISE)

Choosing Analyses -- Virtuoso® Analog Design Environment (1) X

Analysis ☐ tran ☐ dc ☐ ac ☐ noise
☐ xf ☐ sens ☐ dcmatch ☐ stb
☐ pz ☐ sp ☐ envlp ☐ pss
☐ pac ☐ pstb ☒ pnoise ☐ pxf
☐ psp ☐ qpss ☐ qpac ☐ qpnoise
☐ qpxf ☐ qpzp ☐ hb ☐ hbac
☐ hbnoise

Periodic Noise Analysis

PSS Beat Frequency (Hz)

Multiple pnoise ☐

Sweep type Relative Harmonic

Output Frequency Sweep Range (Hz)

Start Stop

Sweep Type

Add Specific Point ☐

Sidebands

When using shooting engine, default value is 7.

Output

Positive Output Node

Output

Positive Output Node

Negative Output Node

Input Source

Noise Type

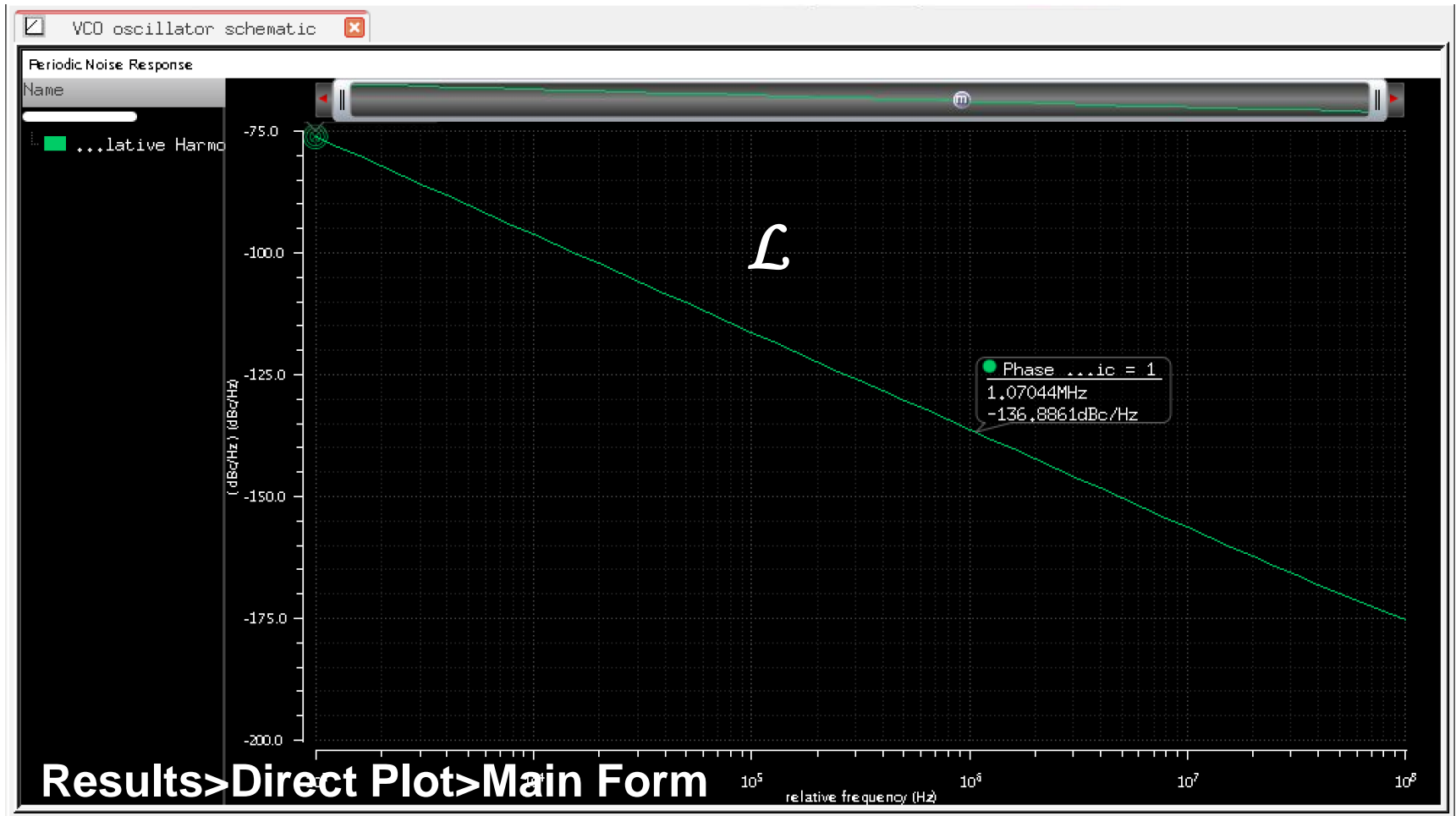
sources: single sideband (SSB) noise analysis

Noise Separation ☐ yes ☒ no

separate noise into source and gain

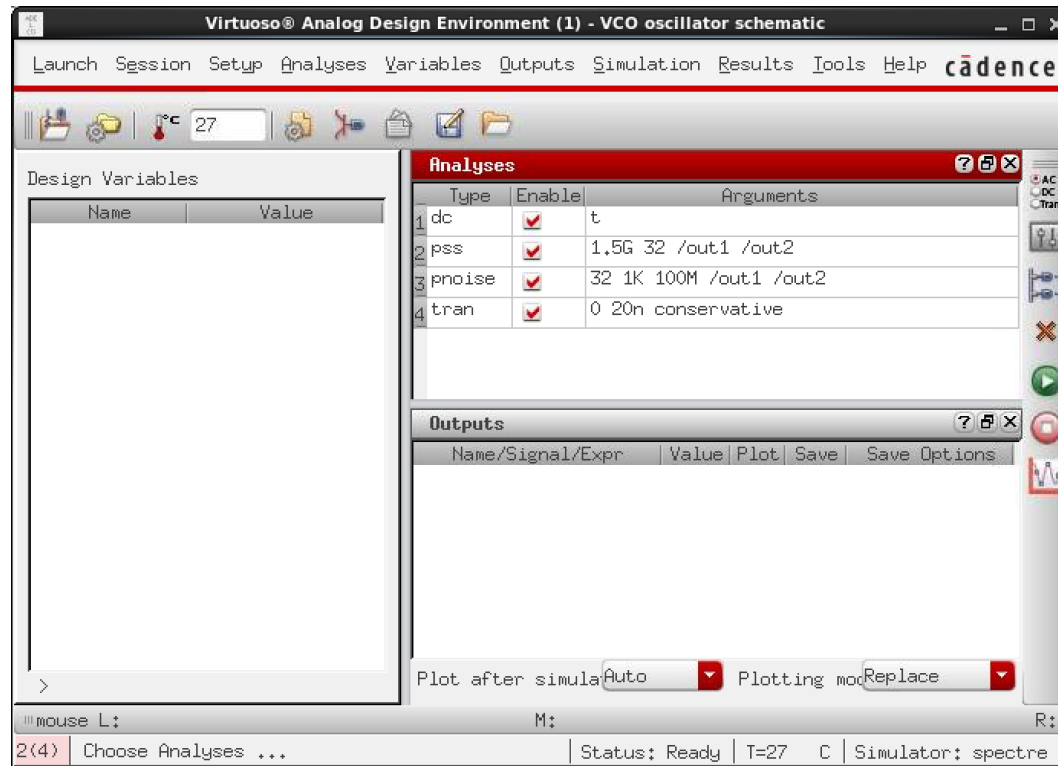
Enabled ☒

Result of PNOISE Analysis



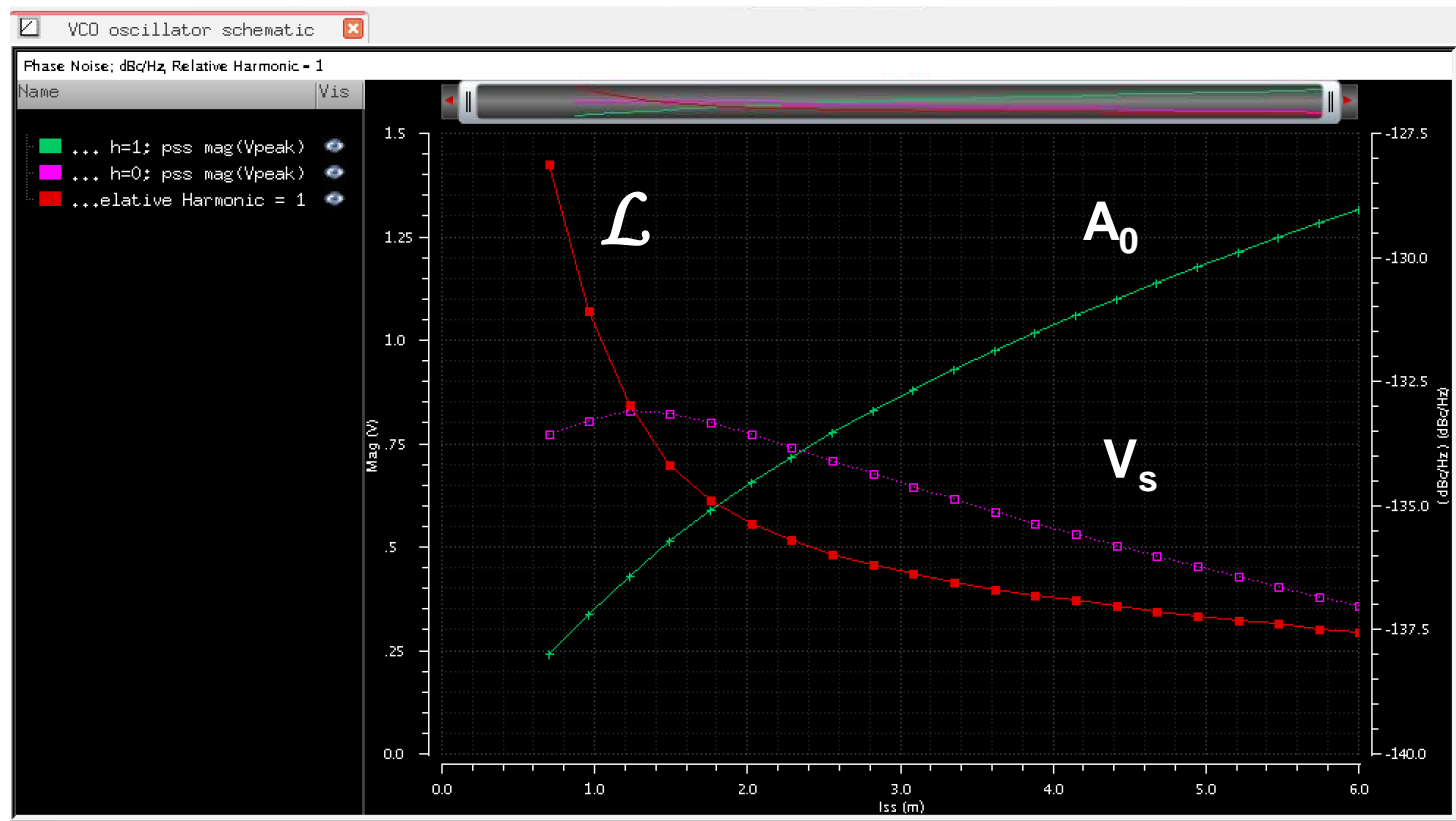
- $\mathcal{L} = -136.9 \text{ dBc/Hz}$

Analog Design Environment (ADE)



- Set analyses:
 - PSS (sweep variable)
 - PNOISE

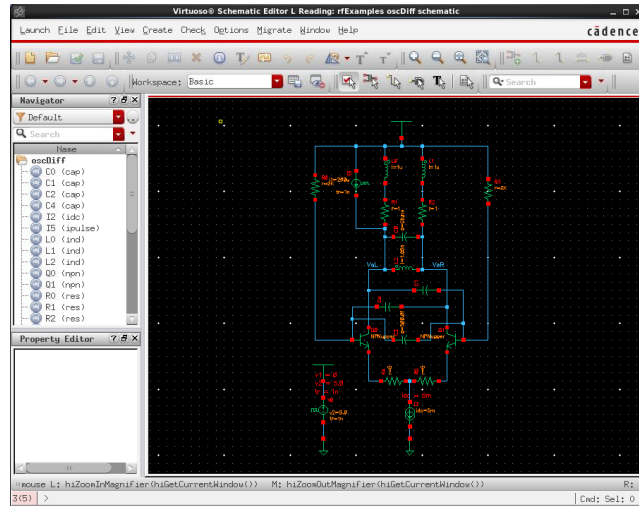
Exercise: sweep I_{ss} from 0.7 to 6.0 mA



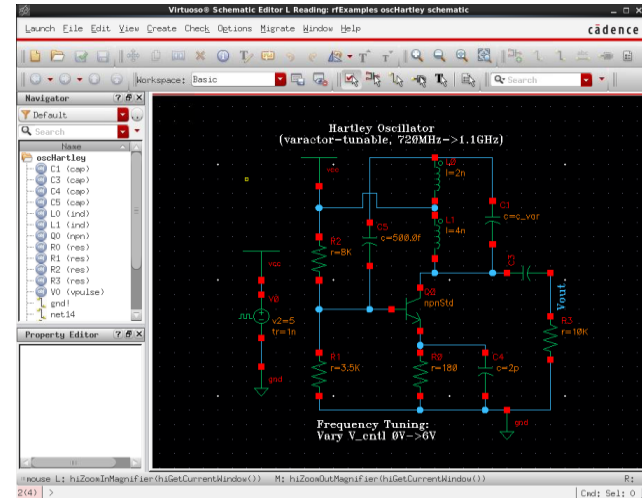
- Amplitude of differential output increases (but saturates)
- Source average voltage goes down
- Phase noise decreases (but saturates)

Library: rfExamples

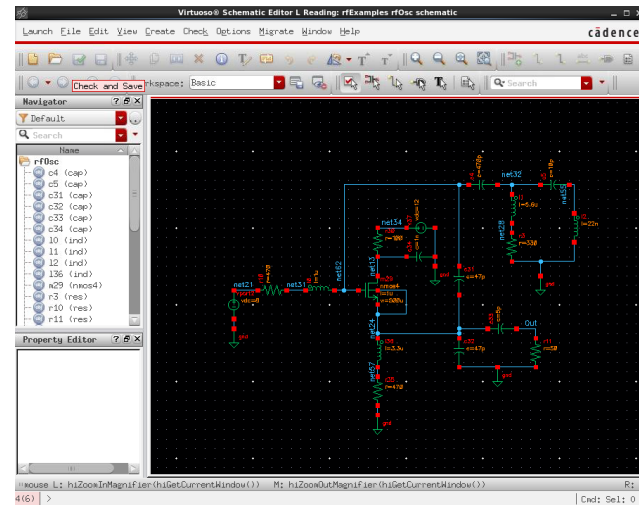
oscDiff



oscHartley



rfOsc



vp_osc

