# High-Speed Serial Interface Circuits and Systems

## Design Exercise3 –

## LC VCO

High-Speed Circuits and Systems Lab., Yonsei University

# LC VCO Structure

✓LC Tank
- Spiral inductor (symmetric type)
- Ideal capacitor

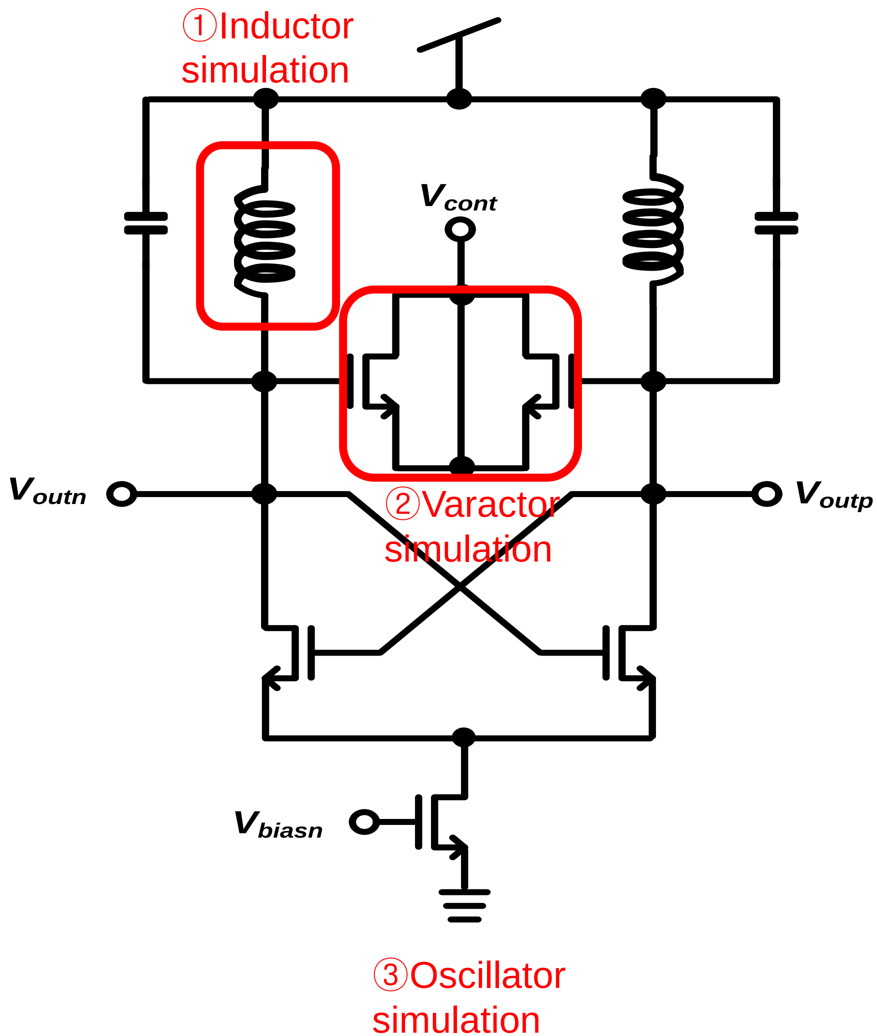
✓Varactor
- Accumulation varactor

✓Cross coupled circuit
- Negative resistance
- To compensate for the loss of the tank

✓Source MOSFET

✓OSC frequency

$$f_o = \frac{1}{2\pi\sqrt{LC}}$$



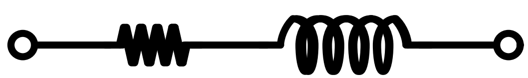
# Design Example

✓ LC voltage controlled oscillator (VCO)

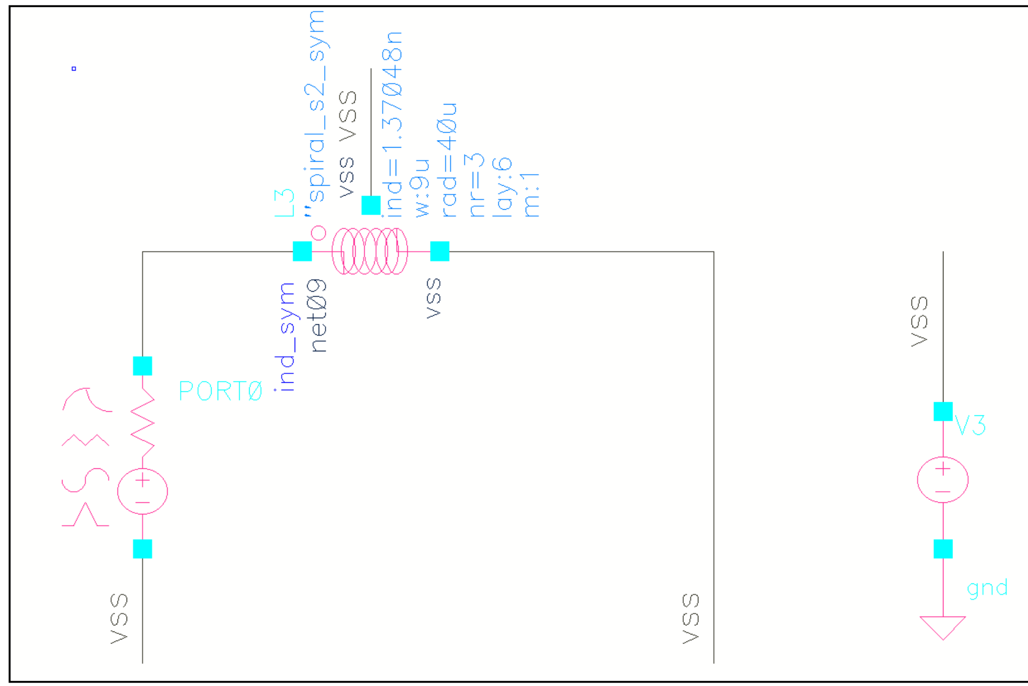
- Supply voltage: 1.8V
- Frequency tuning range: > 30-MHz
- Oscillation frequency : 1.5-GHz
- Phase noise @ 1-MHz offset with 1.5-GHz: < -125dBc

# Inductor Model

- An equivalent circuit model of inductor
  - Series connection of resistance and inductance
  - Analyze inductance into using Z-parameter



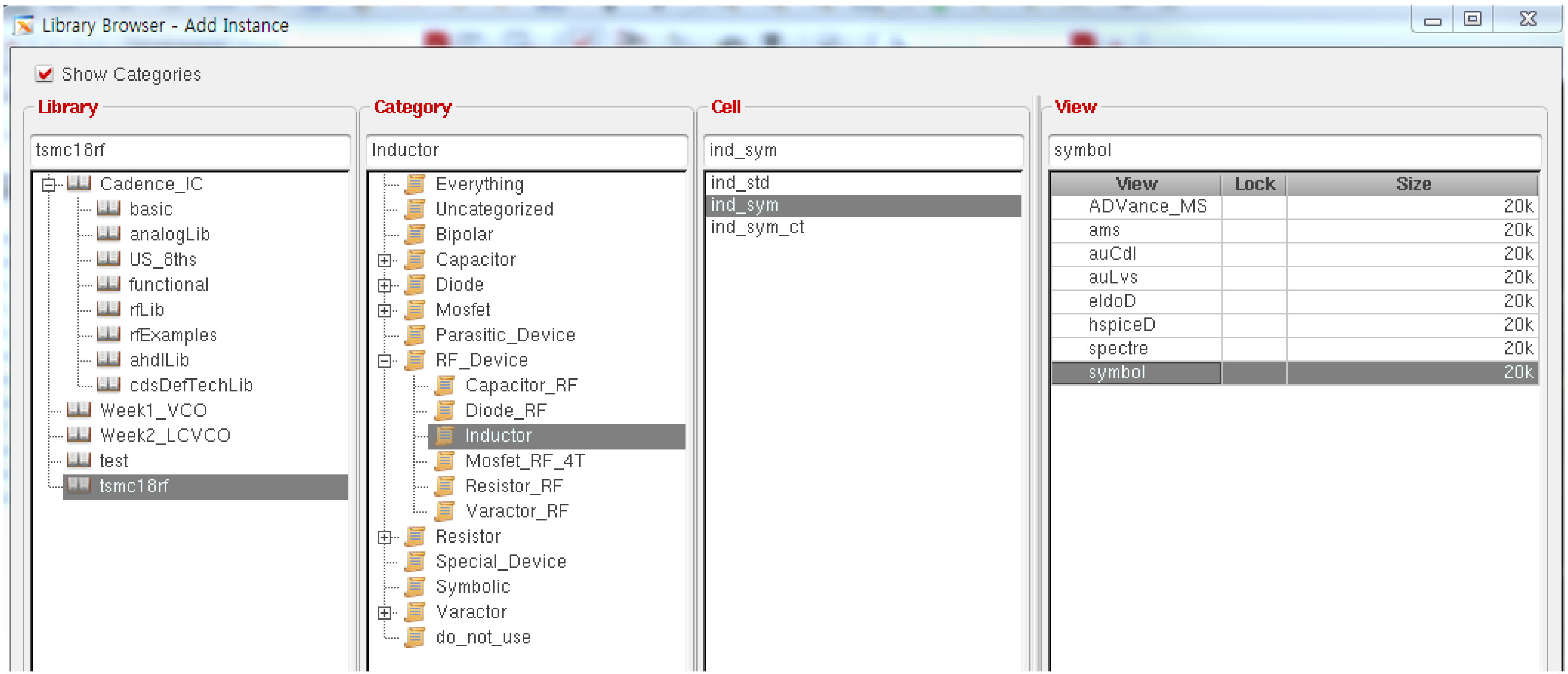
**< Equivalent circuit of inductor >**




< Simulation schematic >

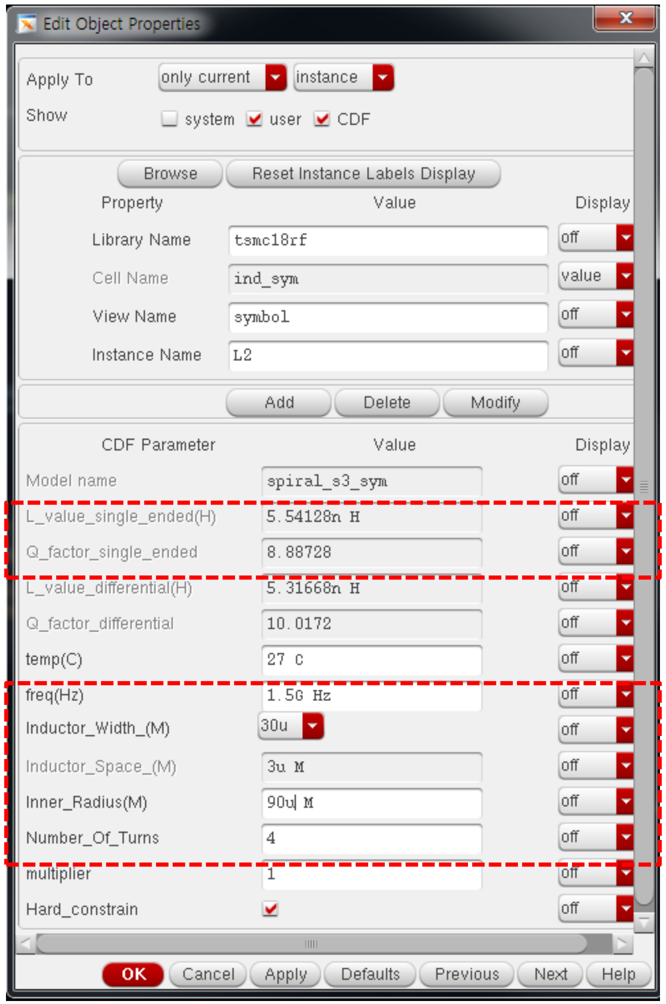
# Inductor

- Inductor selection
  - Tsmc18rf → RF_Device → Inductor → ind_sym → symbol
  - Symmetric inductor selection



# Inductor Parameters

- Setting of frequency, inductor width, inner radius and number of turns.

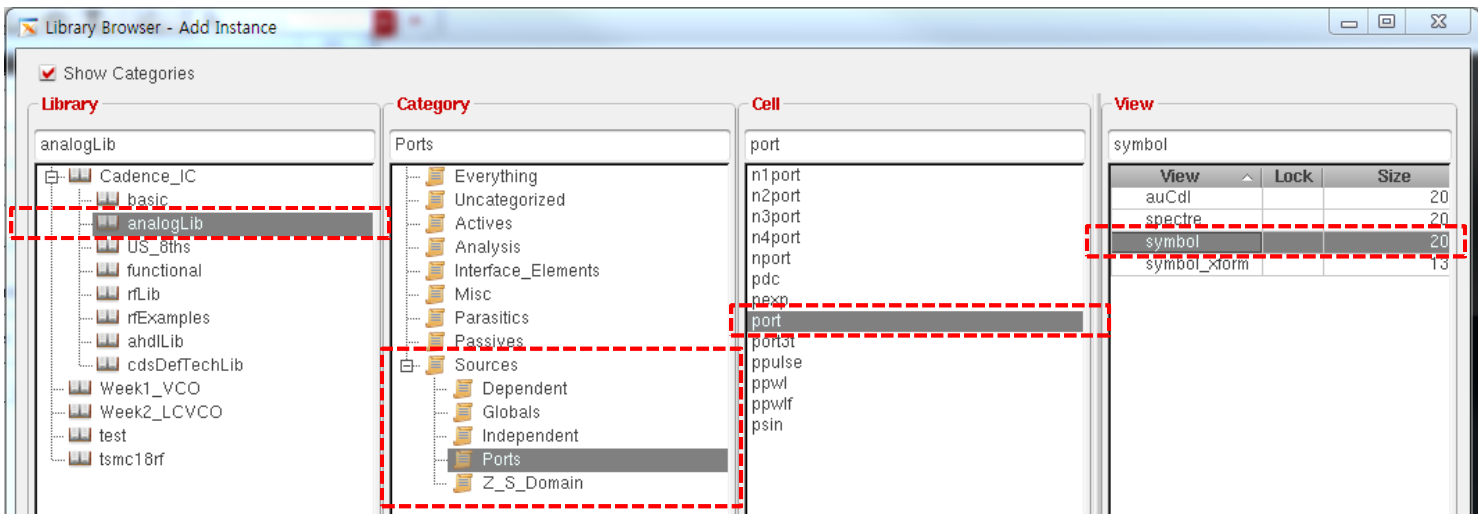



- Freq(Hz) : 1.5G
- Inductor_Width (M) : 30u
- Inner_Radius (M) : 90u
- Number_Of_Turns : 4

→ Inductance : 5.54nH
→ Q_factor : 8.88

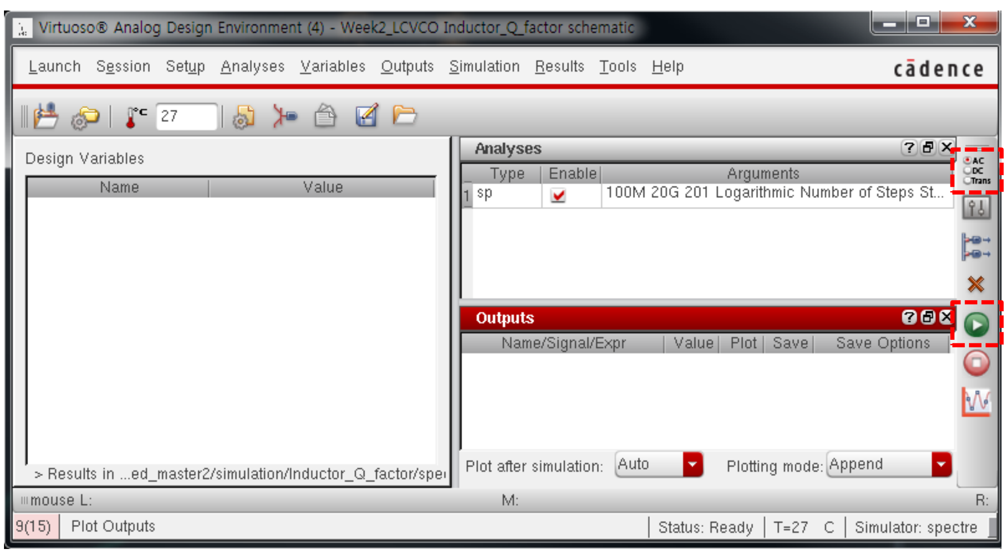
# Port for S-parameter Simulation

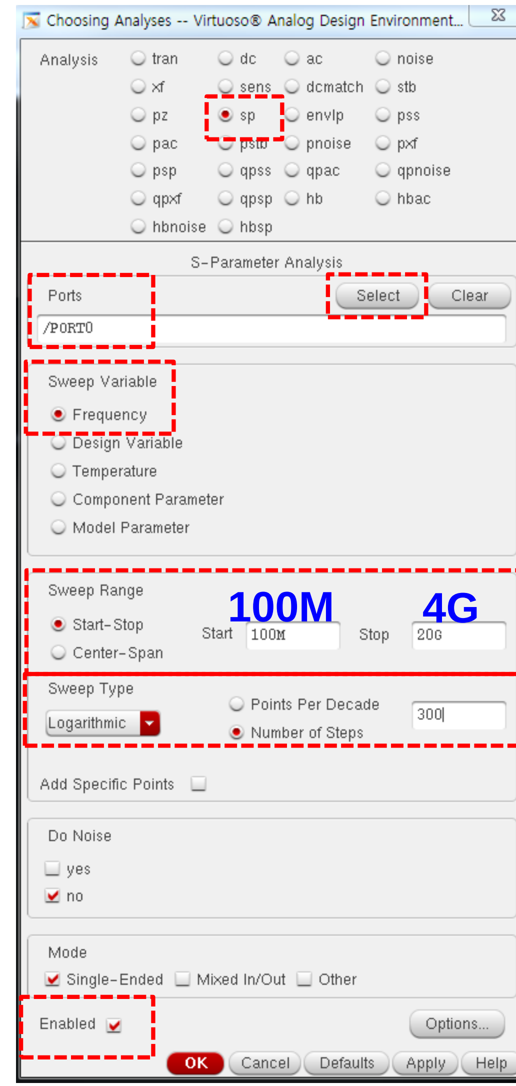
- Port
  - Show Categories check
  - analogLib → Sources → Ports → port → symbol



# S-parameter Simulation Setup

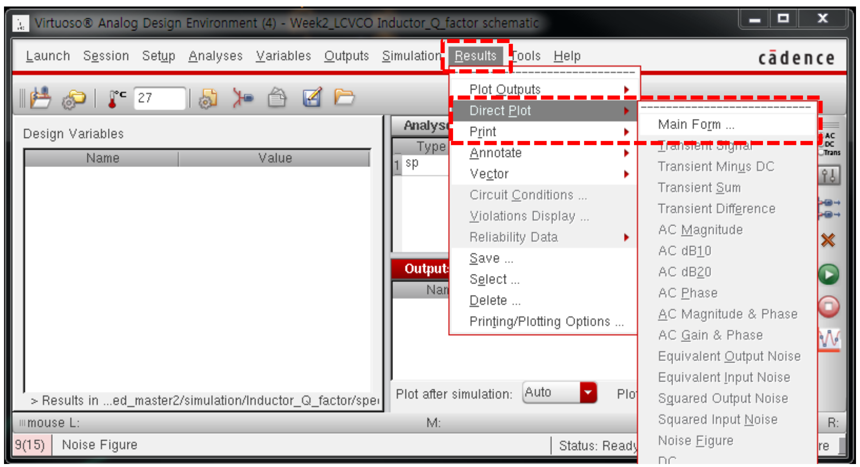
- Simulation condition setting
  - Analysis : sp (S-Parameter Analysis)
  - Ports : Port0  (schematic node choice)
  - Sweep Variable : Frequency
  - Sweep Range : 100M ~ 5G
  - Sweep Type : Logarithmic
  - Number of Steps : 301
  - Enabled check → OK → Netlist and Run

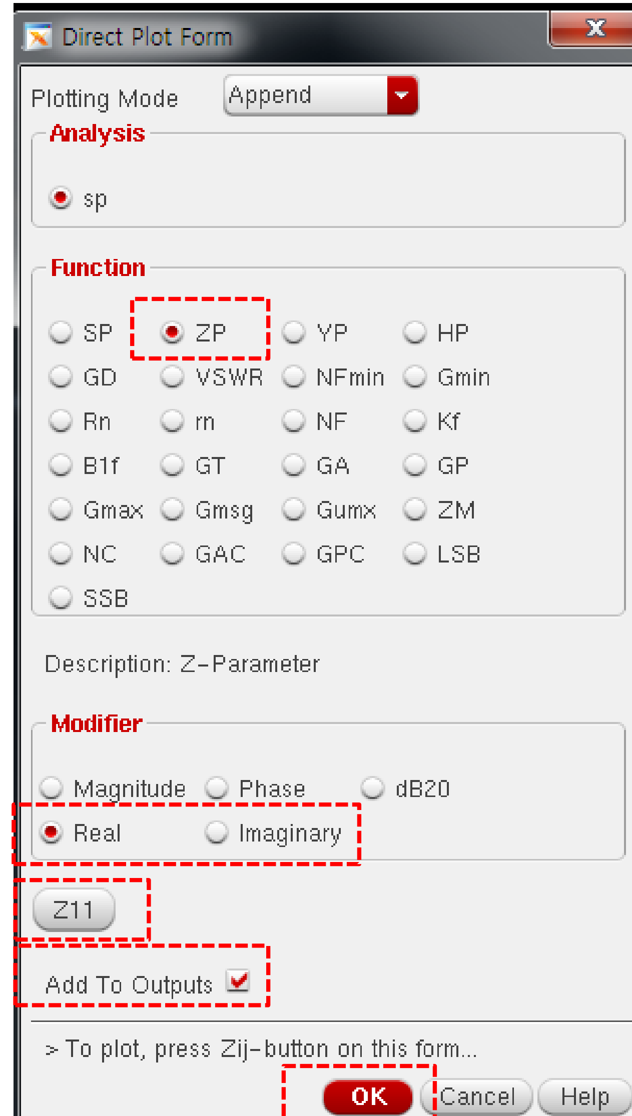


# Plotting Z-parameter

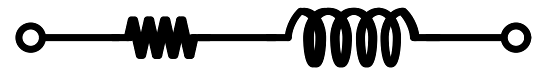
- Simulation condition setting
  - Results → Direct Plot → Main Form
  - Function : ZP
  - Add To Outputs choice
  - Modifier : Real → Z11 and Imaginary → Z11
  - OK

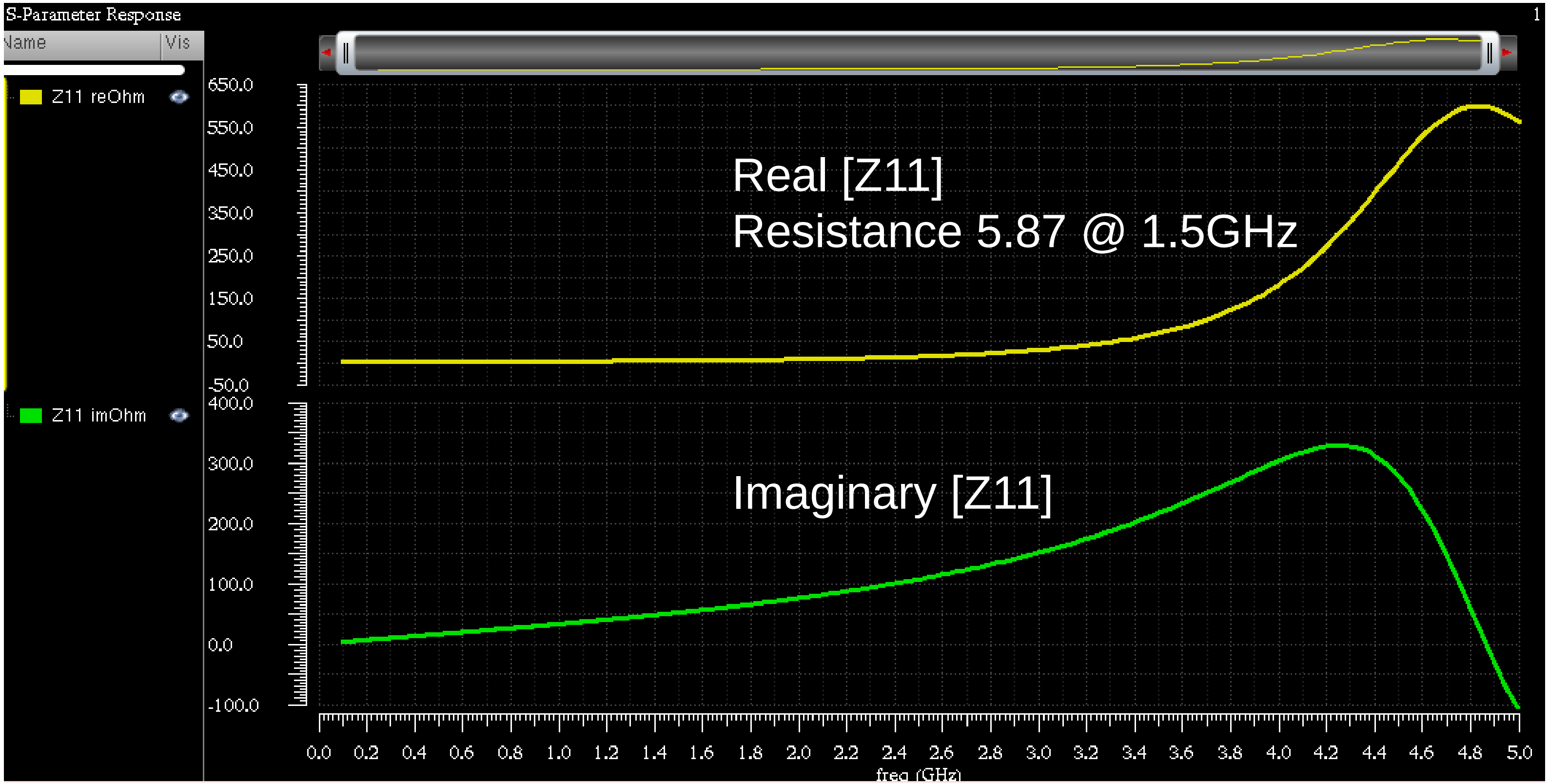


# Z-parameter Results

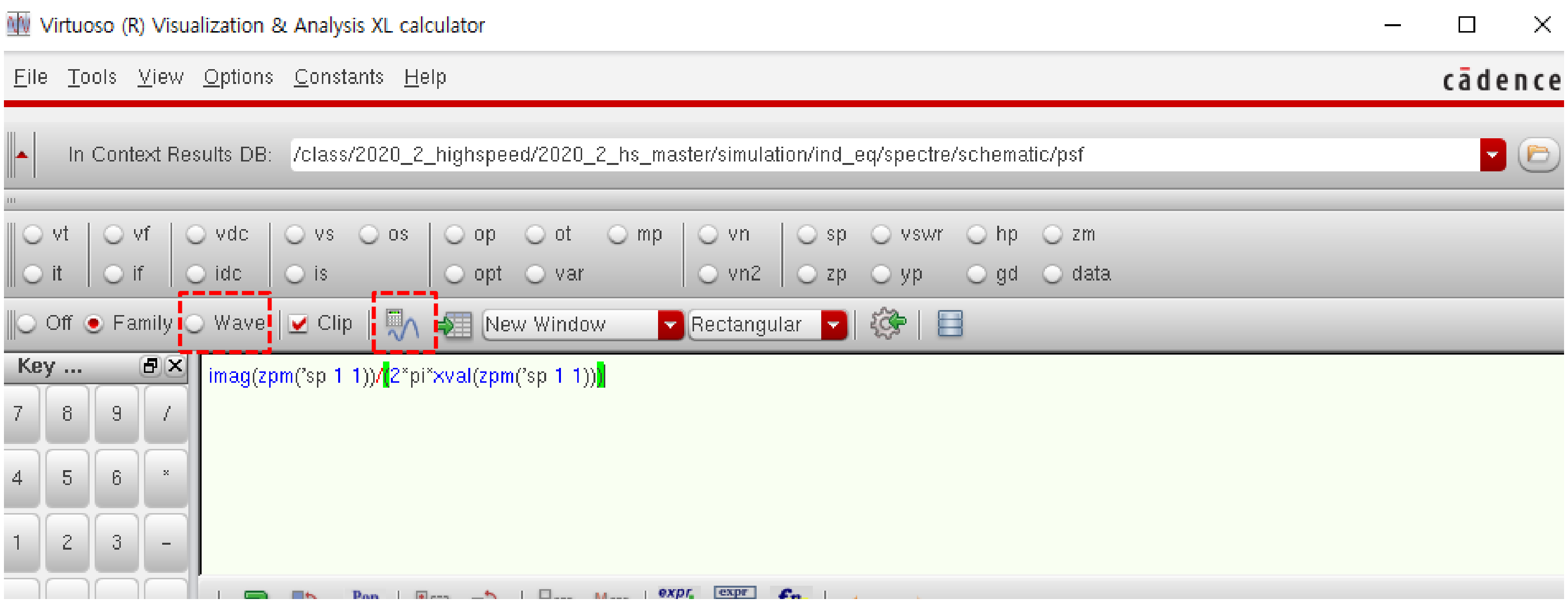
- $Z = R + j\omega L$
  - Resistance = Real [Z11]
  - Inductance = Imaginary [Z11] / ω
  - Check the SRF(self resonance frequency)



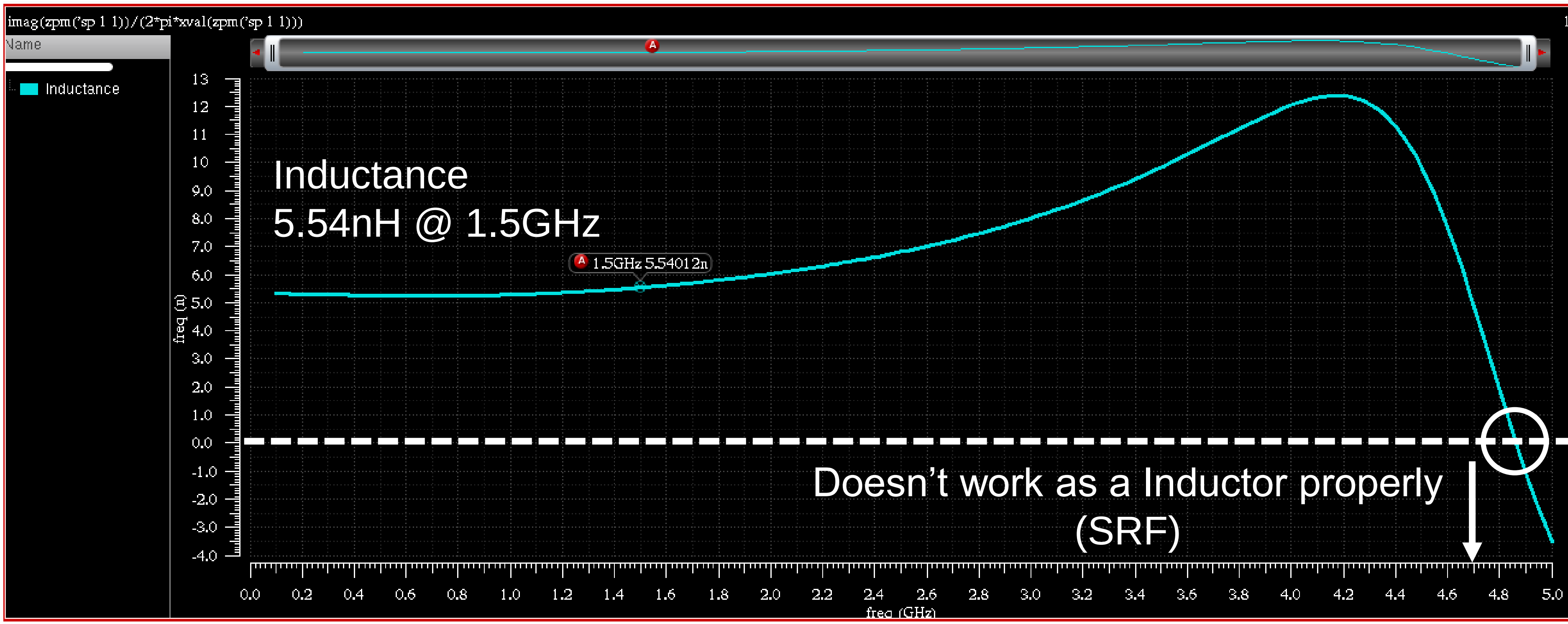
# Inductance

- Simulation condition setting
  - L = $\frac{\omega L}{\omega} = \frac{Imag[Z11]}{\omega}$
  - Calculator (Visualization & Analysis XL)
  - Wave choice → imag(zpm('sp 1 1))/(2*pi*xval(zpm('sp 1 1)))



# Inductance

- Inductance simulation
  - Inductance : 5.54nH @ 1.50GHz

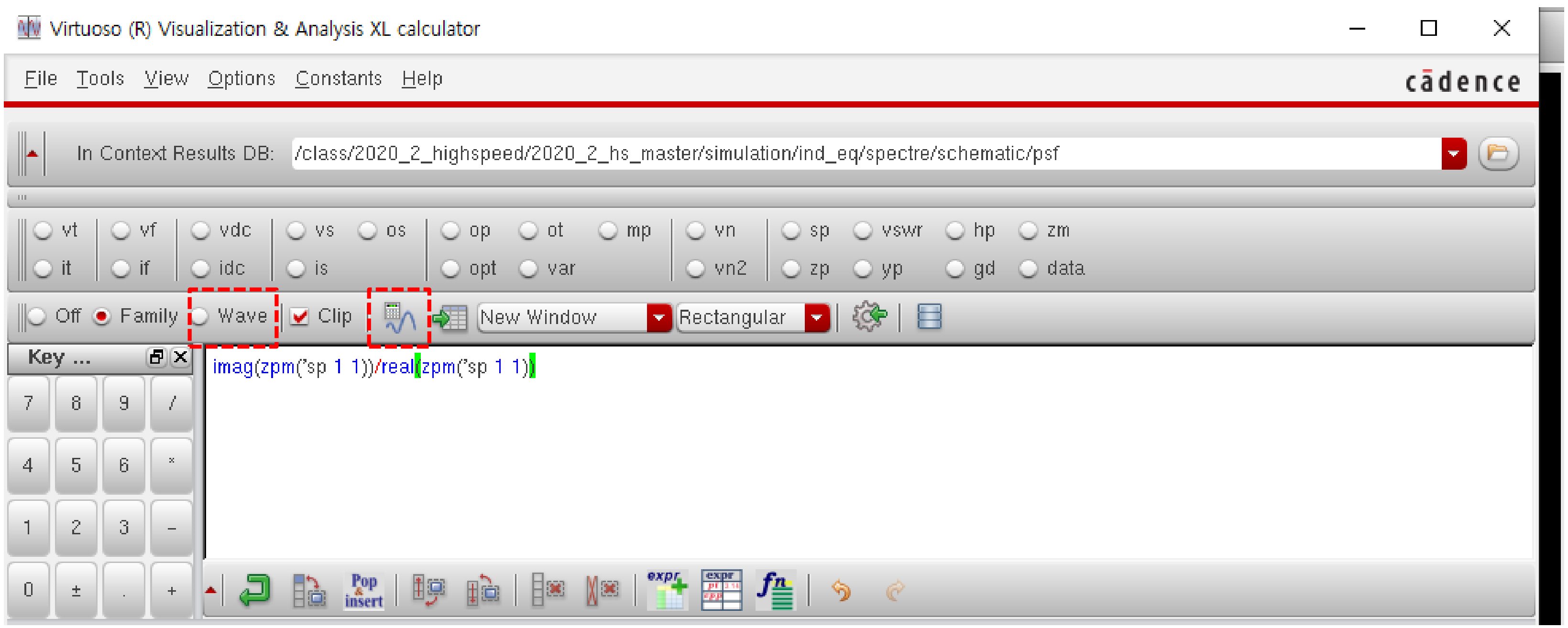


# Q-factor

- In an series RL circuit

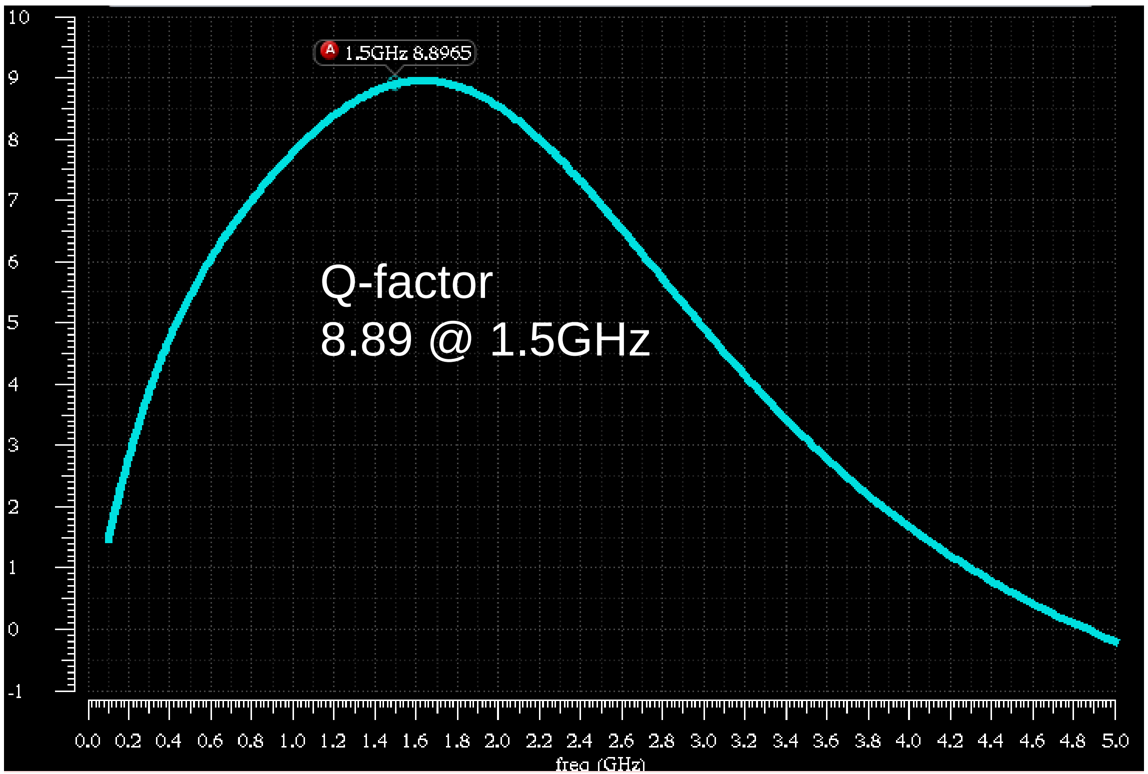
$$Q = \omega \frac{energy\,stored}{energy\,loss} = \frac{\omega L}{R} = \frac{imag(Z11)}{real(Z11)}$$

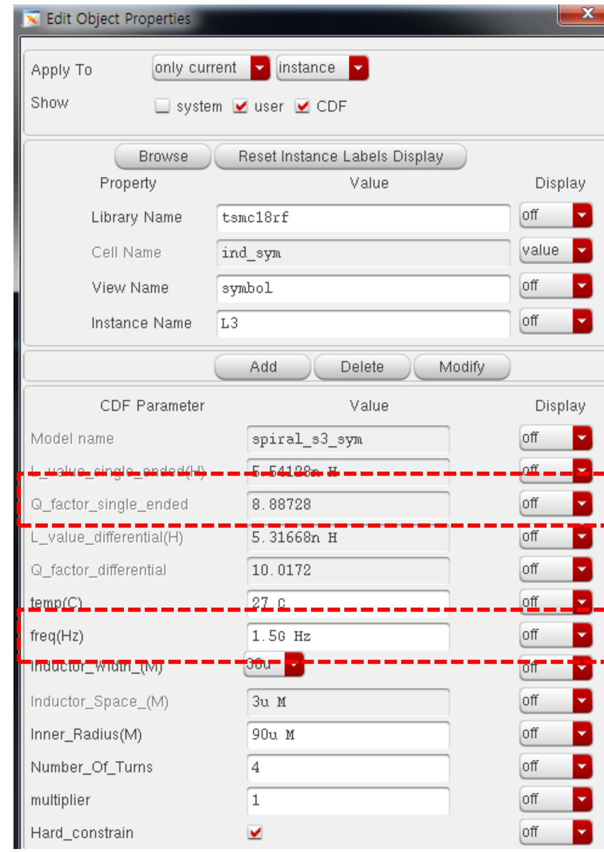
  - Calculator (Visualization & Analysis XL)
  - Wave choice → imag(zpm('sp 1 1))/real(zpm('sp 1 1))



# Q-factor Results

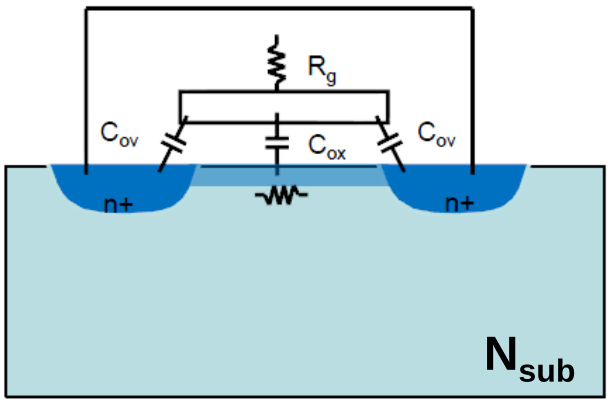
- Inductor Q-factor simulation
  - Inductor Q-factor : 8.89 @ 1.50GHz



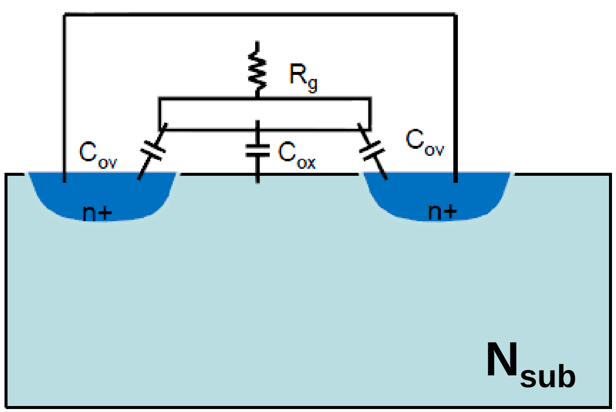



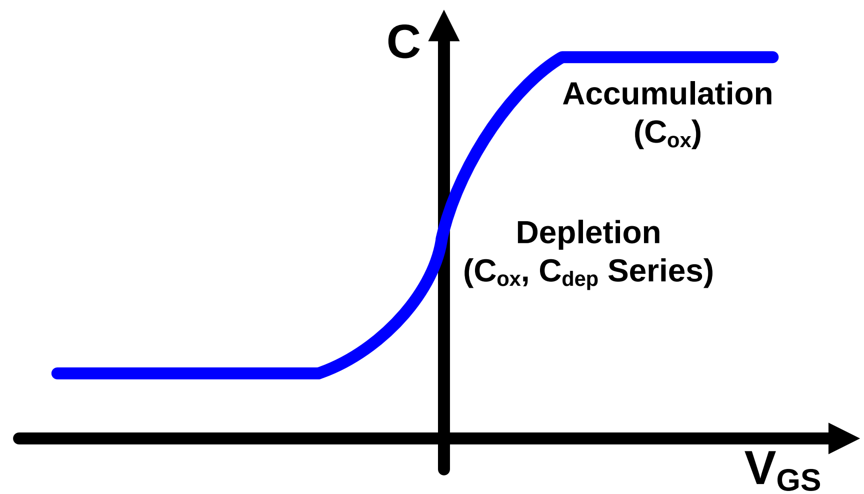
# Accumulation Mode Varactor

- On (Accumulated channel)

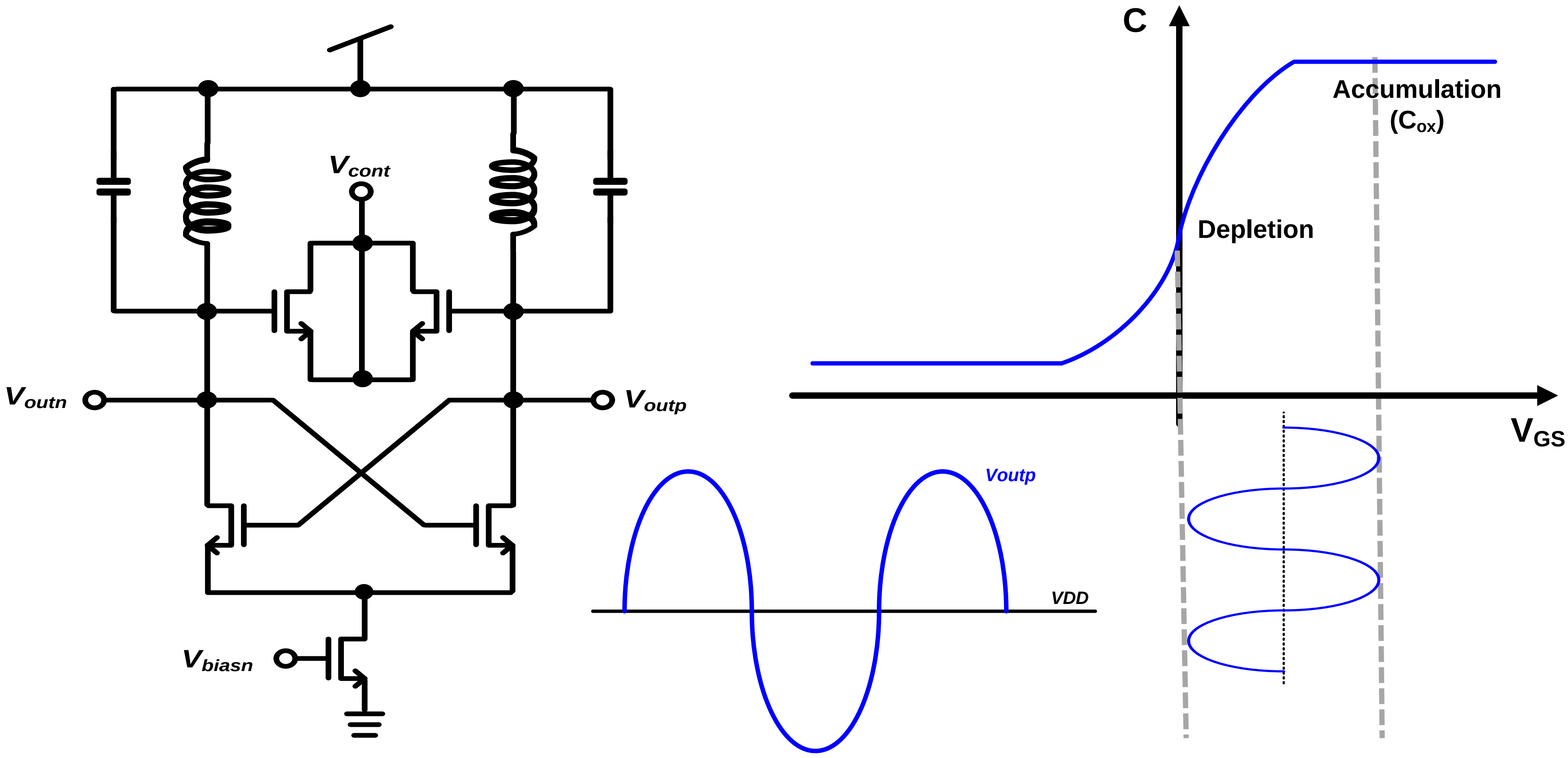



- OFF(Depleted)



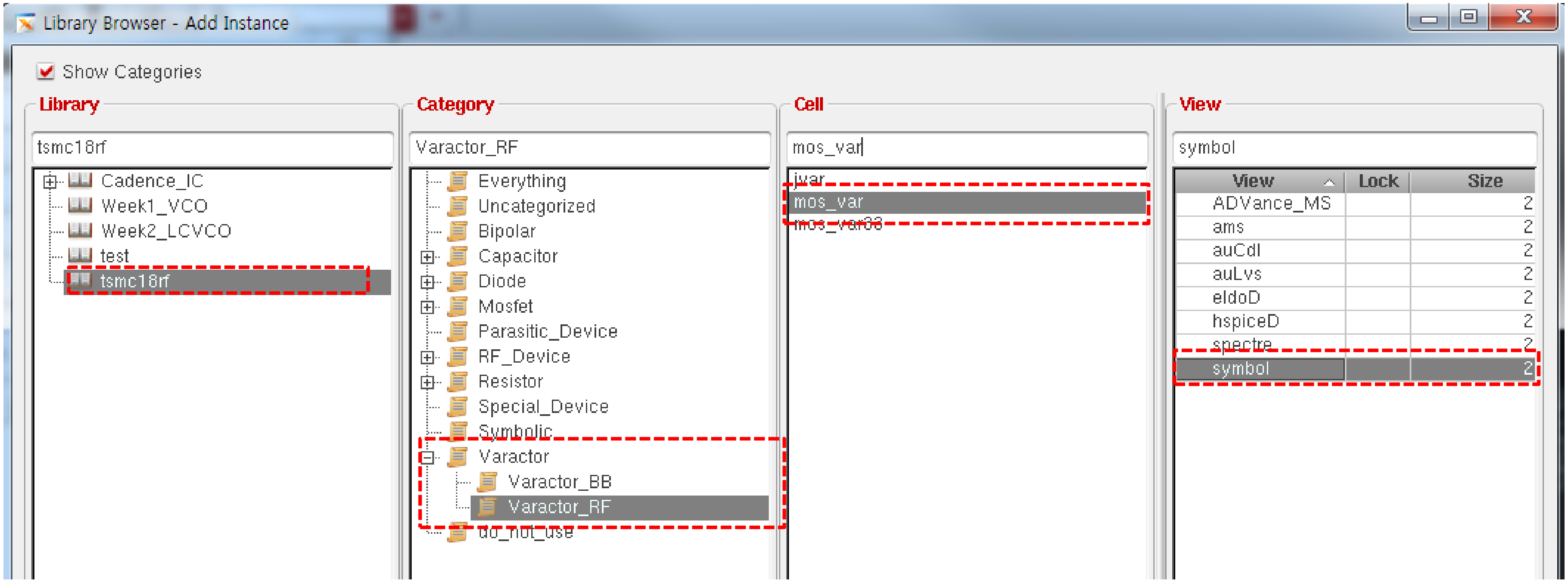
# Oscillator with Varactor




- Change average capacitance from control voltage.

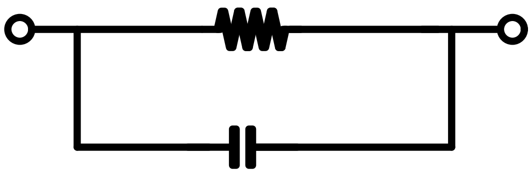
# Varactor

- Varactor selection
  - Tsmc18rf → Varactor → Varactor_RF → mos_var → symbol

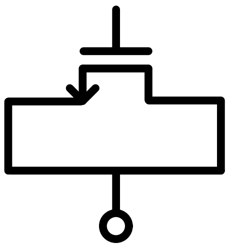


# Varactor Modeling

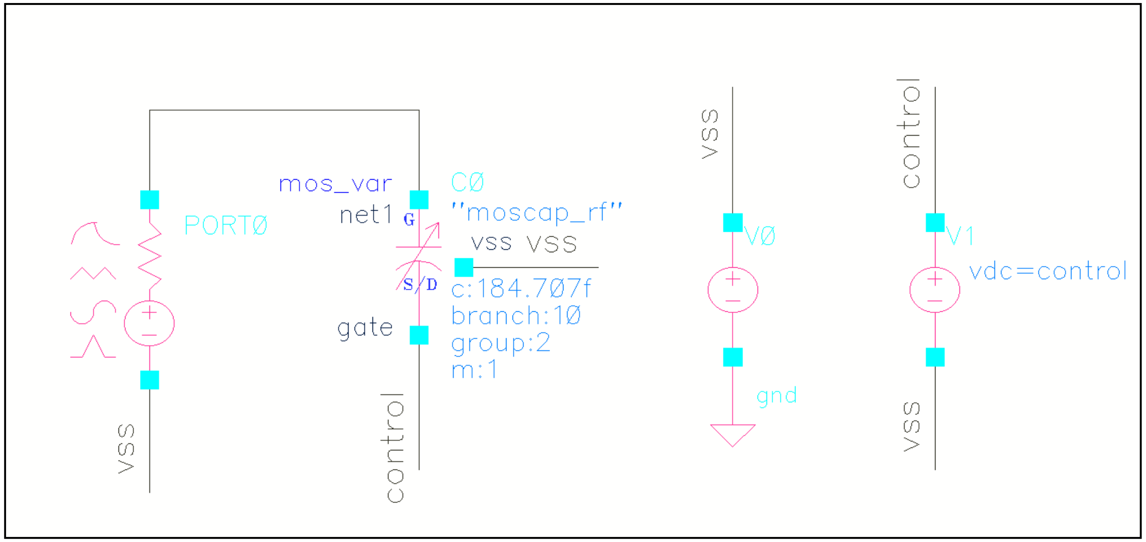
- An equivalent circuit model of varactor
  - Parallel connection of resistance and capacitance
  - Analyze capacitance into using Y-parameter



**< Equivalent circuit of varactor >**



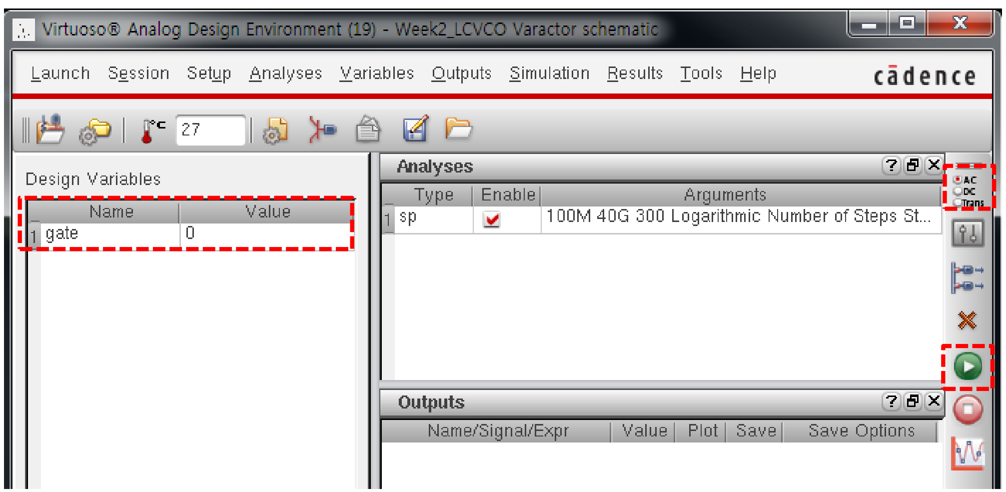

**< Varactor structure >**

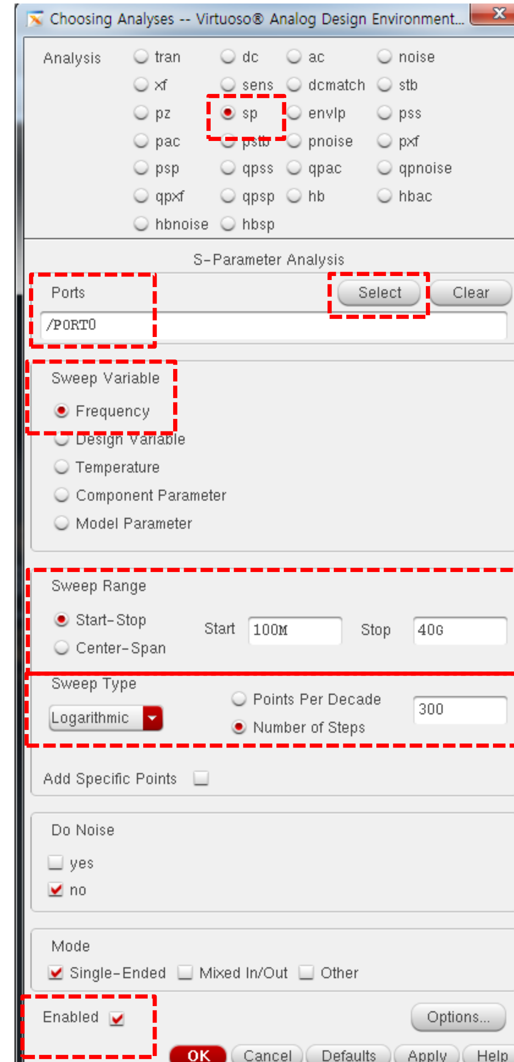



< Test schematic >

# S - Parameter

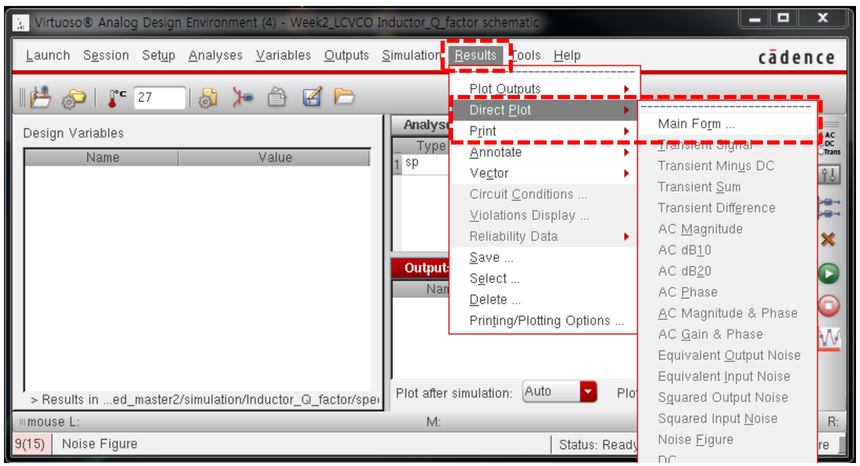
- Simulation condition setting
  - Analysis : sp (S-Parameter Analysis)
  - Ports : Port0  (schematic node choice)
  - Sweep Variable : Frequency
  - Sweep Range : 100M ~ 40G
  - Sweep Type : Logarithmic
  - Number of Steps : 301
  - Enabled check → OK → Netlist and Run

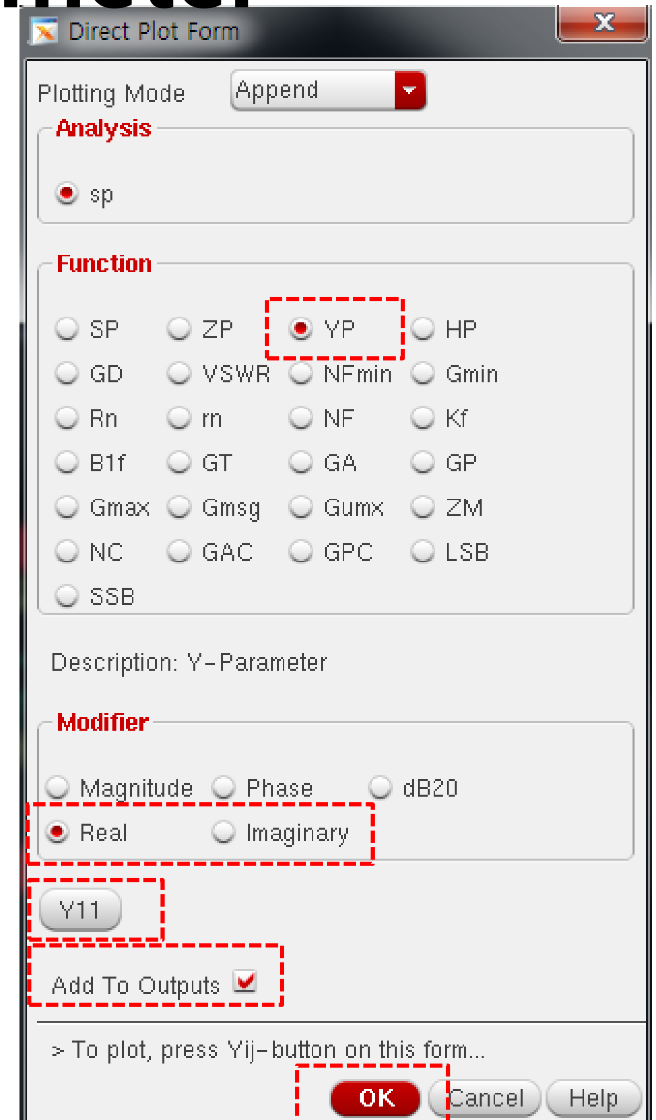


# Plotting Y- Parameter

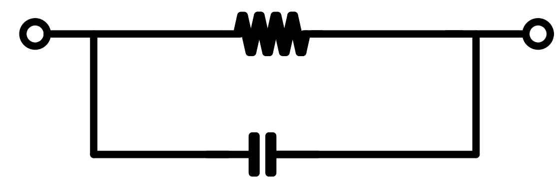
- Simulation condition setting
  - Results → Direct Plot → Main Form
  - Function : YP
  - Add To Outputs choice
  - Modifier : Real → Y11 and Imaginary → Y11
  - OK



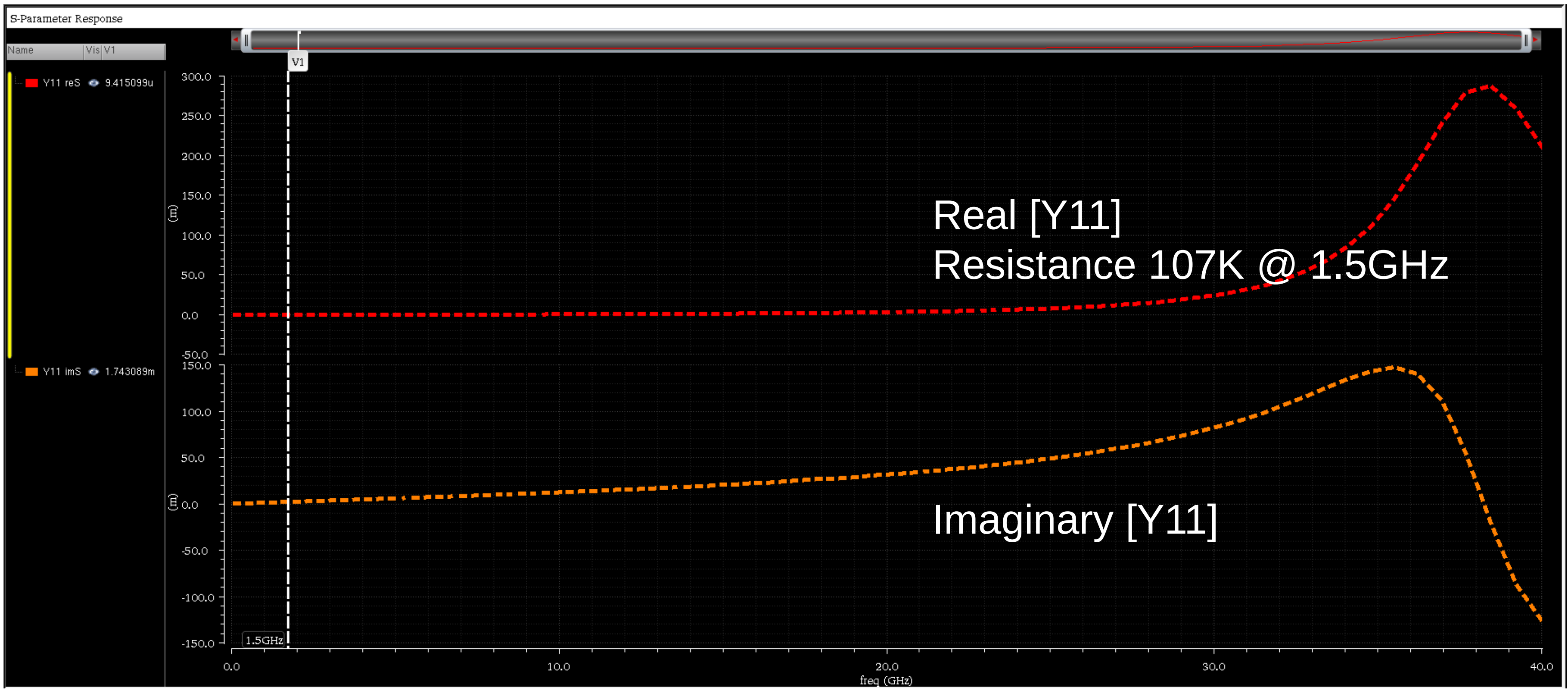



# Y- Parameter

- $Y = 1/R + j\omega C$
  - Resistance = 1/ Real [Y11]
  - Capacitance = Imaginary [Y11] / $\omega$

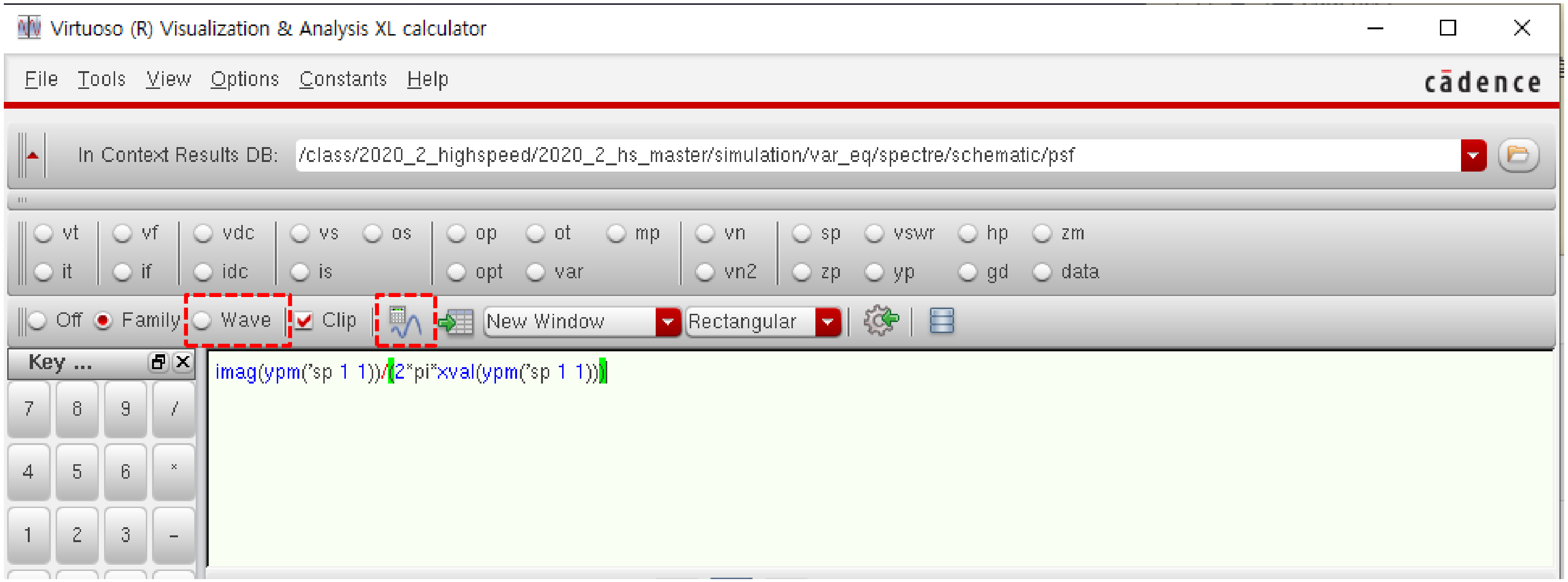


< Equivalent circuit of varactor >



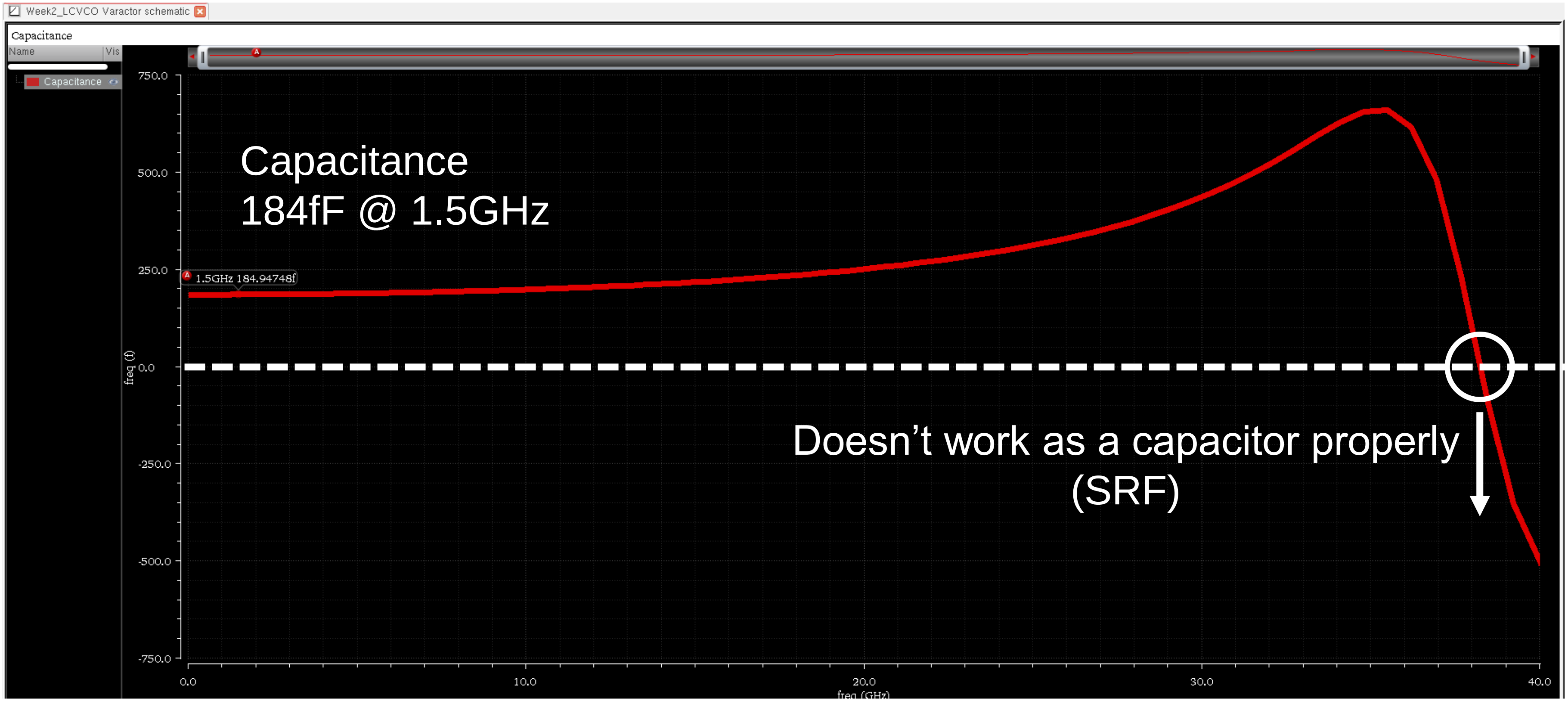
# Capacitance

- Simulation condition setting
  - C = $\frac{\omega C}{\omega} = \frac{Imag[Y11]}{\omega}$
  - Calculator (Visualization & Analysis XL)
  - Wave choice → imag(yp(1 1 ?result "sp")) /(2*pi*xval(yp(1 1 ?result "sp")))



# Capacitance

- Capacitance simulation
  - Capacitance : 184fF @ 1.50GHz



# Q-factor

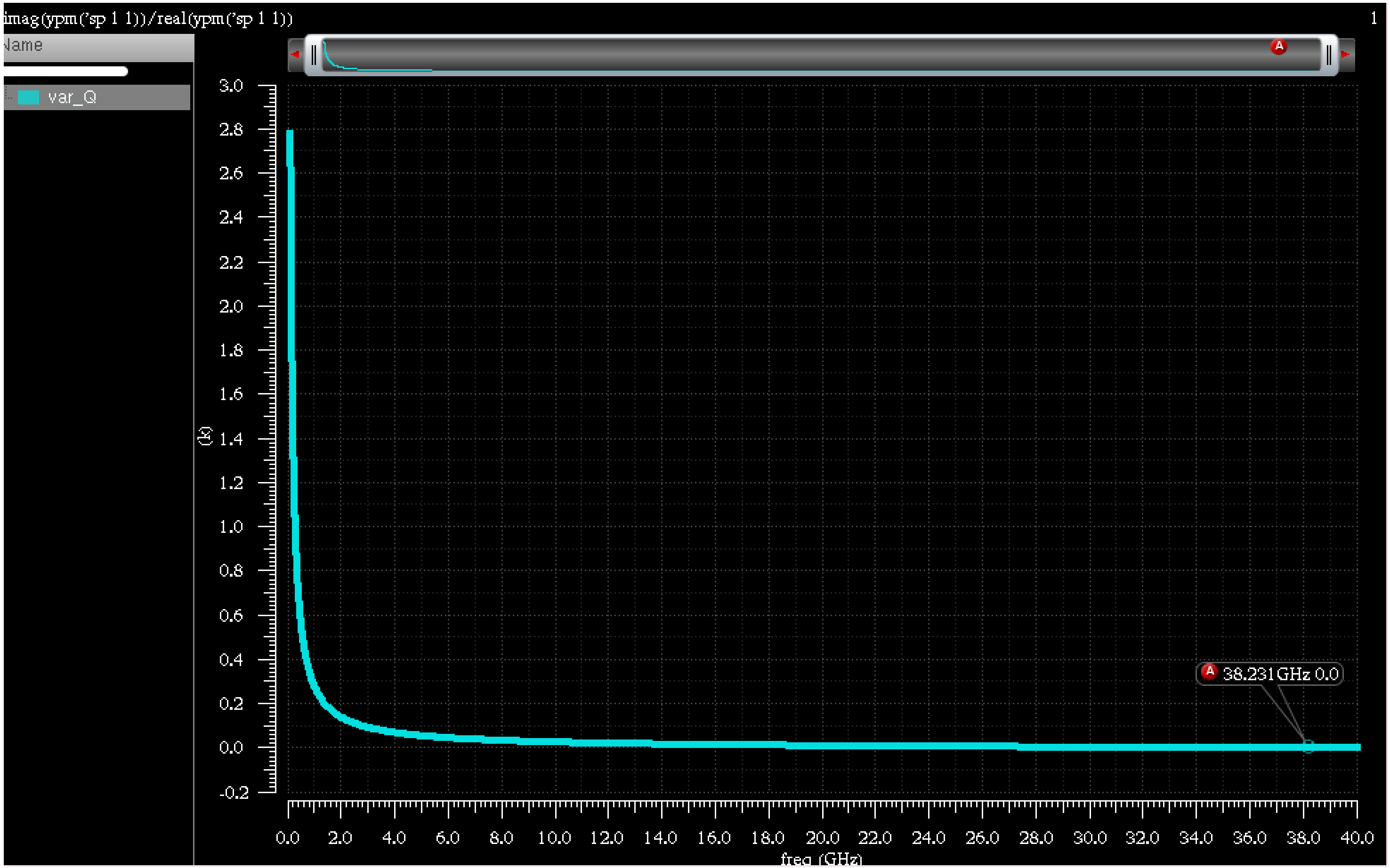
- In an parallel RC circuit..

$$Q = \omega \frac{energy\,stored}{energy\,loss} = \omega CR = \frac{imag(Y11)}{real(Y11)}$$

  - Calculator (Visualization & Analysis XL)
  - Wave choice → imag(ypm('sp 1 1))/real(ypm('sp 1 1))

# Q-factor Results

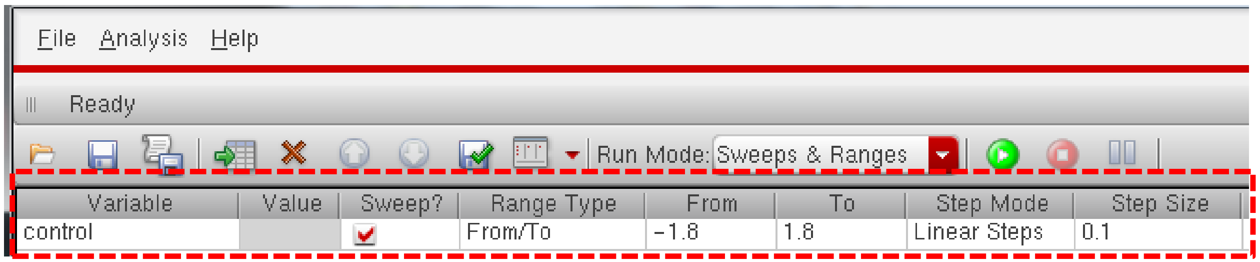
- Varactor Q-factor simulation



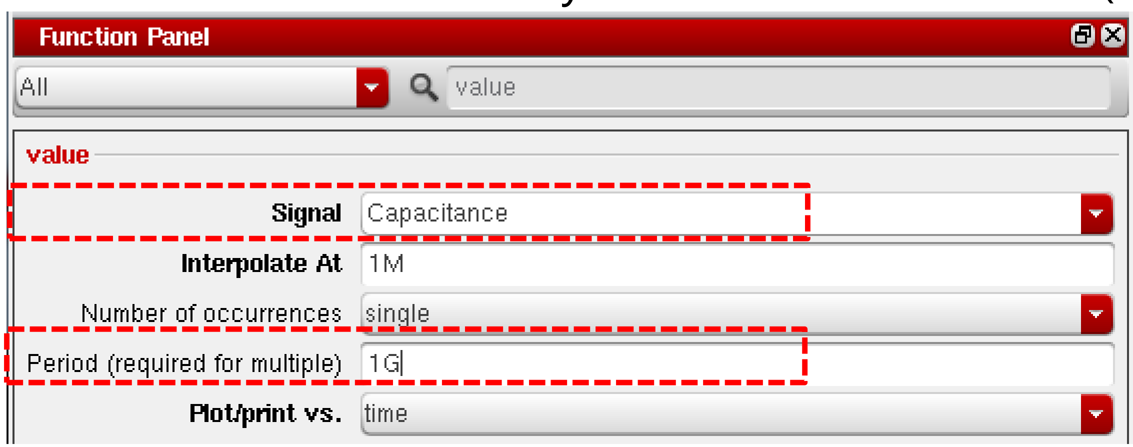

 

# Capacitance

- Control voltage sweep
  - Tools → Parametric Analysis
    - Voltage : -1.8V ~ 1.8V

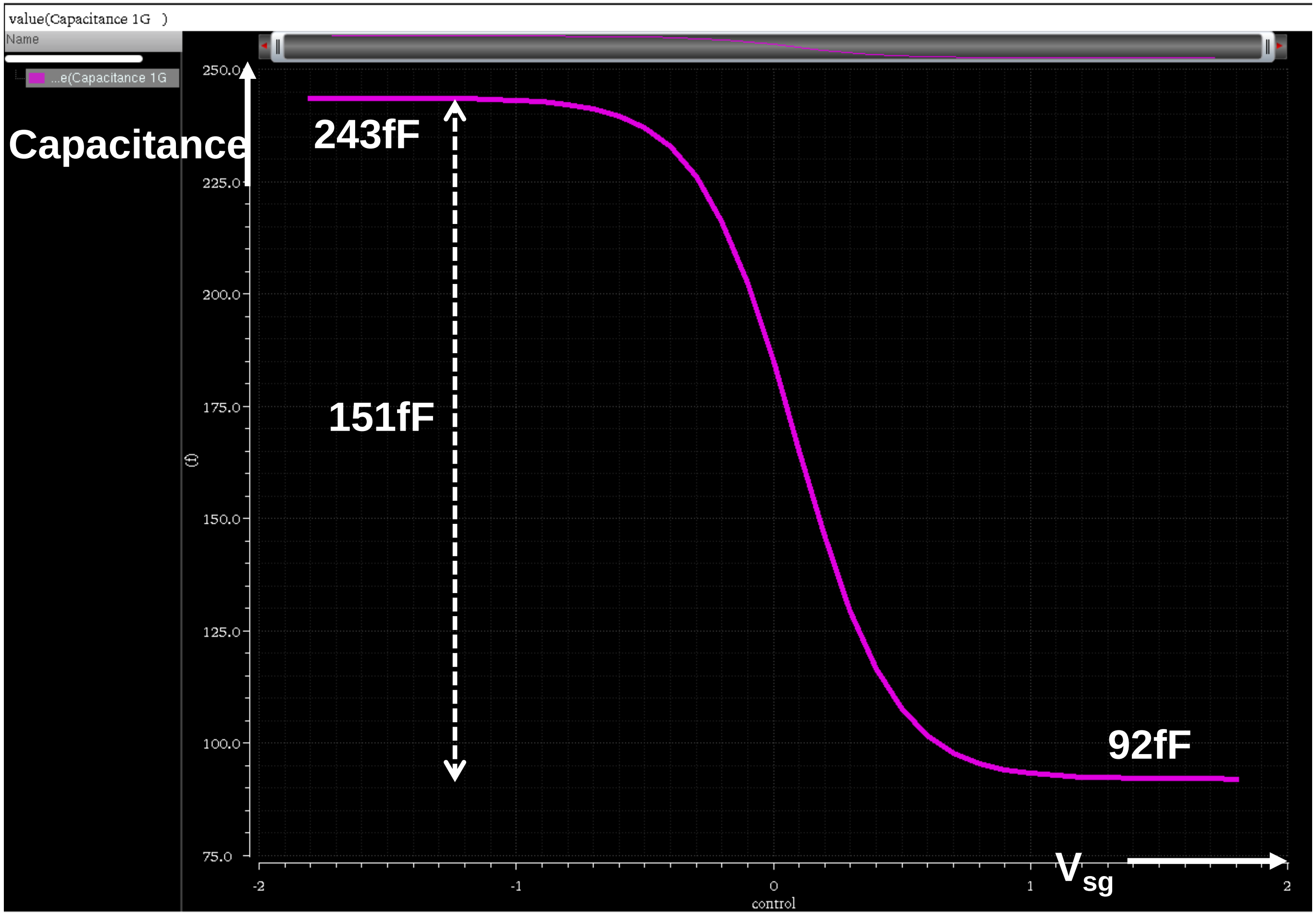



  - Calculator → Family → value → 파형 선택 (Capacitance) → Plot



# Capacitance

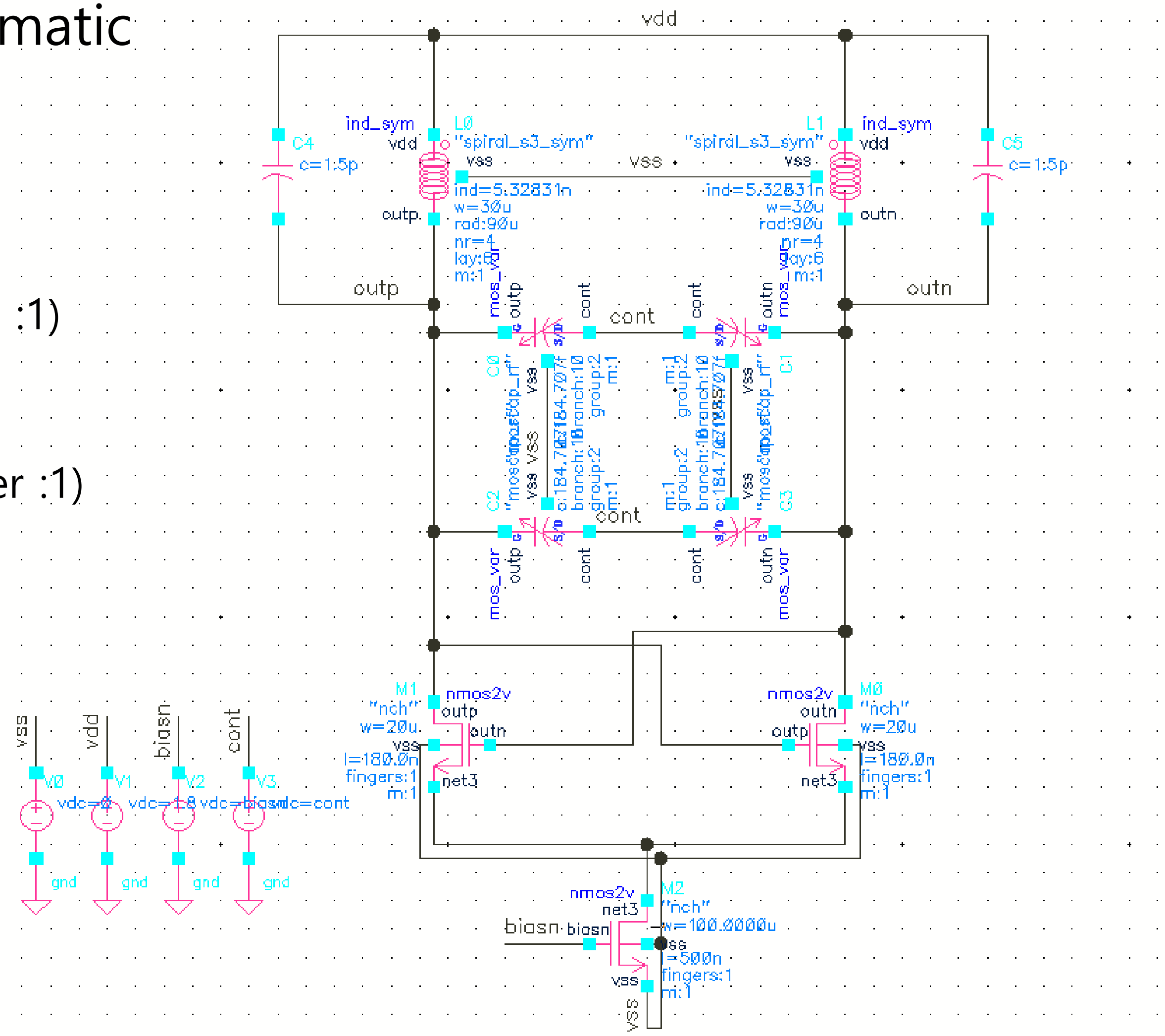
- $V_{SG}$ VS Capacitance



# LC VCO Schematic

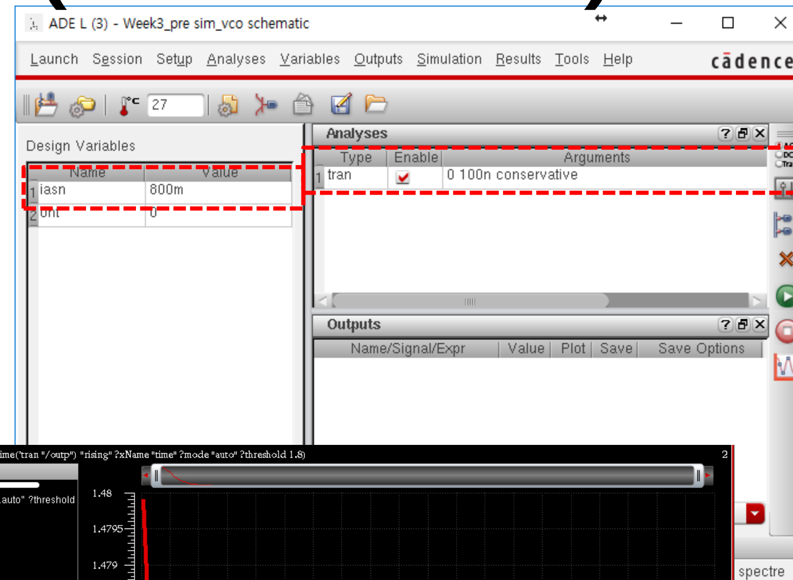
- Simulation LC VCO schematic
  - Inductor : 5.54nH
  - Capacitor : 1.5pF
  - Input NMOS
    - Length : 180n
    - Total Width : 20u (finger :1)
  - Source NMOS
    - Length : 500n
    - Total Width : 100u (finger :1)
  - Varactor
  - vdd : 1.8V
  - biasn : 0.8V
  - cont : 변수 지정 (cont)

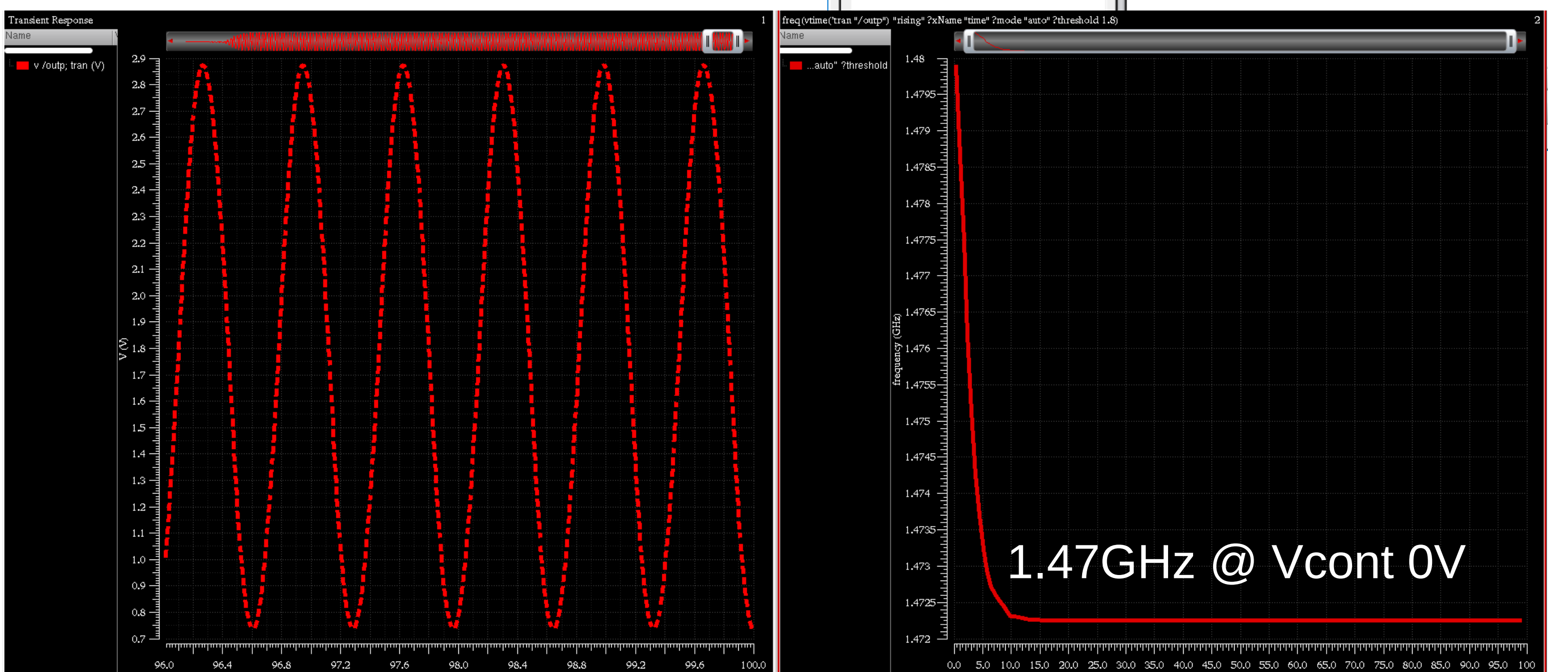
  - Initial condition
    outp & outn
    :1.8V, 1.85V



# OSC Frequency (Vcont = 0V)

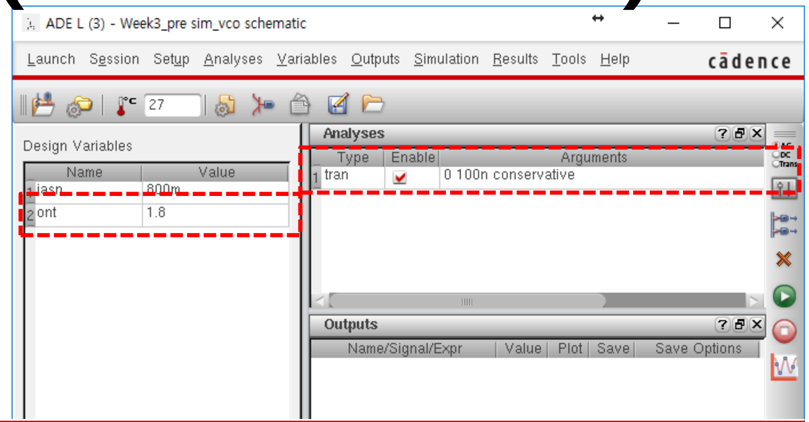
- Control Voltage 0V
  - OSC frequency : 1.47GHz
  - Transient simulation (100ns)
  - Output 파형 및 Frequency 측정

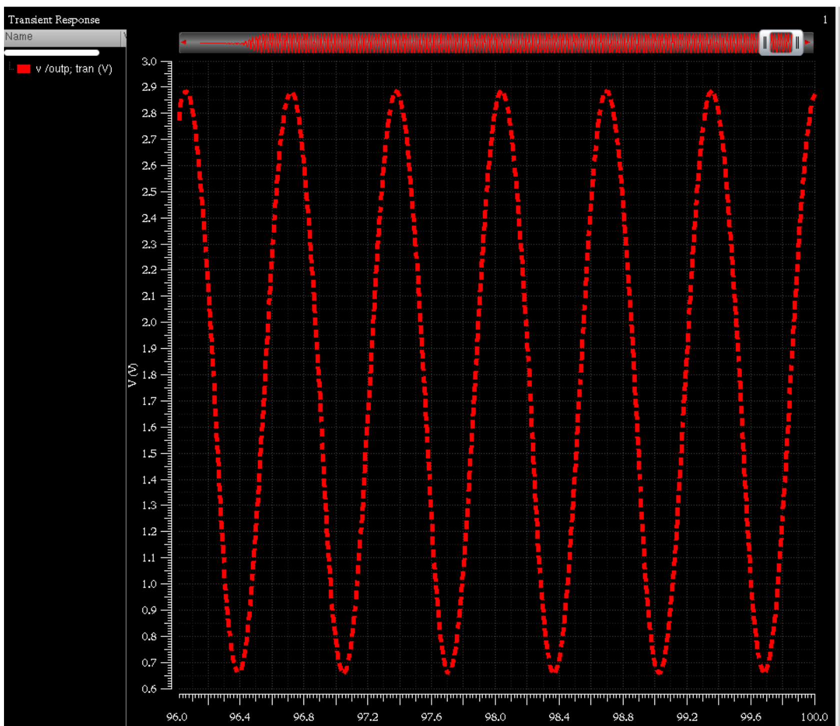


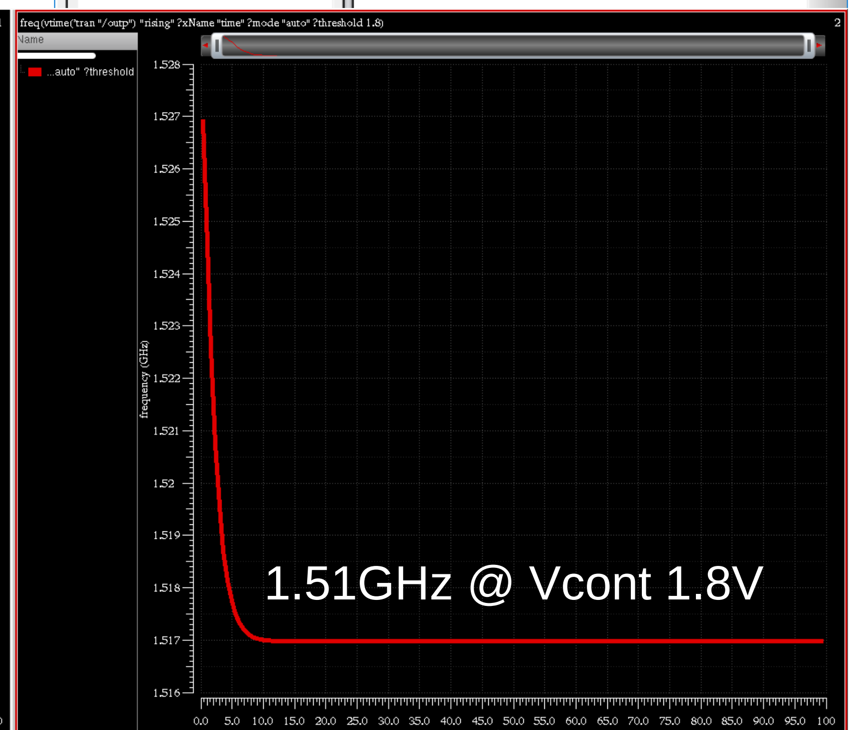



# OSC Frequency (Vcont = 1.8V)

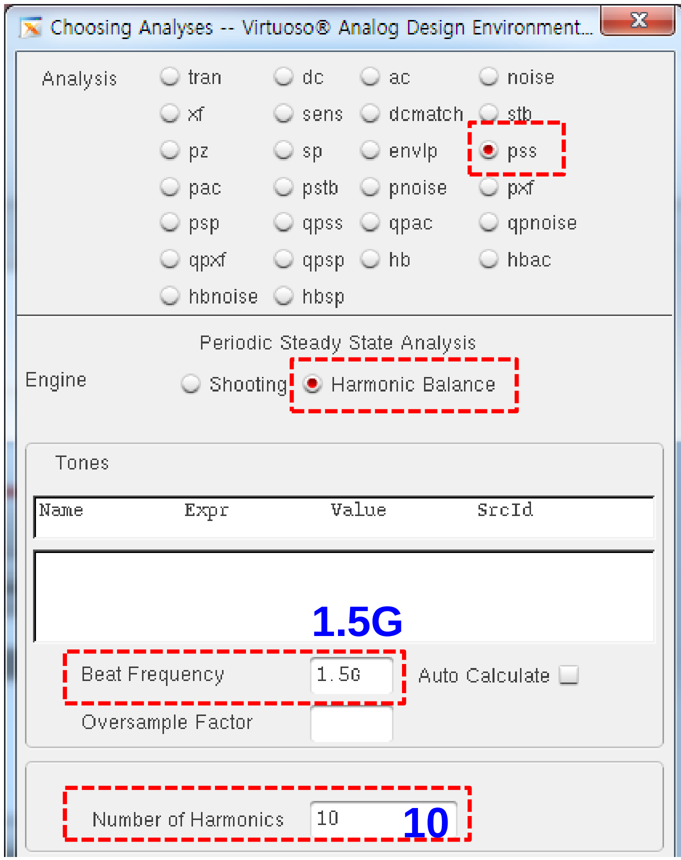
- Control Voltage 1.8V
  - OSC frequency : 1.51GHz
  - Transient simulation (100ns)
  - Output 파형 및 Frequency 측정

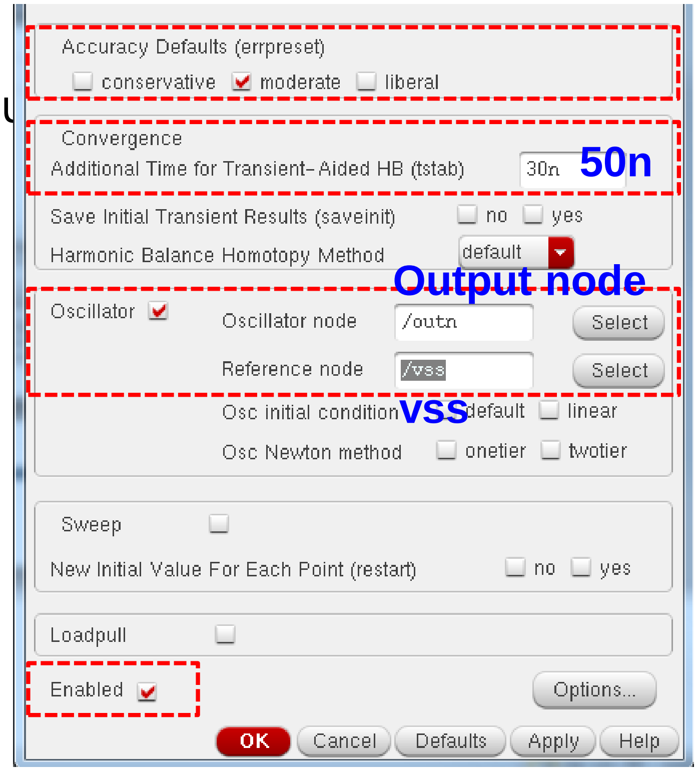


# Phase Noise (PSS)

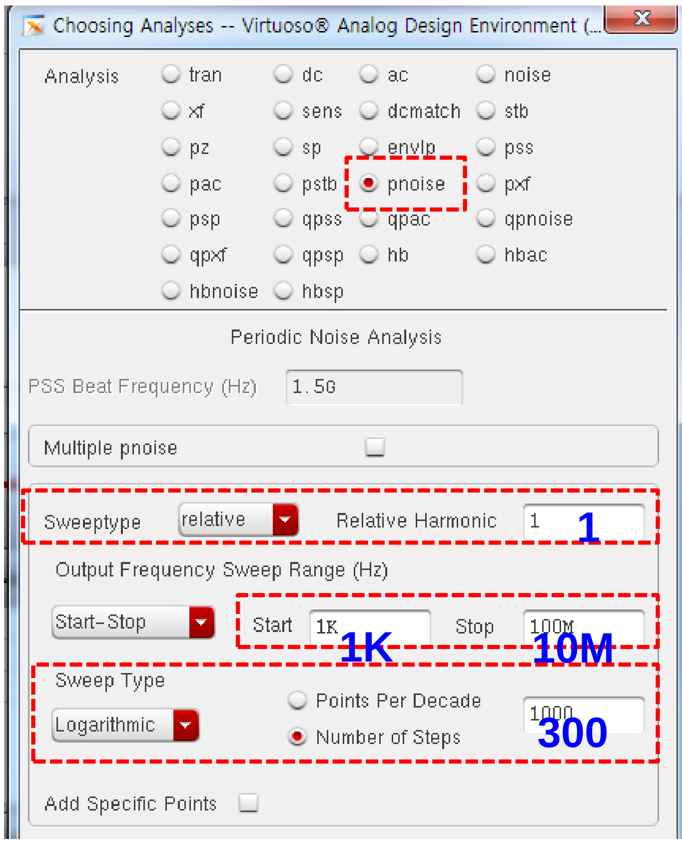


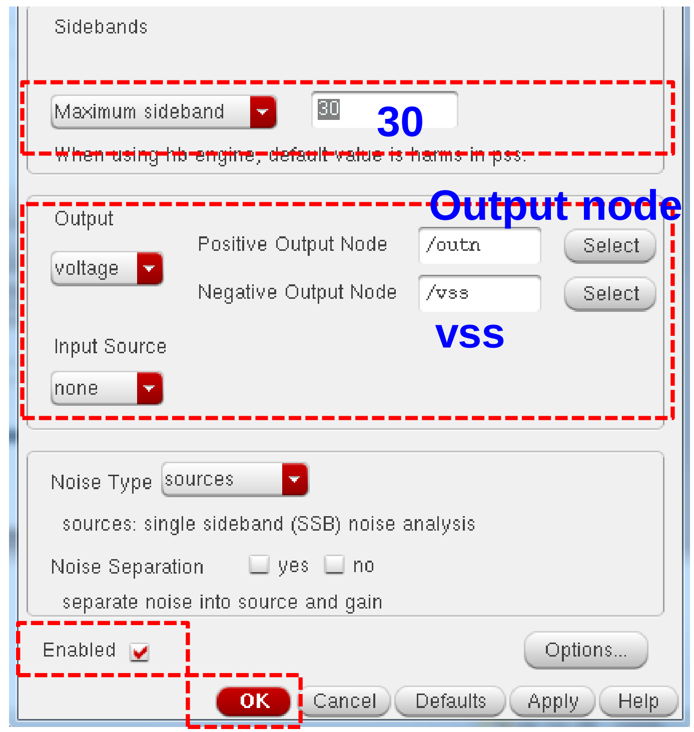




tstab : Oscillation
안정 구간 설정

# Phase Noise (Pnoise)

- Pnoise
  - Setup PSS first, then Pnoise

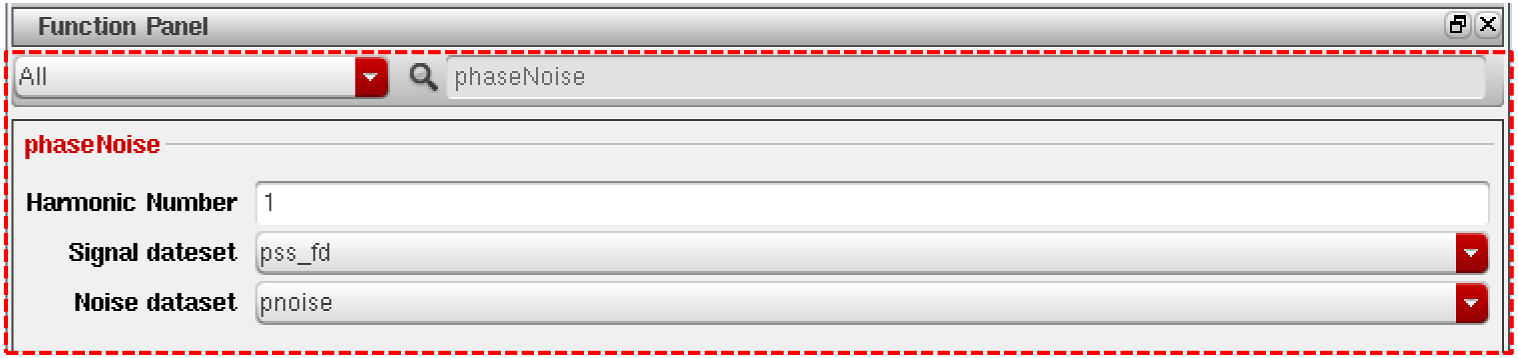



Output : Voltage 설정
Output Node 설정
Input : none

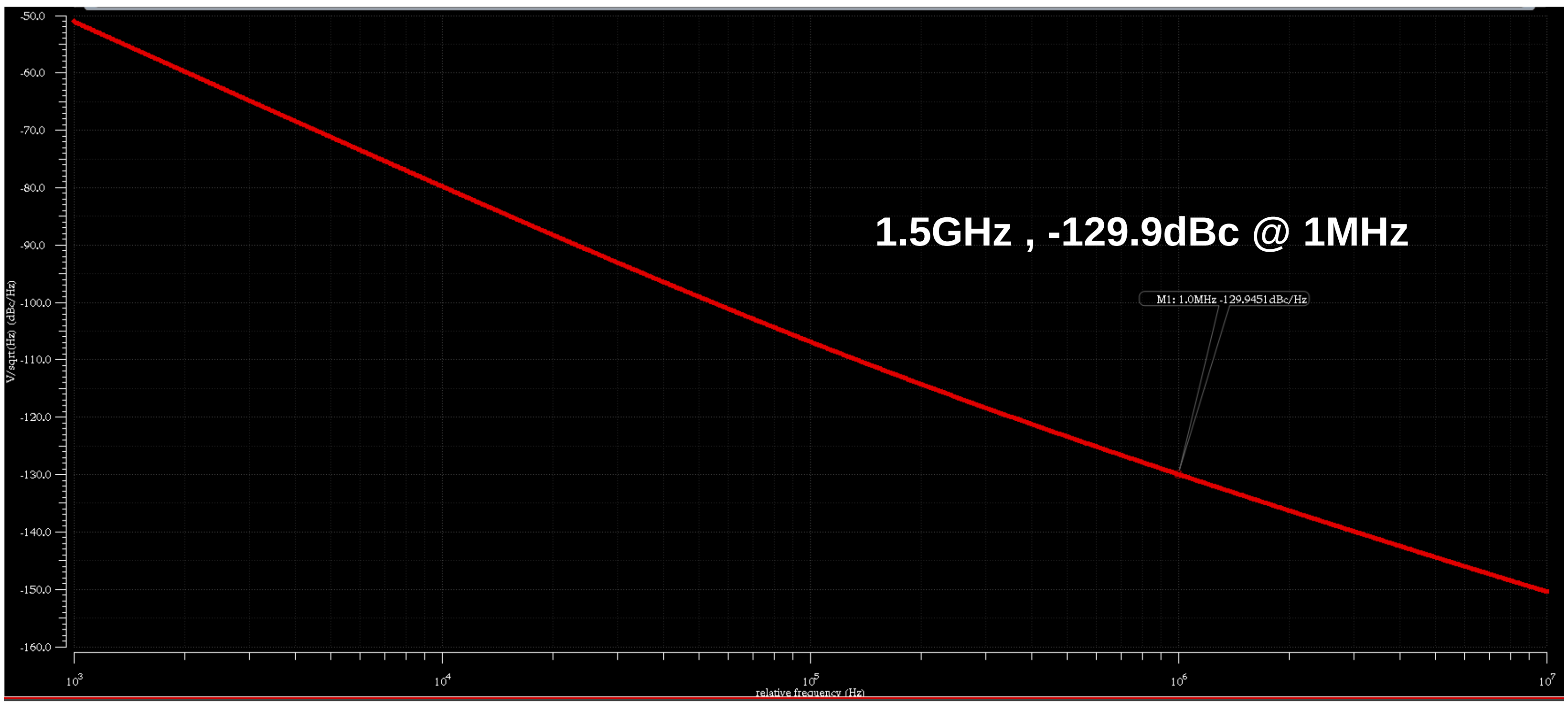
# Phase Noise

- Phase noise
  - Calculator (Visualization & Analysis XL)
  - Function Panel (phaseNoise 입력)
    - Harmonic Number : 1
    - Signal dataset : pss_fd
    - Noise dataset : pnoise
  - Apply



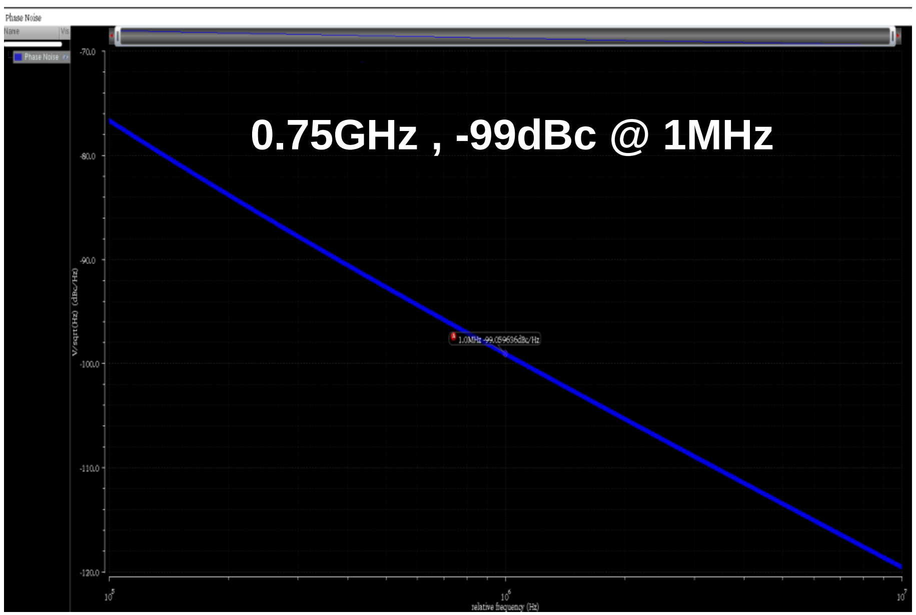
# Phase Noise

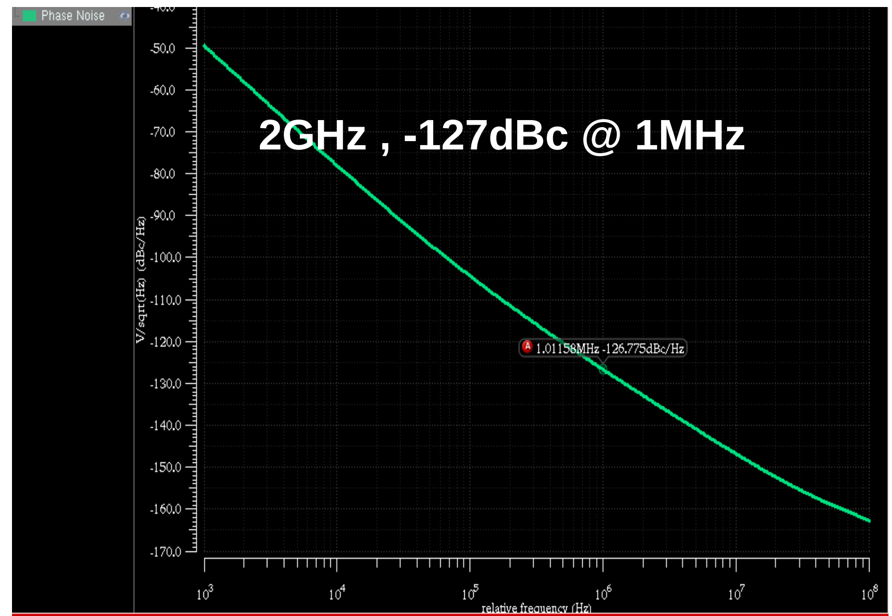
- Phase noise
  - $V_{cont}$ = 1.48V
  - 1.5GHz, -129.9dBc @ 1MHz



# VCO Comparison

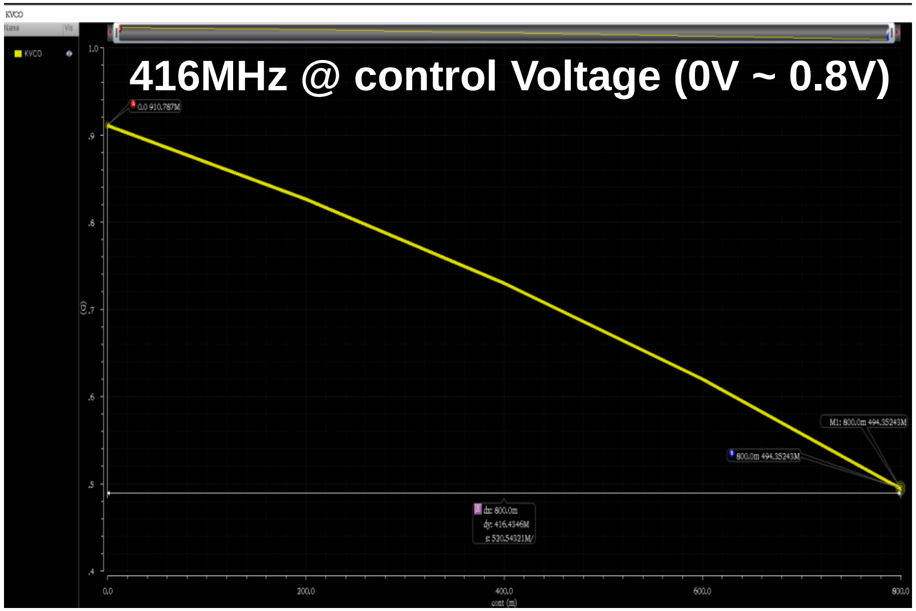
- Phase noise
  - Ring VCO : -99dBc @ 0.75GHz 1MHz offset
  - LC VCO : -132dBc @ 1.17GHz 1MHz offset
  - **LC VCO is better for phase noise.**

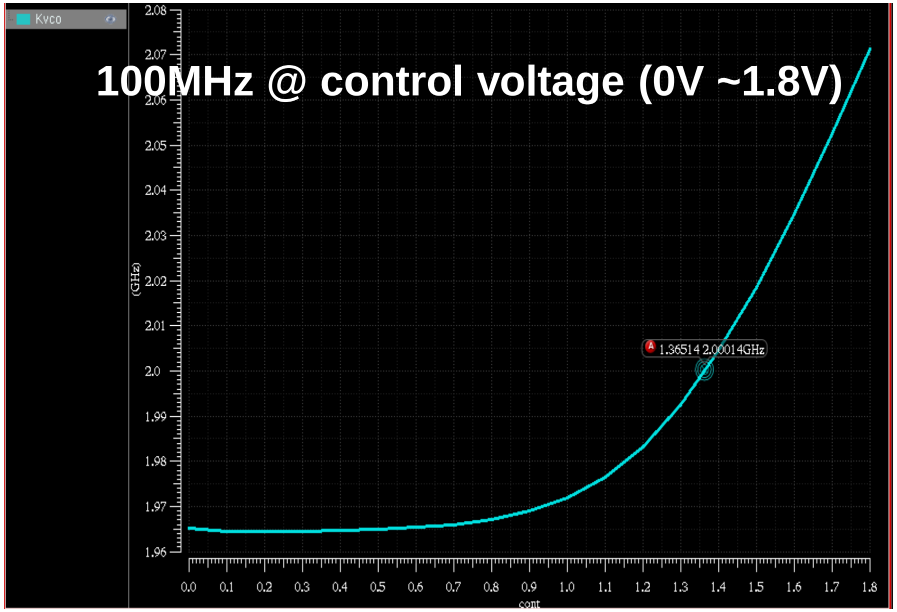


# VCO Comparison

- Frequency tuning range
  - Ring VCO : 416MHz  @ control voltage (0V ~ 0.8V)
  - LC VCO : 100MHz @ control voltage (0V ~ 1.8V)
  - **Ring VCO is better for frequency tuning range.**



# Homework

- ✓ Design 2-GHz (±100MHz) LC VCO with tuning range larger than 100MHz

- ✓ Verify and plot output waveforms and $K_{VCO}$. (Use plot method of DE2)
- ✓ Verify and plot phase noise with control voltage(0V, 0.9V, 1.8V) generating 2-GHz clock.
- ✓ Indicate LC VCO schematic, inductor value, and using varactor count in the report.

- ✓ LC VCO specification
  - -Supply voltage : 1.8V
  - -Load capacitance: 1.5 pF
  - -Phase noise : Min -115dBc/Hz
  - -Frequency tuning range : Min 100MHz

- ✓ Deadline : 09/24(Thu) 19:00
  - ➢ Upload pdf file to YSCEC