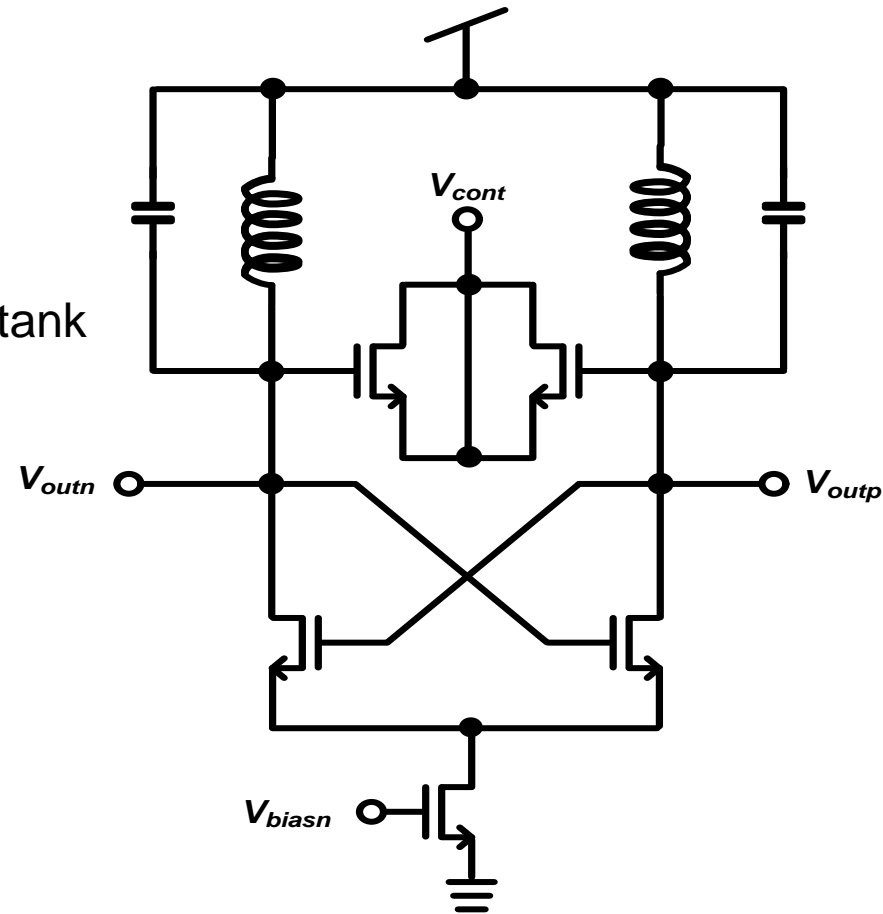


LC VCO Structure

● LV VCO Structure

- LC Tank
 - Spiral inductor (symmetric type)
 - Ideal cap
- Cross coupled circuit
 - Negative resistance
 - To compensate for the loss of the tank
- Source MOSFET
- Varactor
 - Accumulation varactor
- OSC frequency

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

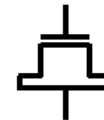
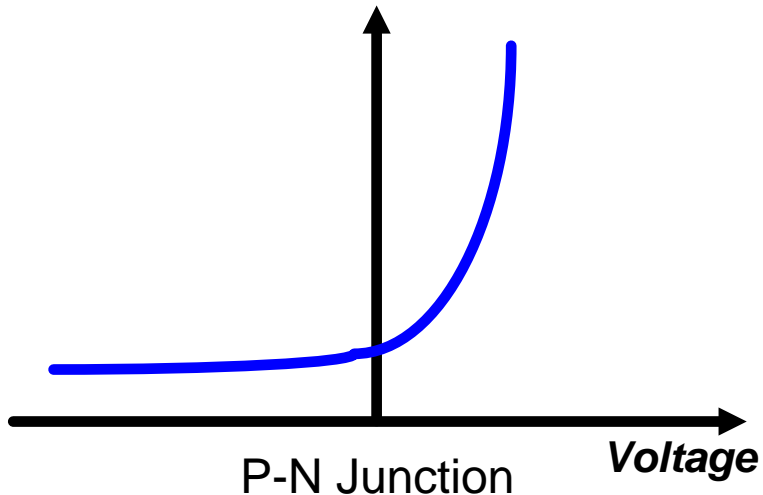


Varactor

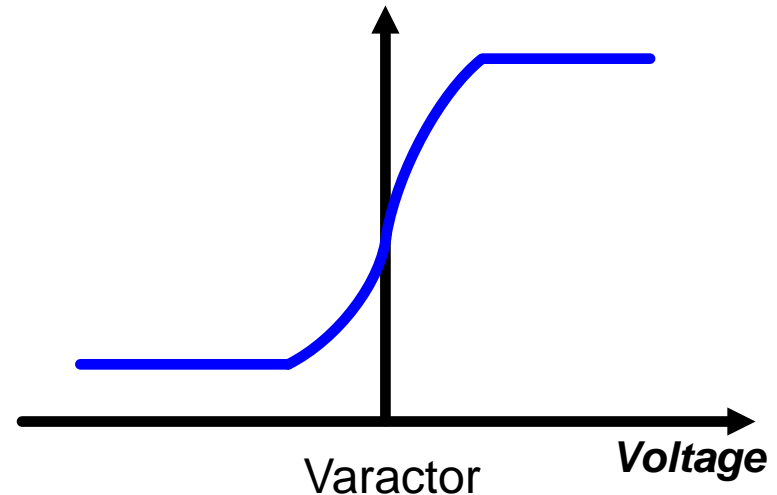
- Varactor type
 - P-N Junction
 - MOS Varactor
 - Inversion mode
 - Accumulation mode



Capacitance

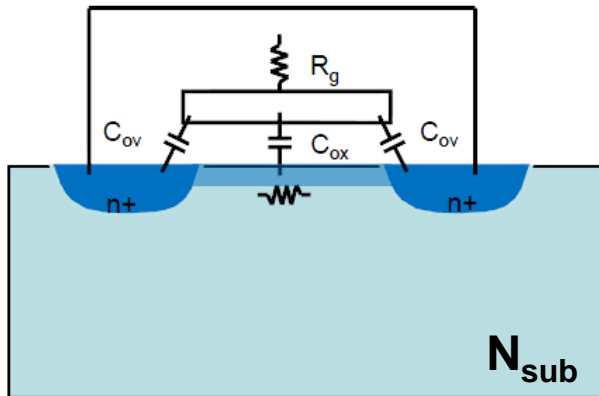


Capacitance

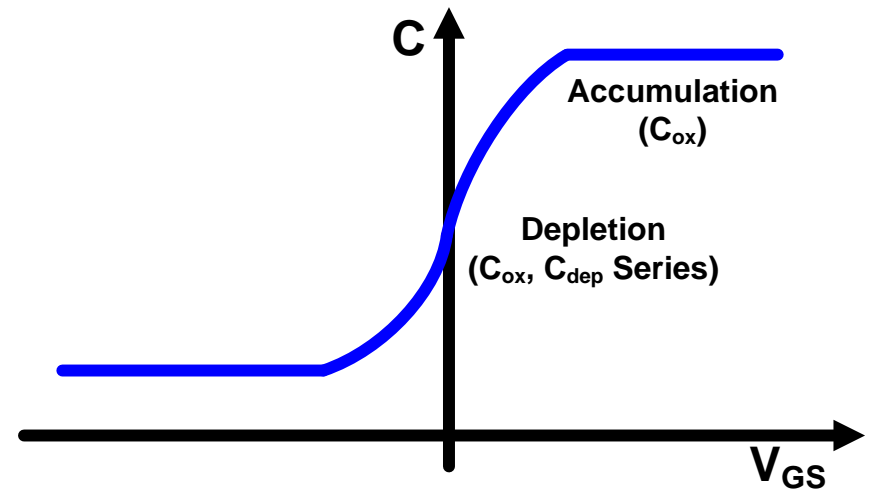
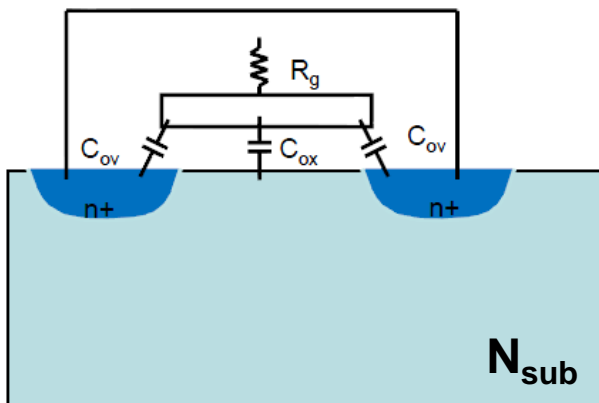


Accumulation Mode Varactor

- On (Accumulated channel)



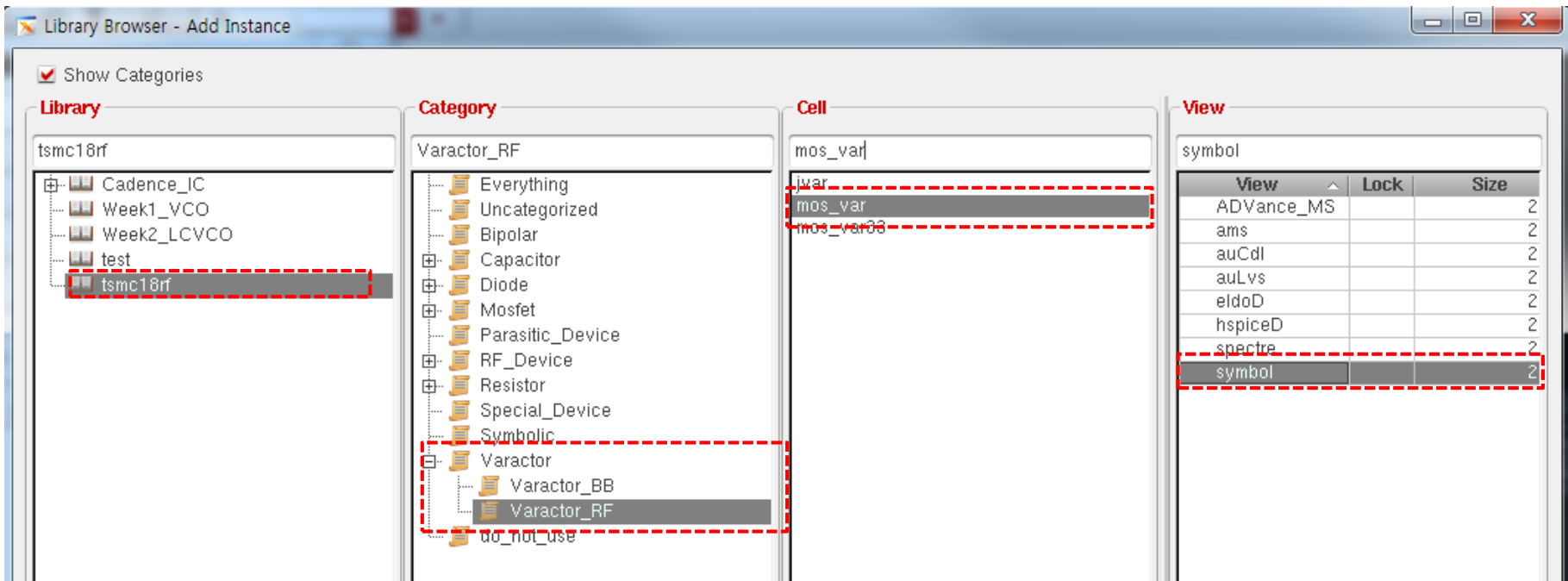
- OFF (Depleted)



TSMC Varactor

Varactor selection

- Tsmc18rf → Varactor → Varactor_RF → mos_var → symbol



Varactor Setting

- Setting of Fingers_per_Group, Number_of_Group and multiplier
- Extract min and max capacitance

Property	Value	Display
Library Name	tsmc18rf	off
Cell Name	mos_var	value
View Name	symbol	off
Instance Name	C0	off

CDF Parameter	Value	Display
Model name	moscap_rf	off
Capacitance{@V=0}(F)	184.707 F	off
Cmin{@V=-vdd}(F)	92.1189 F	off
Cmax{@V=vdd}(F)	243.293 F	off
Width_per_Finger(M)	2.5u M	off
Length_per_Finger(M)	500n M	off
Fingers_per_Group(B)	10	off
Number_of_Groups(G)	2	off
Create_Guard_Ring	<input checked="" type="checkbox"/>	off
multiplier	1	off
Hard_constraint	<input checked="" type="checkbox"/>	off

- Fingers_per_Group(B) : 10

- Number_of_Groups (G) : 2

- Multiplier : 1

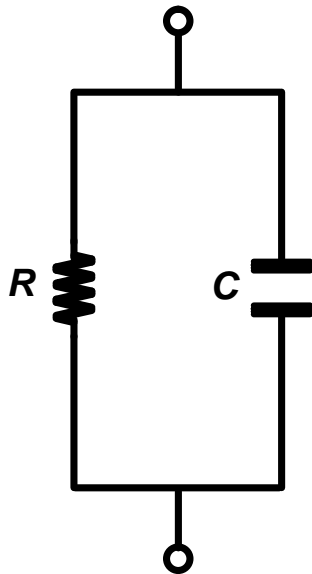
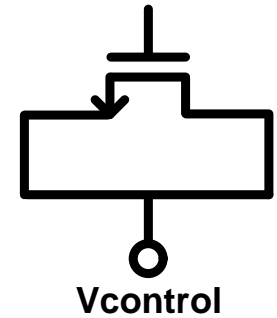
→ Min Capacitance : 92f

→ Max Capacitance : 243fF

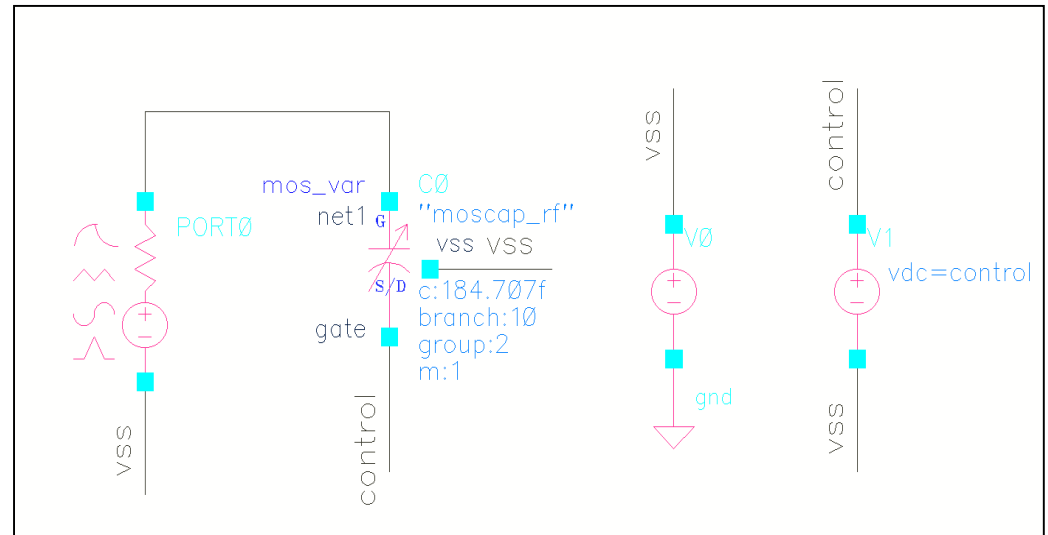
→ Δ Capacitance : 151fF

Varactor Modeling

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



< Equivalent circuit of varactor >

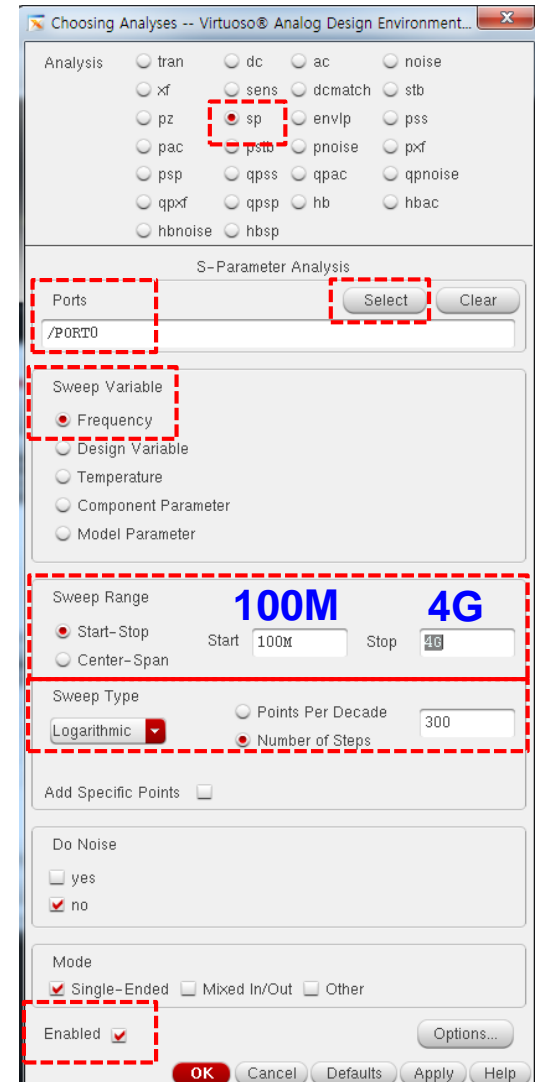
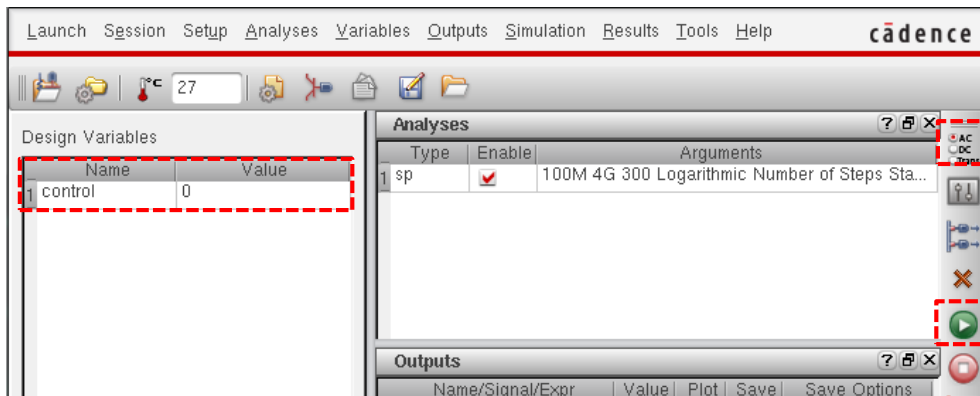


< Test schematic >

S - Parameter

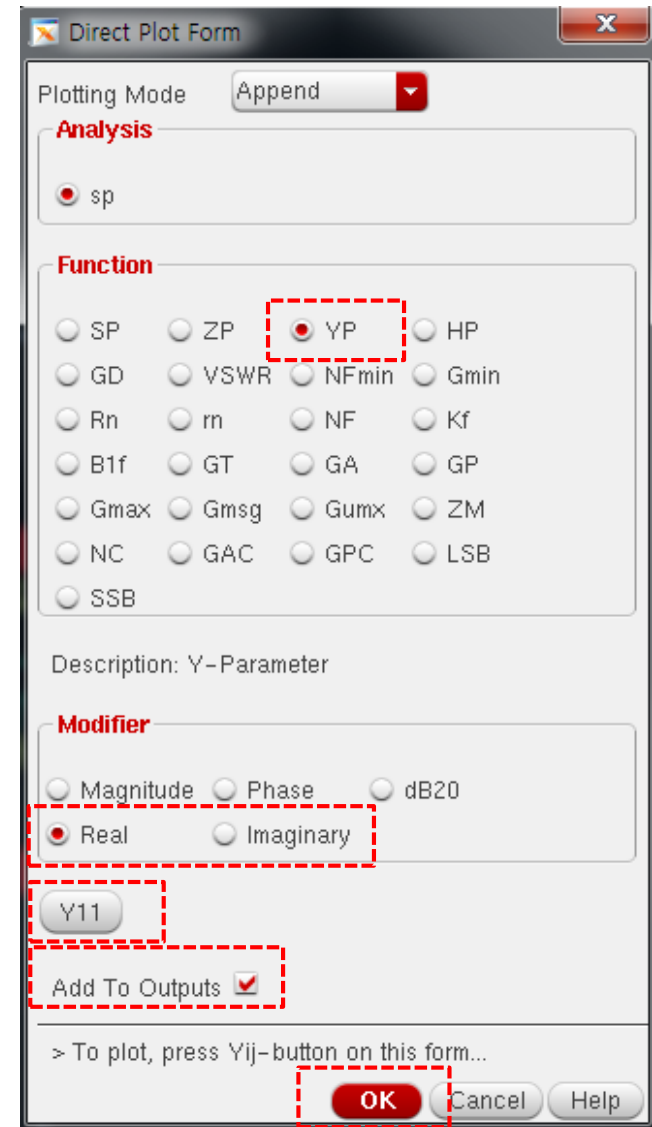
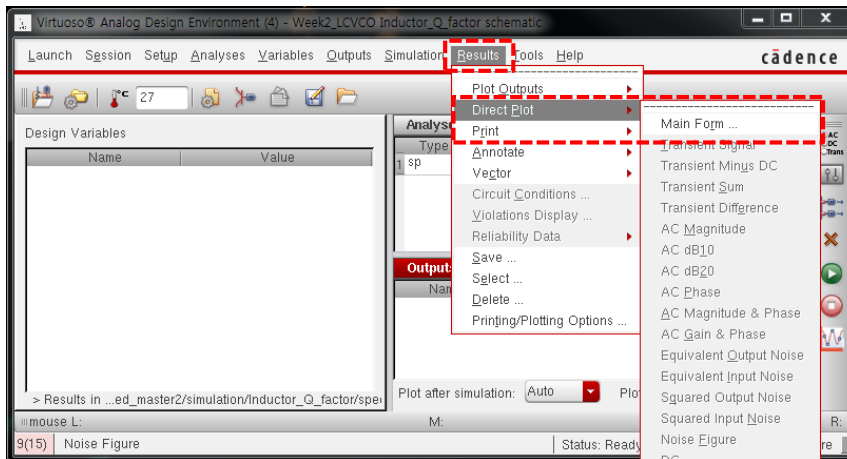
Simulation condition setting

- Control voltage : 0V
- Analysis : sp (S-Parameter Analysis)
- Ports : Port0 (schematic node choice)
- Sweep Variable : Frequency
- Sweep Range : 100M ~ 4G
- Sweep Type : Logarithmic
- Number of Steps : 300
- Enabled check → OK → Netlist and Run



Y-Parameter

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

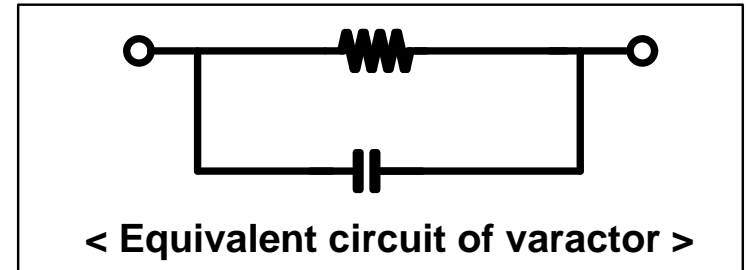


Y- Parameter

● $Y = \frac{1}{R} + j\omega C$

– Resistance = $\frac{1}{\text{Real}[Y_{11}]}$

– Capacitance = $\frac{\text{Imaginary}[Y_{11}]}{\omega}$



Capacitance

Simulation condition setting

- $C = \frac{\omega C}{\omega} = \frac{\text{Imag}[Y11]}{\omega}$
- Calculator (Visualization & Analysis XL)
- Wave choice → `imag(yz(1 1 ?result "sp"))/(2*pi*xval(yz(1 1 ?result "sp")))`
- Outputs → Setup → Name (Capacitance) → Get Expression → Add → OK

The following tables represent the state of the software windows during the process:

Calculator Window:

Expression: `imag(yz(1 1 ?result "sp"))/(2*pi*xval(yz(1 1 ?result "sp")))`

Outputs Window (Initial State):

Name/Signal/Expr	Value	Plot	Save	Save Options
1 Y11 reS		<input checked="" type="checkbox"/>	<input type="checkbox"/>	
2 Y11 imS		<input checked="" type="checkbox"/>	<input type="checkbox"/>	
3 Capacitance		<input checked="" type="checkbox"/>	<input type="checkbox"/>	

Calculator Dialog (Final State):

Name (opt): Capacitance

Expression: `* pi * xval(yz(1 1 ?result "sp"))`

Buttons: Open, **Get Expression**, Close

Will be: Plotted/Evaluated

Buttons: **Add**, Delete, Change, Next, New Expression

Buttons: **OK**, Cancel, Apply, Help

Capacitance (Control = 0V)

- Capacitance simulation
 - Capacitance : 184fF @ 1.50GHz

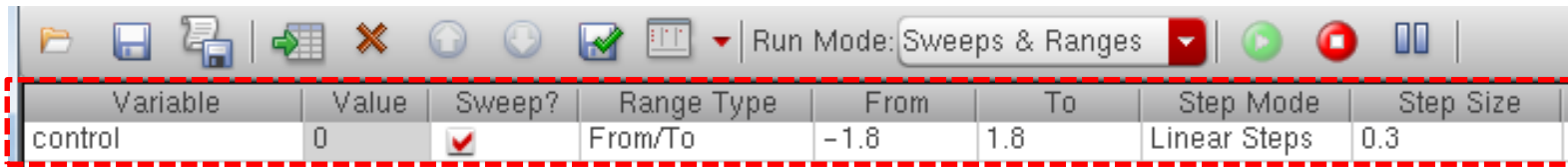


Capacitance Variation

- Control voltage sweep

- Tools → Parametric Analysis

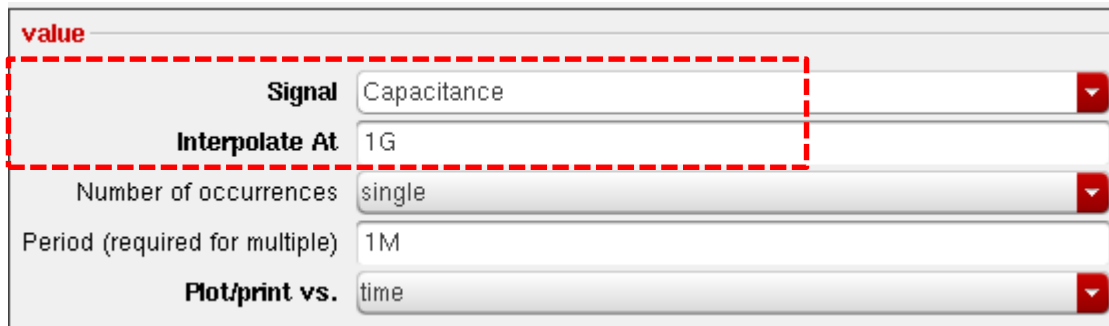
- Control voltage : -1.8V ~ 1.8V (Linear steps :0.3V)



Variable	Value	Sweep?	Range Type	From	To	Step Mode	Step Size
control	0	<input checked="" type="checkbox"/>	From/To	-1.8	1.8	Linear Steps	0.3

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

- Interpolate At : 1G



value

Signal: Capacitance

Interpolate At: 1G

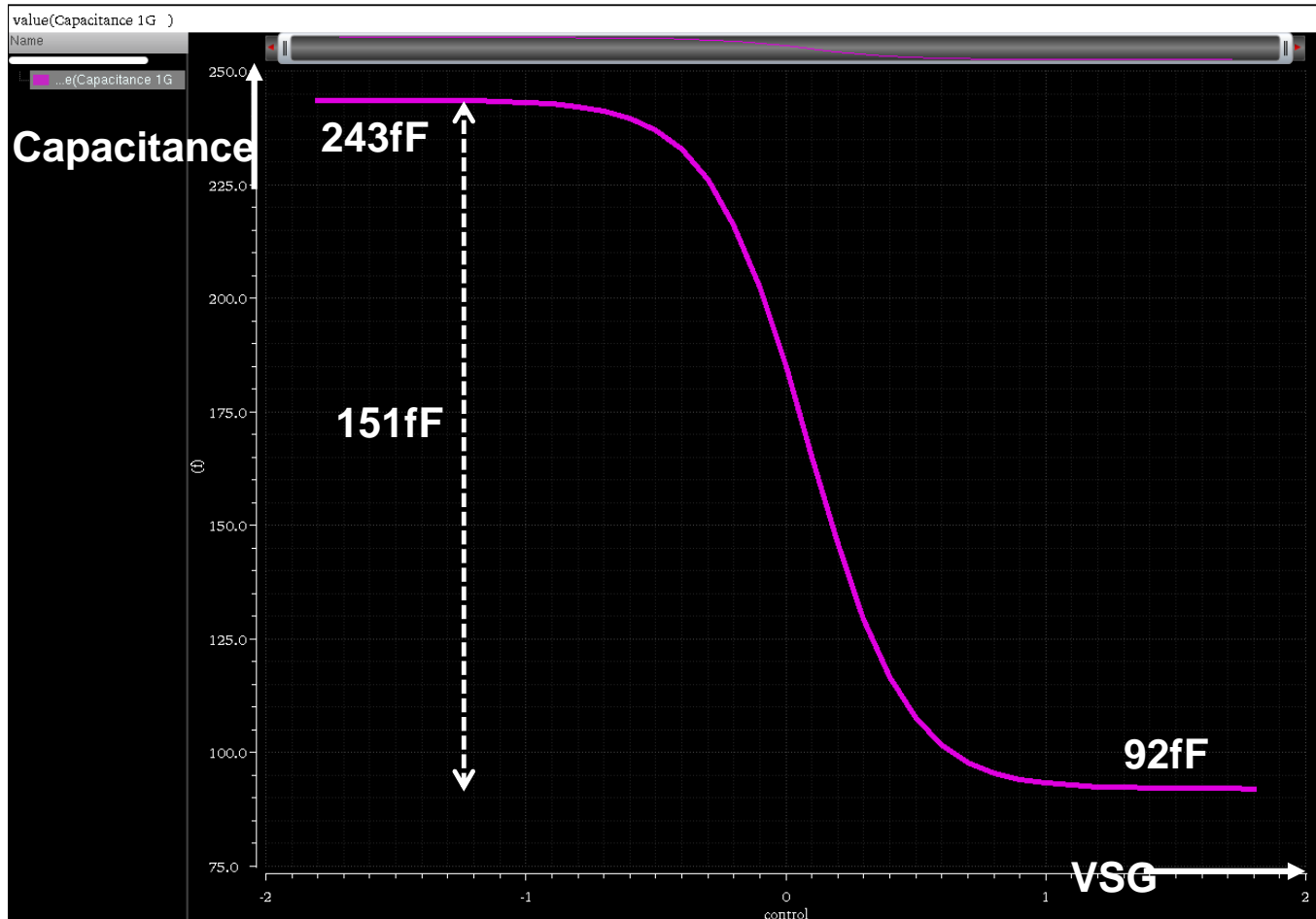
Number of occurrences: single

Period (required for multiple): 1M

Plot/print vs.: time

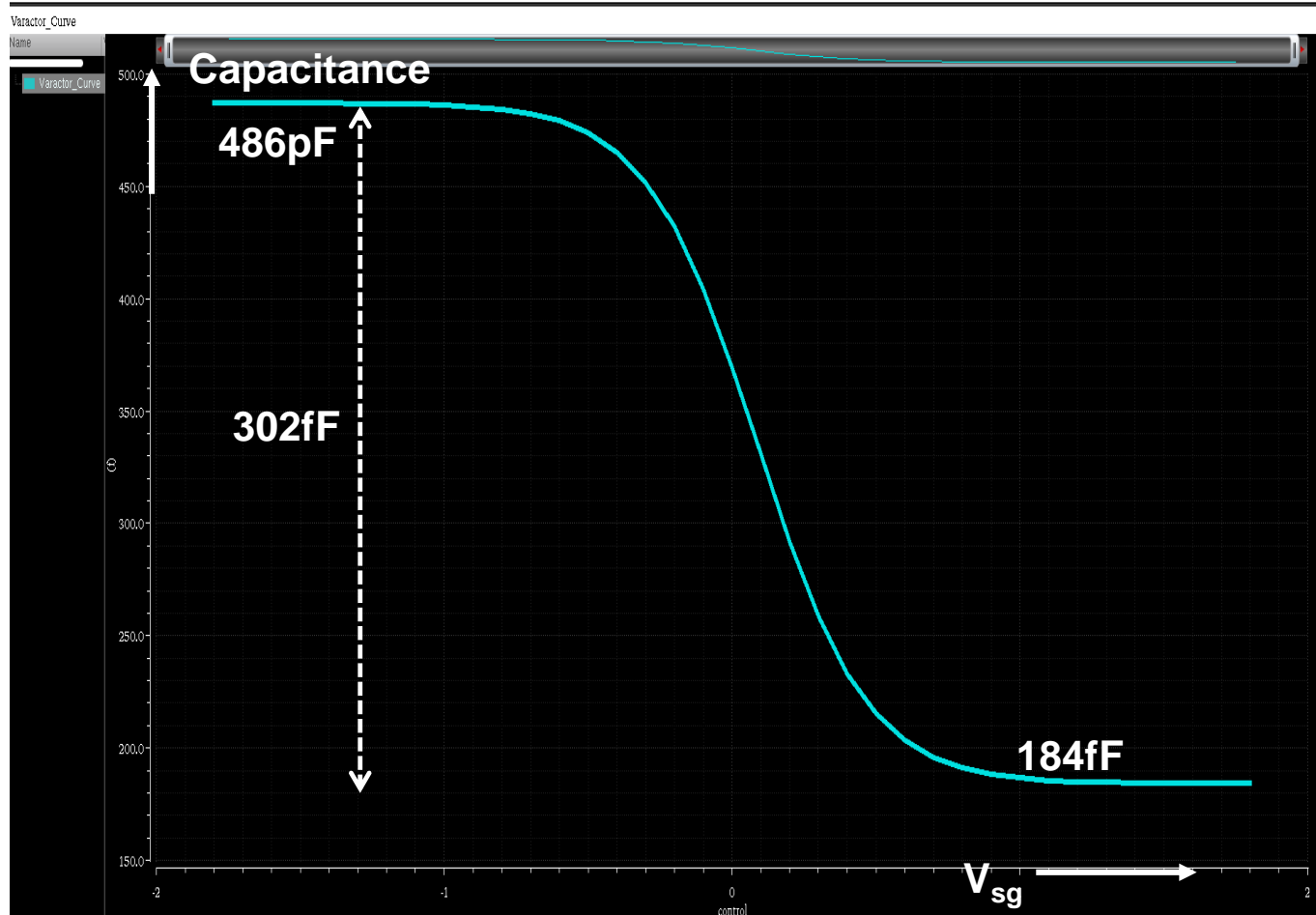
Capacitance Variation

- V_{SG} vs Capacitance
 - Multiplier : 1



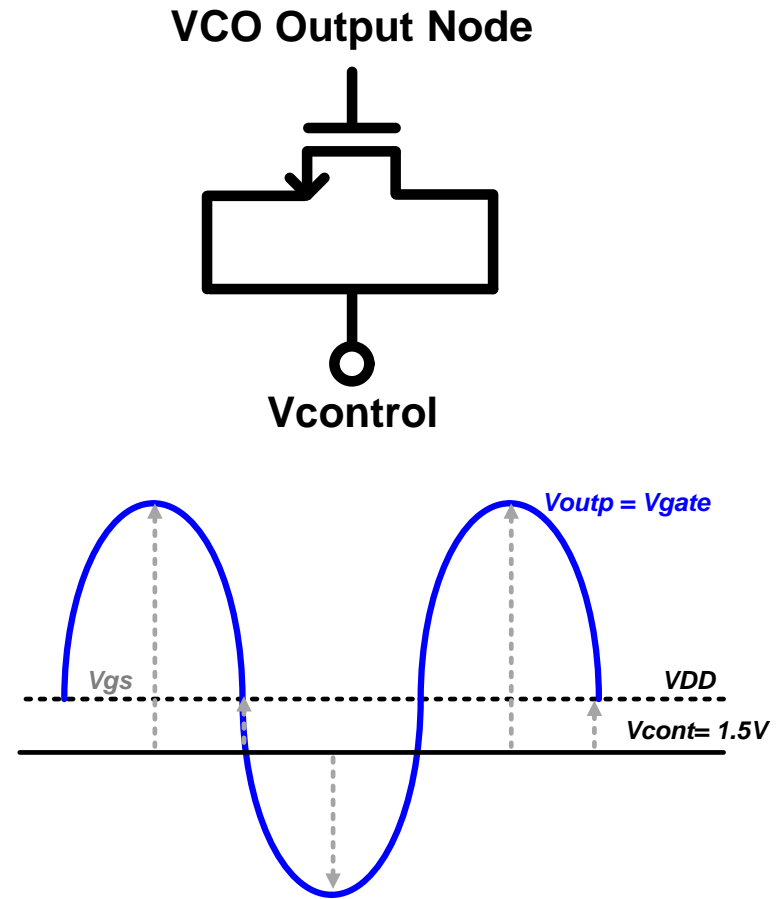
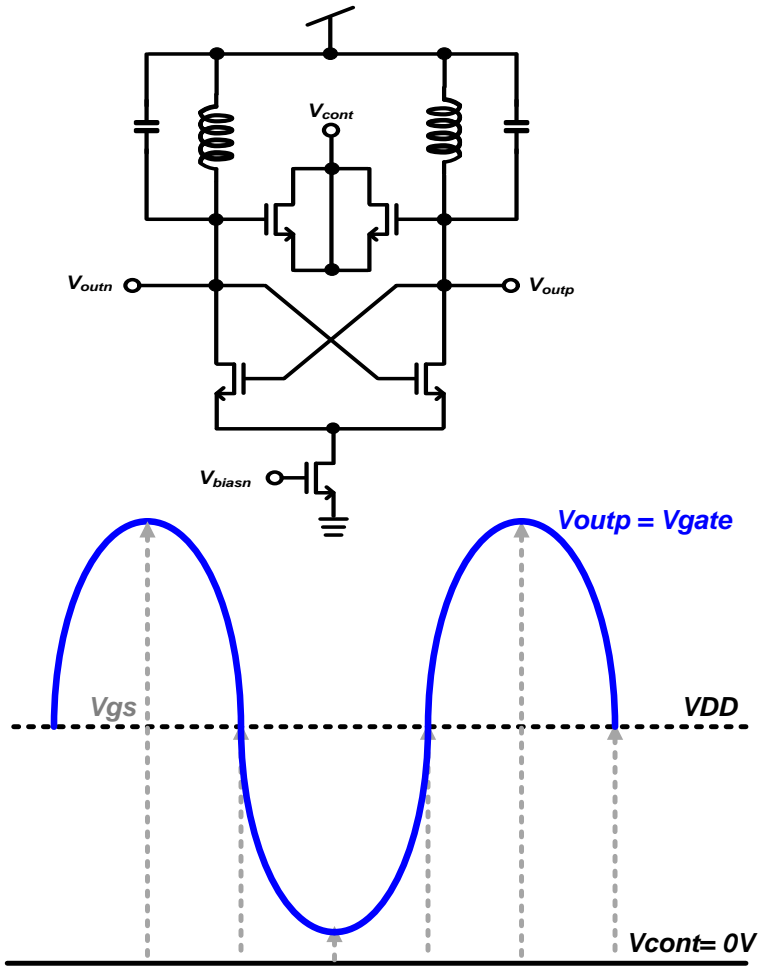
Capacitance Variation

- V_{GS} vs Capacitance
 - Multiplier : 2



Varactor Operation

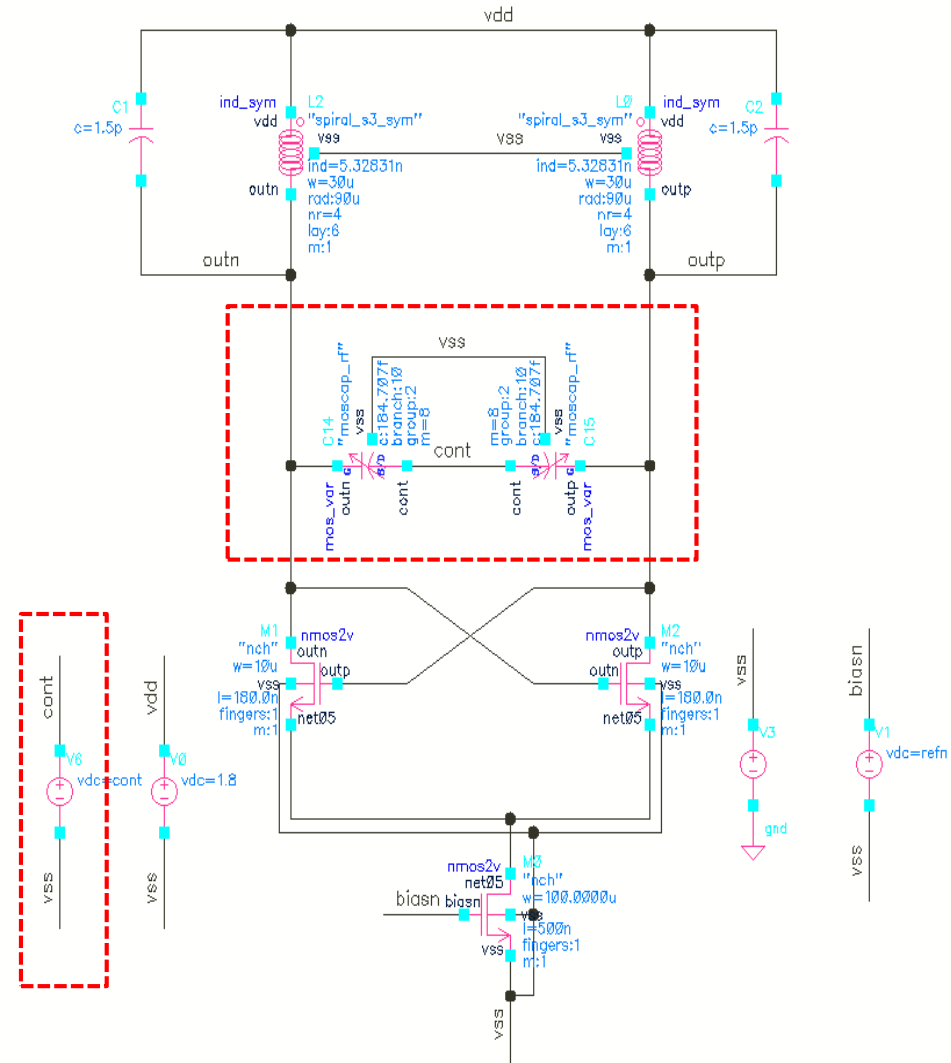
- Change average capacitance from control voltage.



LC VCO Schematic

Simulation LC VCO schematic

- Inductor : 5.42nH
- Capacitor : 1.5pF
- Input NMOS
 - Length : 180n
 - Total Width : 10u (finger : 1)
- Source NMOS
 - Length : 500n
 - Total Width : 100u (finger : 1)
- Varactor
 - Fingers_per_Group(B) : 10
 - Number_of_Group(G) : 2
 - Multiplier : 8
- vdd : 1.8V
- biasn : 0.8V
- cont : 변수 지정 (cont)



OSC Frequency ($V_{cont} = 0V$)

- Control Voltage 0V
 - OSC frequency : 1.14GHz
 - Transient simulation (300ns)
 - Output 파형 및 Frequency 측정

The image shows two windows from a simulation software. The 'Design Variables' window has a table with the following data:

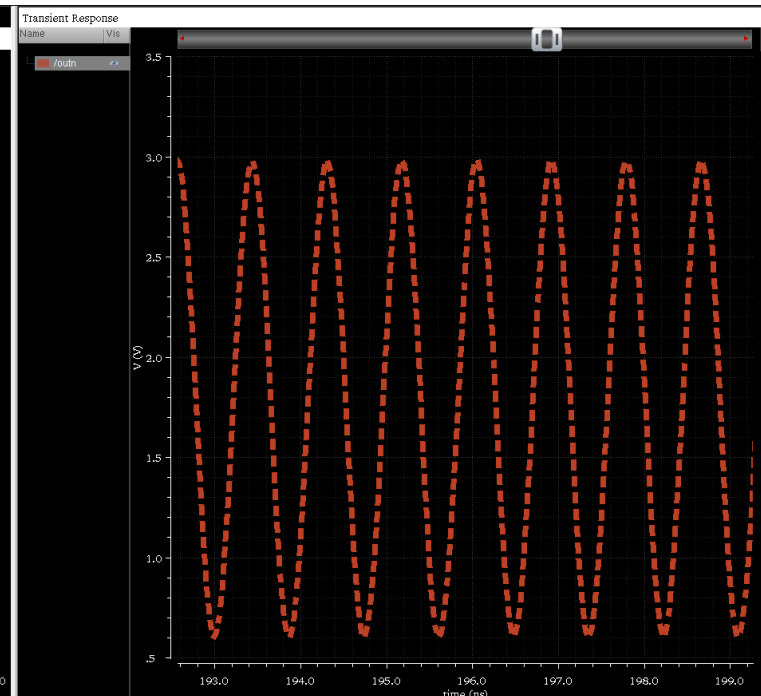
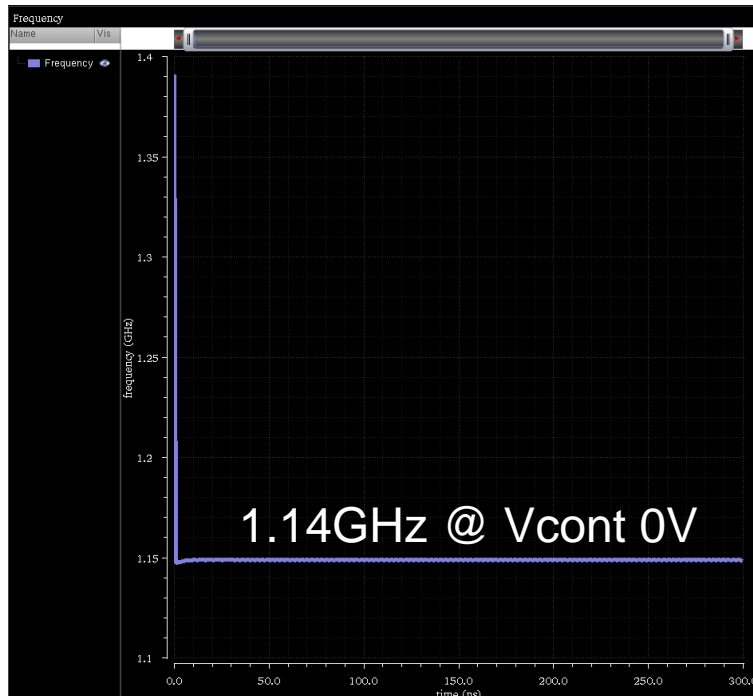
Name	Value
1 cap	2p
2 cont	0
3 tem	300m

The 'Analyses' window shows a table with the following data:

Type	Enable	Arguments
tran	<input checked="" type="checkbox"/>	0 300n moderate
pss	<input type="checkbox"/>	1 0 /outn /vss
pnoise	<input type="checkbox"/>	30 1K 100M 1K /outn /vss

Below the Analyses window is the 'Outputs' window with the following data:

Name/Signal/Expr	Value	Plot	Save	Save Options
outn		<input checked="" type="checkbox"/>	<input type="checkbox"/>	allv
Frequency	wave	<input checked="" type="checkbox"/>	<input type="checkbox"/>	



OSC Frequency ($V_{cont} = 1.8V$)

- Control Voltage 1.8V
 - OSC frequency : 1.25GHz
 - Transient simulation (300ns)
 - Output 파형 및 Frequency 측정

The image shows two windows from a simulation software. The 'Design Variables' window has a table with the following data:

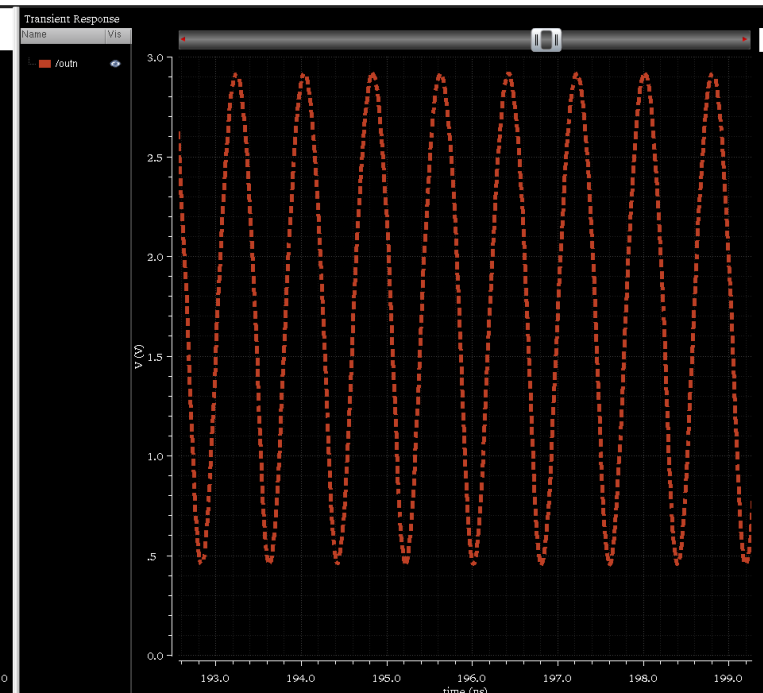
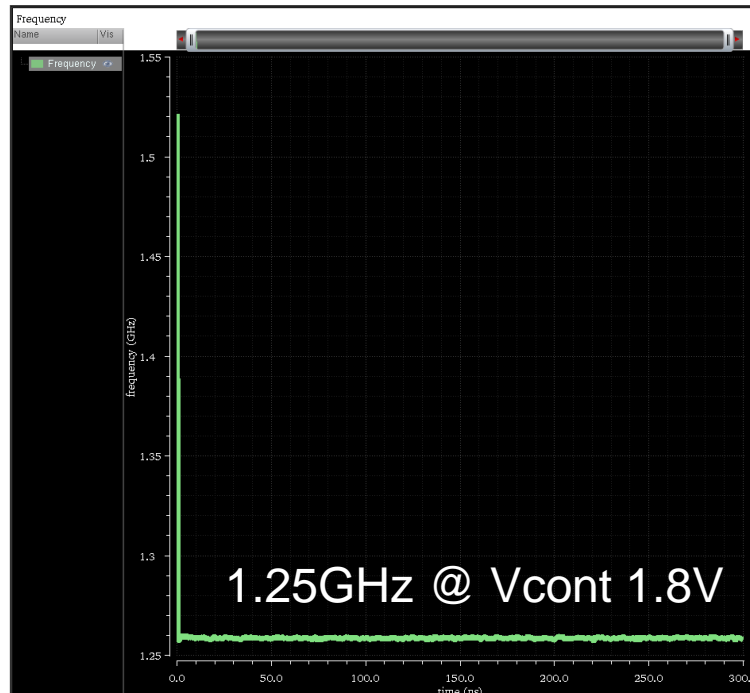
Name	Value
cap	2p
cont	1.8
tem	600m

The 'Analyses' window shows a table with the following data:

Type	Enable	Arguments
tran	<input checked="" type="checkbox"/>	0 300n moderate
psp	<input type="checkbox"/>	10 /outh /vss
pnoise	<input type="checkbox"/>	30 1K 100M 1K /outh /vss

The 'Outputs' window shows a table with the following data:

Name/Signal/Expr	Value	Plot	Save	Save Options
outh		<input checked="" type="checkbox"/>	<input type="checkbox"/>	allv
Frequency	wave	<input checked="" type="checkbox"/>	<input type="checkbox"/>	

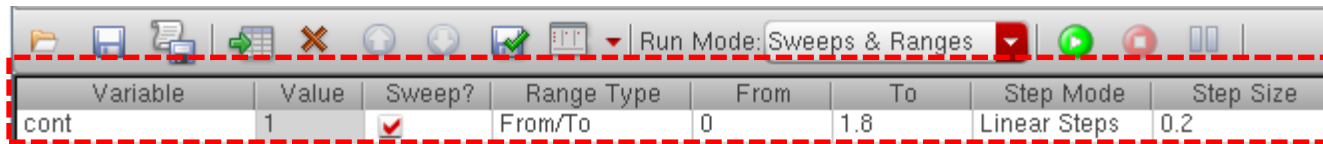


Frequency Tuning Range

- Control voltage sweep

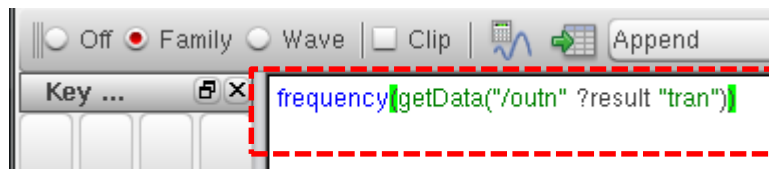
- Tools → Parametric Analysis

- Control voltage : 0 ~ 1.8V (Linear steps :0.2V)



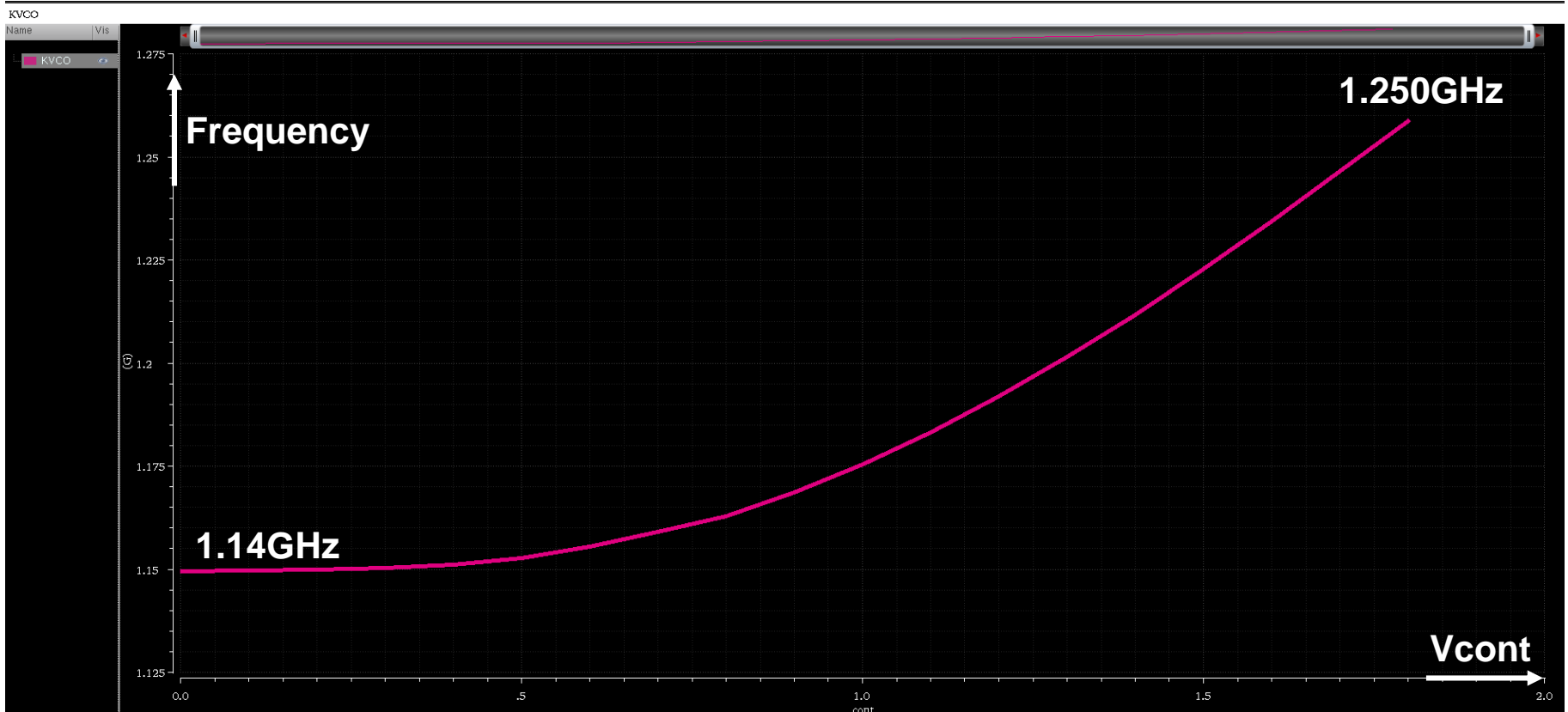
Variable	Value	Sweep?	Range Type	From	To	Step Mode	Step Size
cont	1	<input checked="" type="checkbox"/>	From/To	0	1.8	Linear Steps	0.2

- Calculator → Family → 파형 선택 (Output) → Function (frequency) → Plot



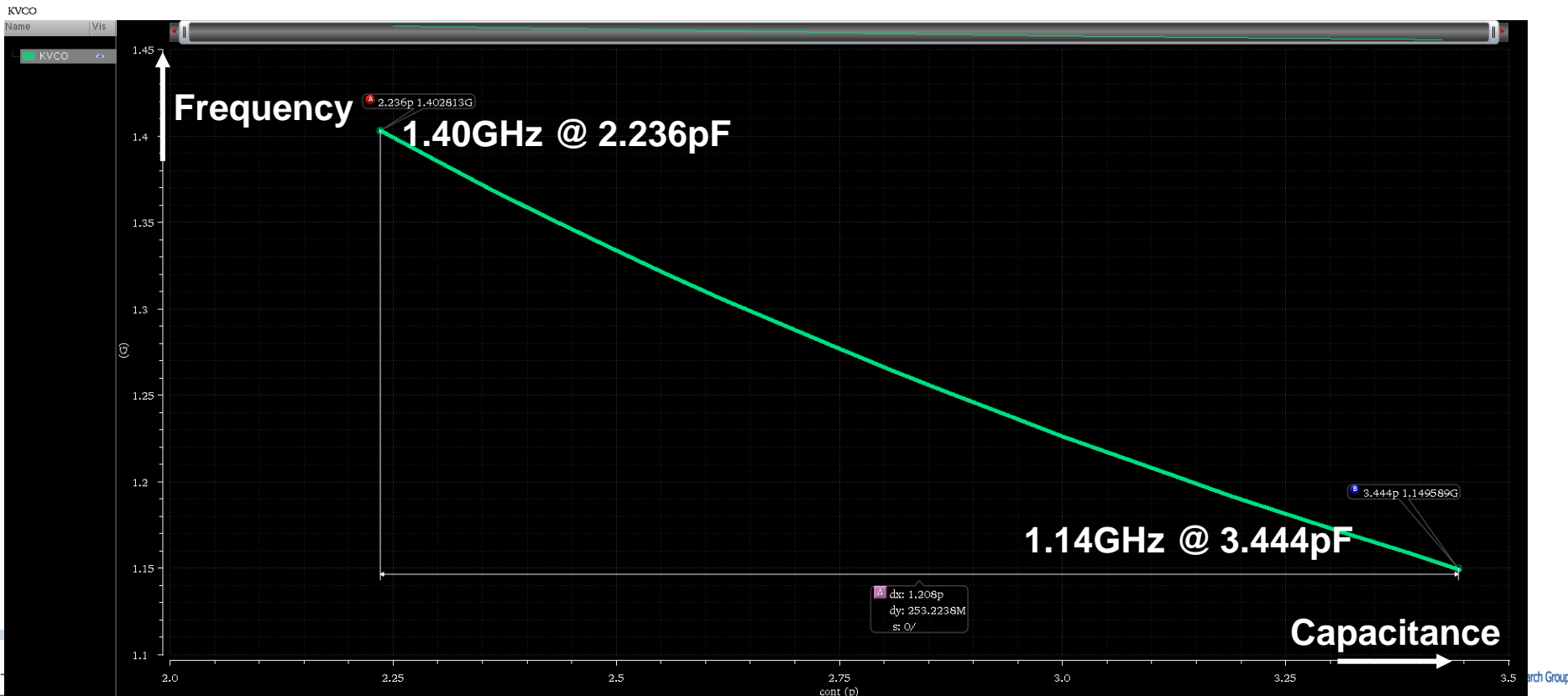
Frequency Tuning Range

- Varactor control sweep
- Varactor control voltage range : 0V ~ 1.8V
- Frequency tuning range : 110MHz

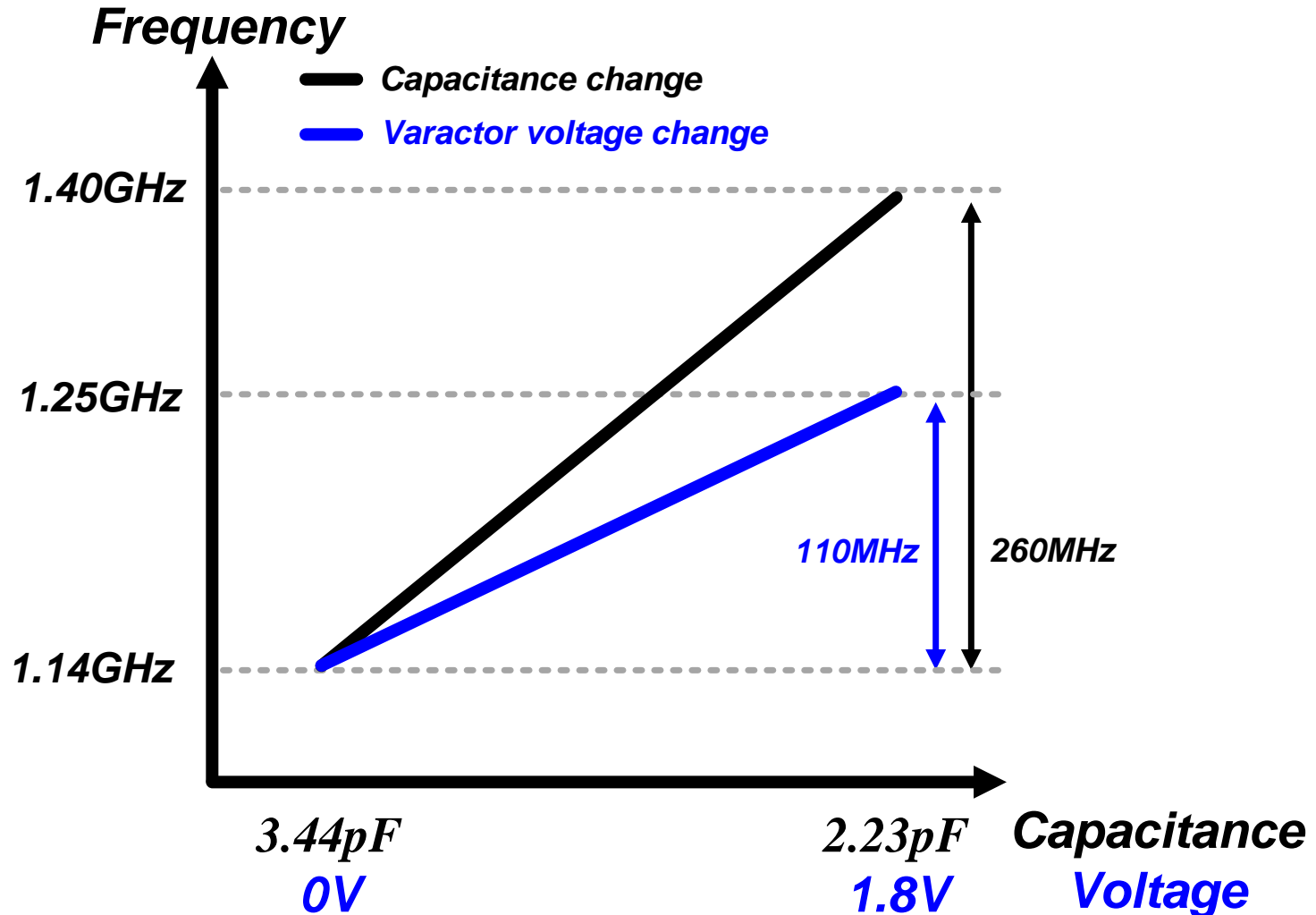


Frequency Tuning Range

- Capacitance value sweep
- Varactor capacitance
 - Control voltage 0V : 1944fF (Total capacitance 3444fF)
 - Control voltage 1.8V : 736fF (Total capacitance 2236fF)
- frequency tuning range : 260MHz

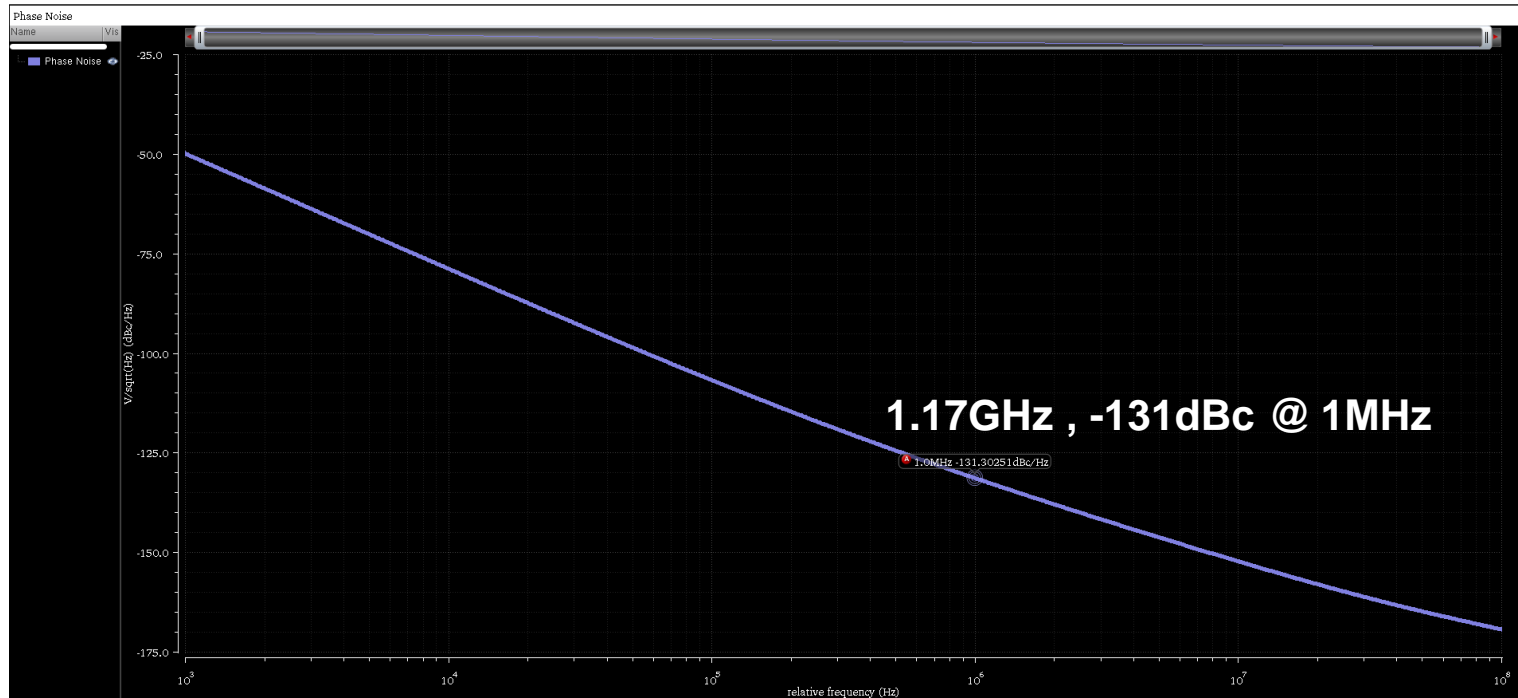


Frequency Tuning Range



Phase Noise (cont : 1V)

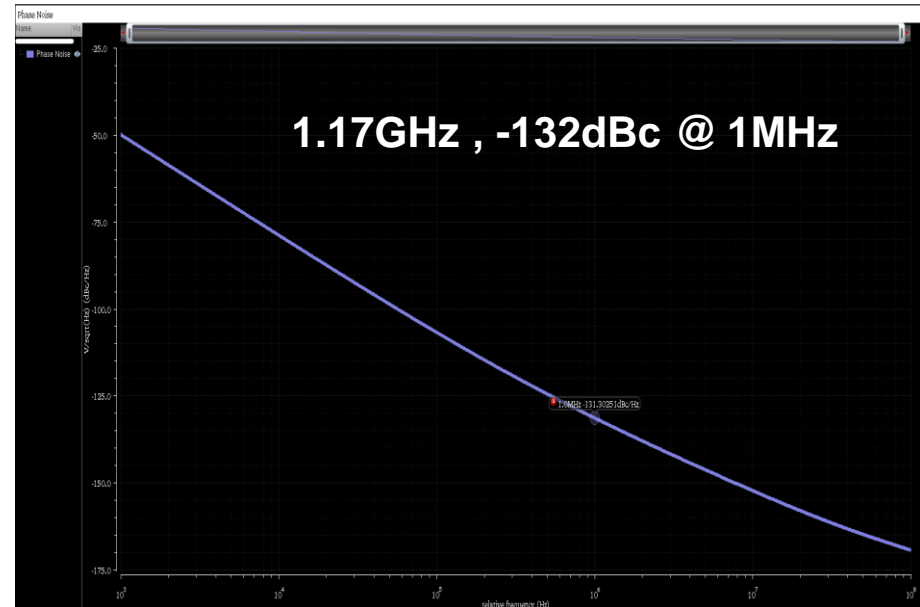
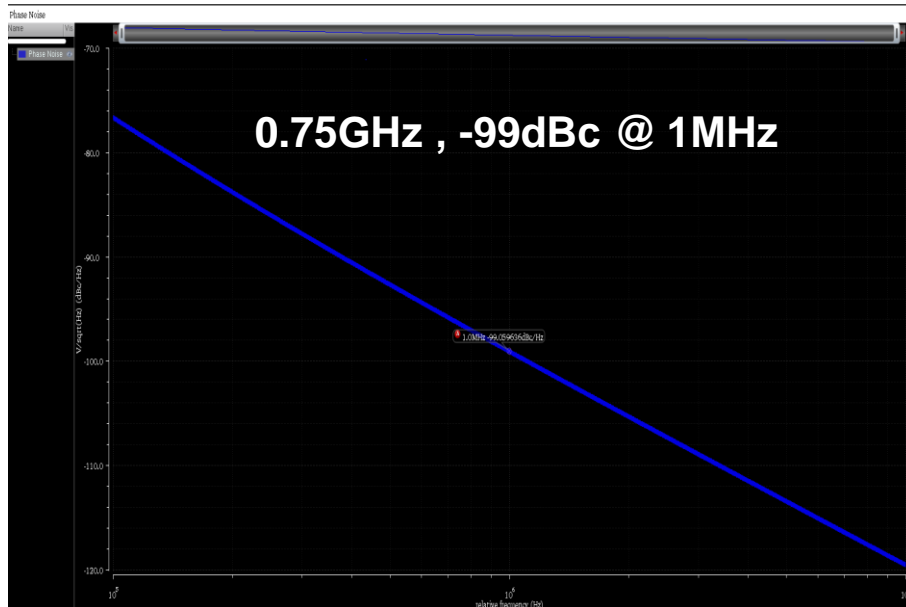
- Phase Noise
 - 1.17GHz, -131dBc @ 1MHz



VCO Comparison #1

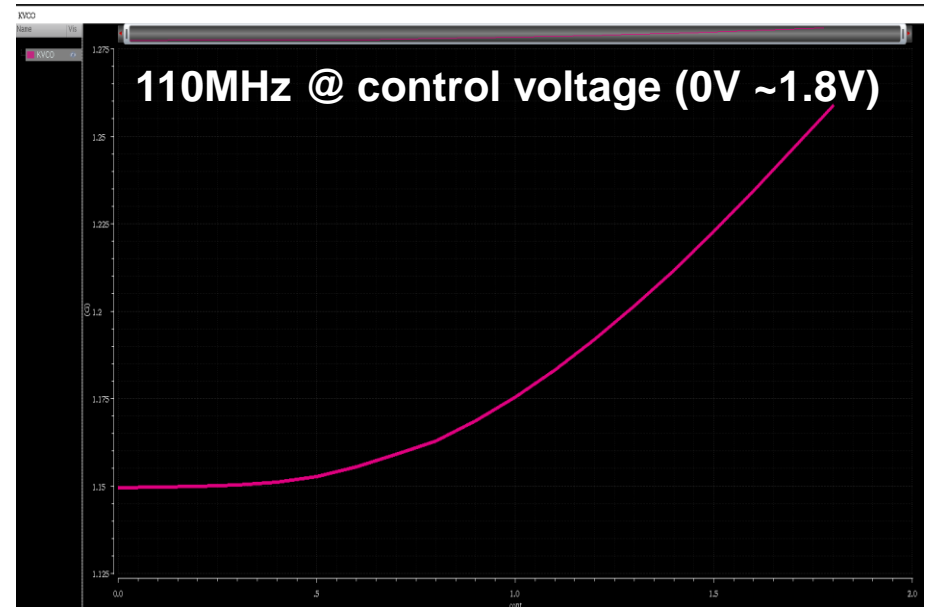
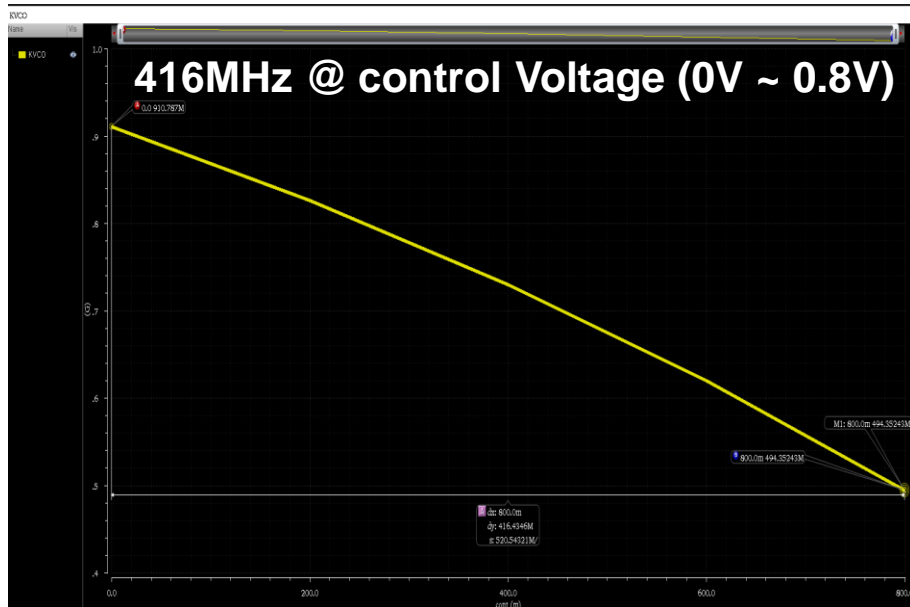
Phase noise

- Ring VCO : -99dBc @ 0.75GHz 1MHz offset
- LC VCO : -132dBc @ 1.35GHz 1MHz offset
- **LC VCO is better for phase noise.**



VCO Comparison #2

- Frequency tuning range
 - Ring VCO : 416MHz @ control voltage (0V ~ 0.8V)
 - LC VCO : 110MHz @ control voltage (0V ~ 1.8V)
 - **Ring VCO is better for frequency tuning range.**



Assignments

- Design 2GHz (± 100 MHz) LC VCO with frequency tuning range 100MHz.
- Verify and plot output waveforms and frequency tuning range.
- Verify and plot phase noise with control voltage 0V , 0.9V and 1.8V.
- Indicate LC VCO schematic, inductor and capacitor value, and using varactor design value.

- LC VCO specification
 - VDD supply voltage : 1.8V
 - Bias voltage : 0.8V
 - Phase noise : Min -115dBc/Hz
 - Frequency tuning range : Min 100MHz

- Due: 29 Mar. 9:30(Hardcopy)

Q & A

superpyunki@gmail.com