Part I: Design of High Frequency VCO and Divider in CMOS Technologies

Wen-Chieh (Steven) Wang

Department of Electronics Engineering

National Chiao-Tung University

Outlines

- Introduction
- Circuit Design Example
  - Case I: High Frequency VCO and Divider
  - Case II: Wide Tuning Range VCO for UWB
- Conclusions

Introduction

- In RFIC design, circuits are sensitive to parasitic, including parasitic capacitors and inductors.
- The Ansoft HFSS helps consider and extract these parasitic effect. Besides, the EM coupling effect can also be figured out.
- The Ansoft Designer/Nexxim is a powerful simulator that can handle larger amount transistors and have shorter simulation times.
- Two case studies using Ansoft tools including Designer/ Nexxim and HFSS are discussed in this presentation.

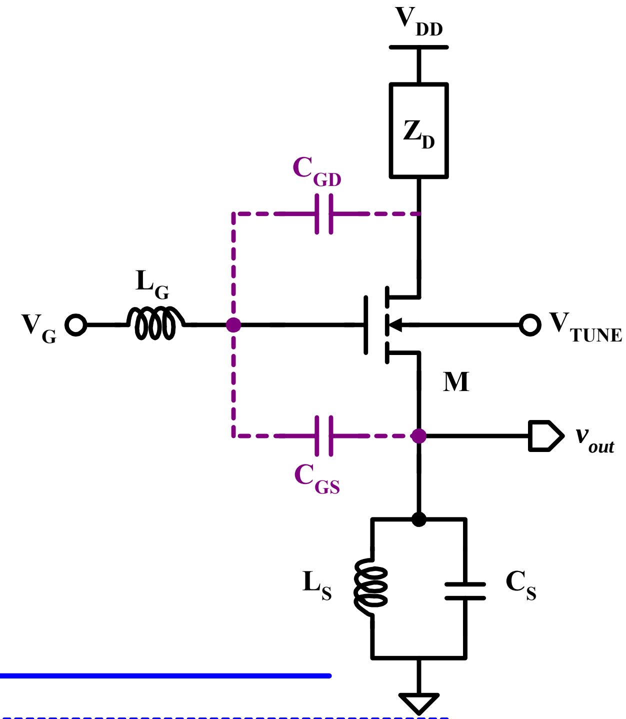
Case I : High Frequency VCO and Divider

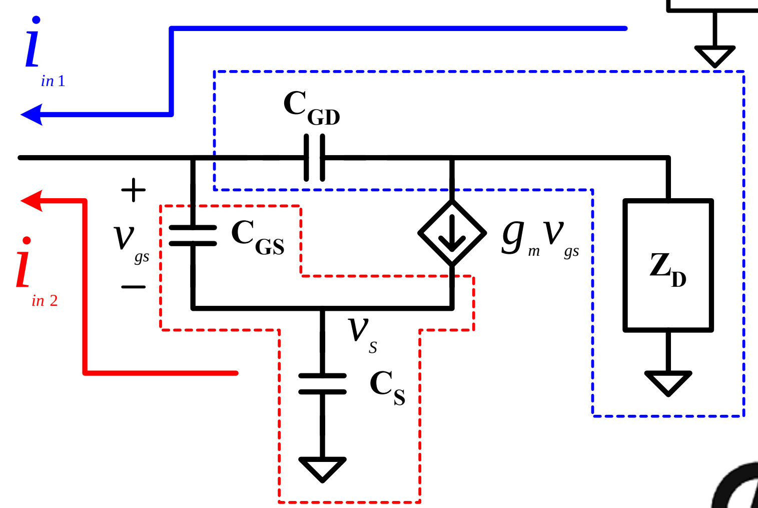
■ Circuit of VCO (single-ended)

- By simple calculation,

$$i_{in1} = a_1 + jb_1; \quad i_{in2} = \alpha\left[a_{gm} + jb_{gm}\right]$$

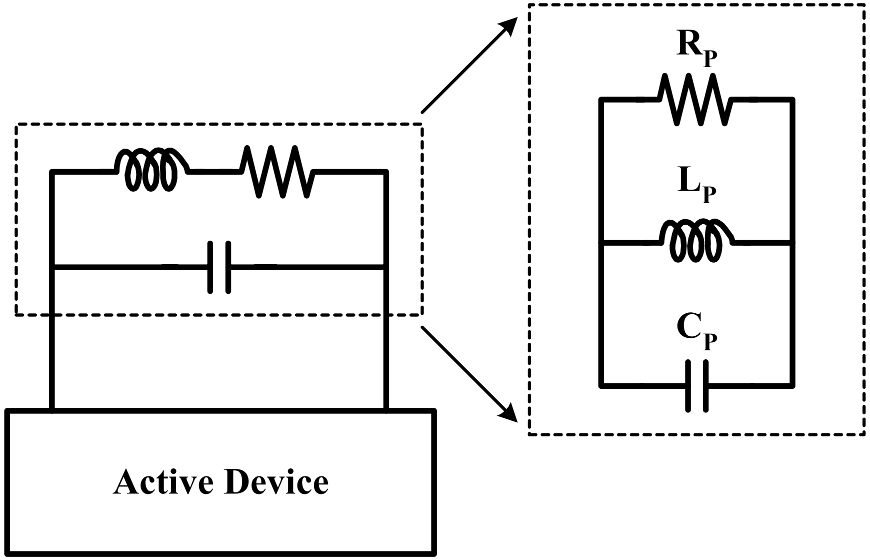
- The negative-R results from $\alpha \cdot a_{gm}$
- Z_D should be designed such that $a_1 > 0$
- It is easy to prove that **Z_D should be inductive** and the resonated frequency of Z_D and C_{GD} should smaller than the VCO oscillating frequency





Case I : High Frequency VCO and Divider

- **Noise consideration**
  - **The general model for a VCO**
    - $\langle v_n^2 \rangle \approx kT/C_P = kT\omega_0^2 L_P$
    - V_{tank} is ratio to R_P
  - **Design guide of the LC tank**
    - Minimizing the value of L_P
    - Minimizing the value of R_P
    - Designing the value of L_P/R_P^2 as small as possible



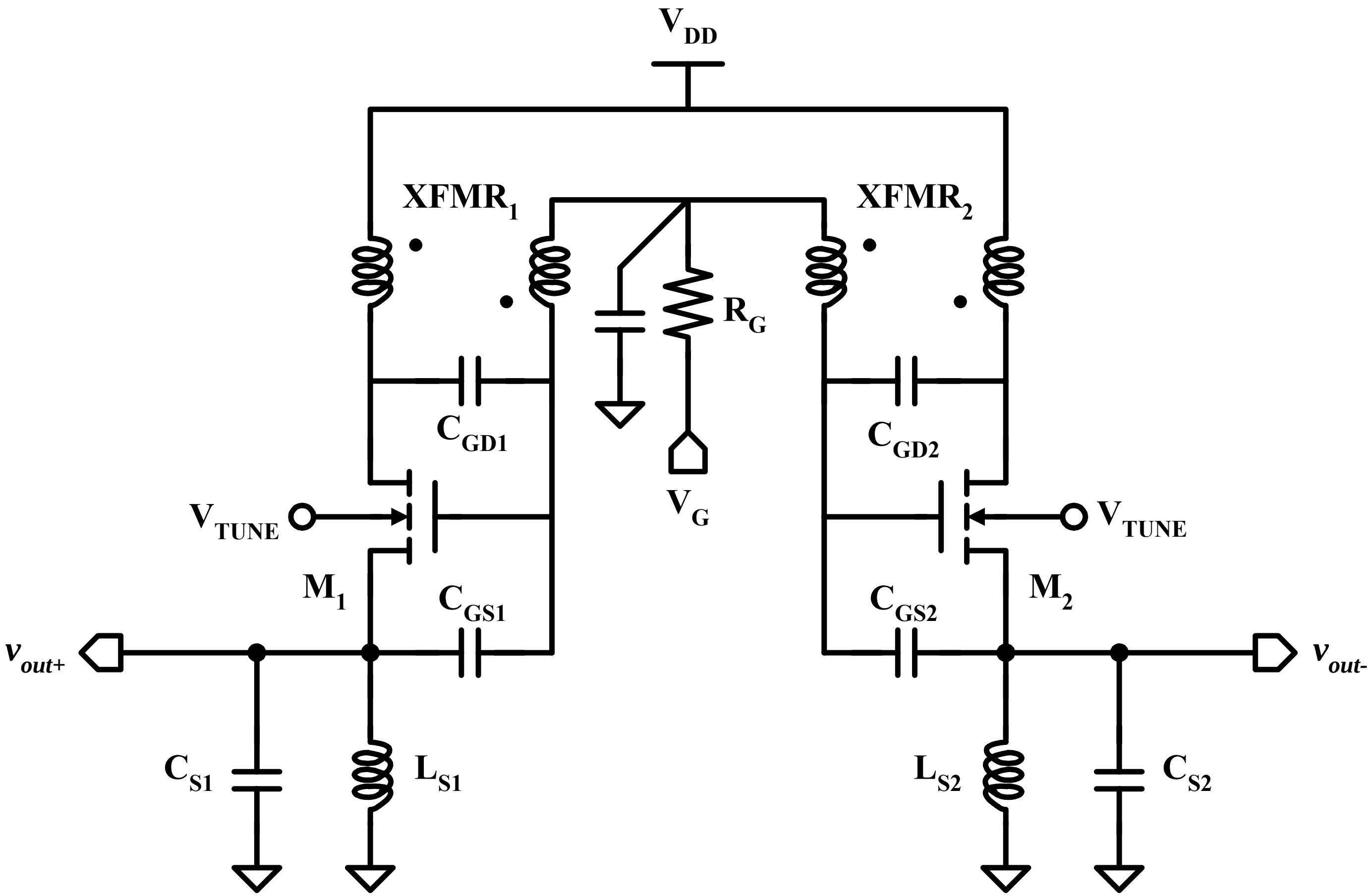
Case I : High Frequency VCO and Divider

- **Consideration of the single-ended VCO**
  - **3 ac ground in the circuit**
    - V_{DD}, V_G, V_{TUNE}
  - **It is difficult to design idea ac ground in high frequency**

- **Differential type of VCO**
  - **Differential circuit structure is needed to prevent such ac ground node.**

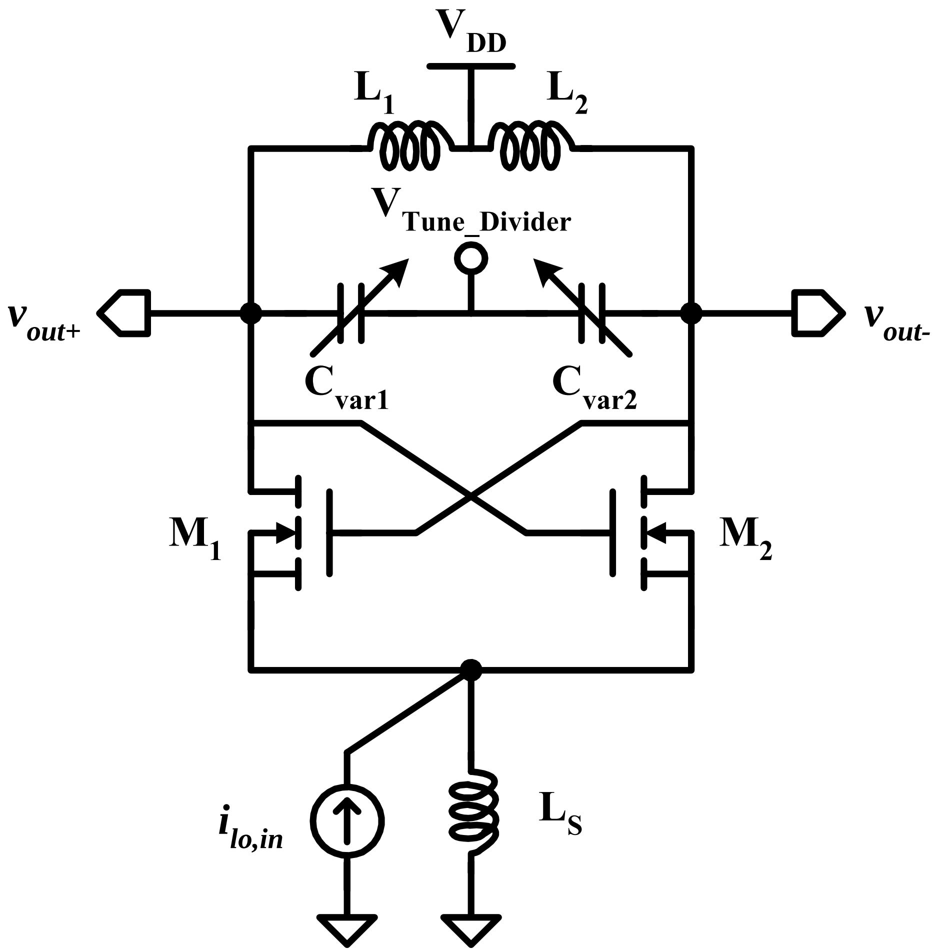
Case I : High Frequency VCO and Divider

- **Circuit structure of the differential VCO**



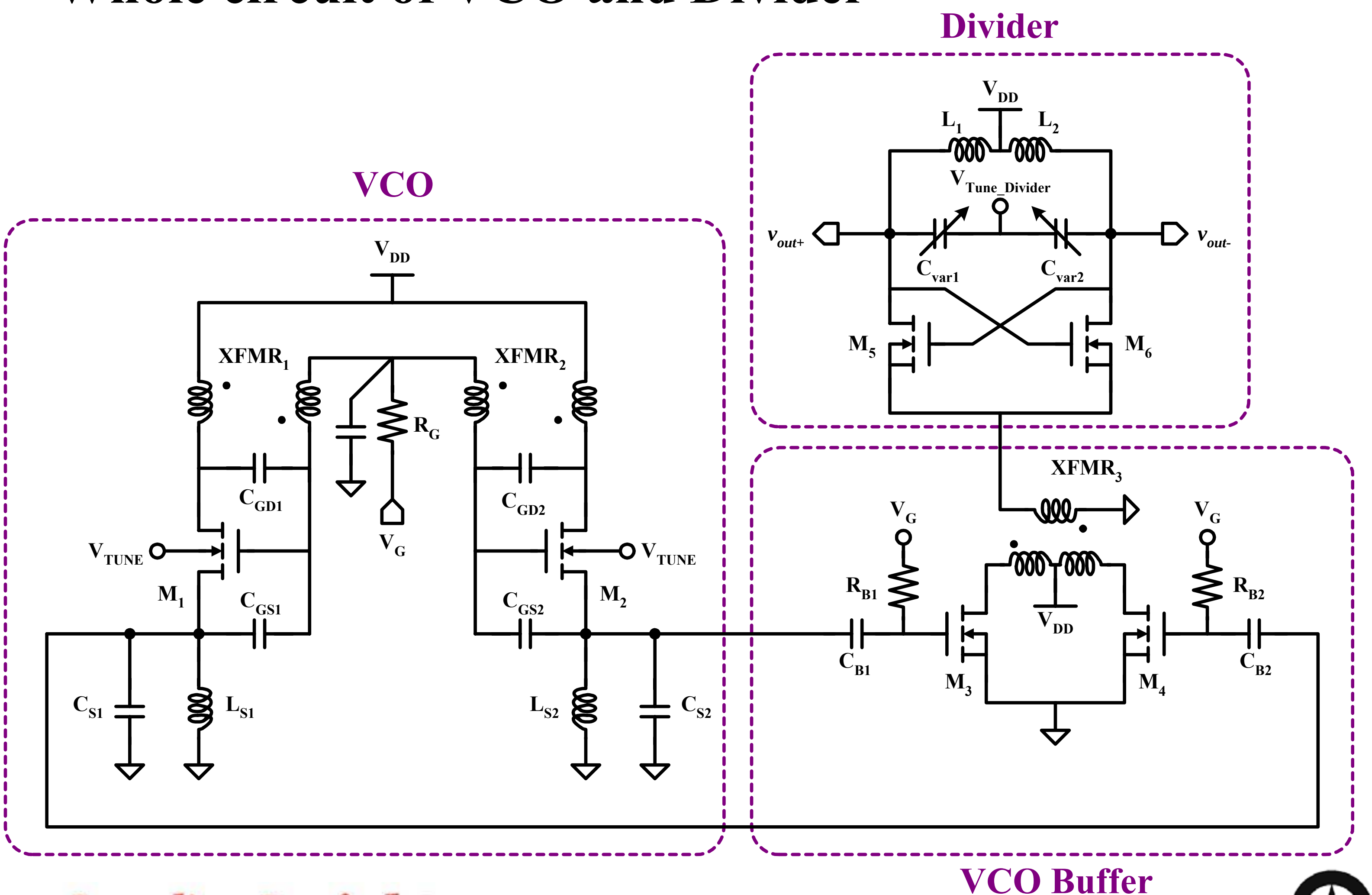
Case I : High Frequency VCO and Divider

- **Injection locked frequency divider**



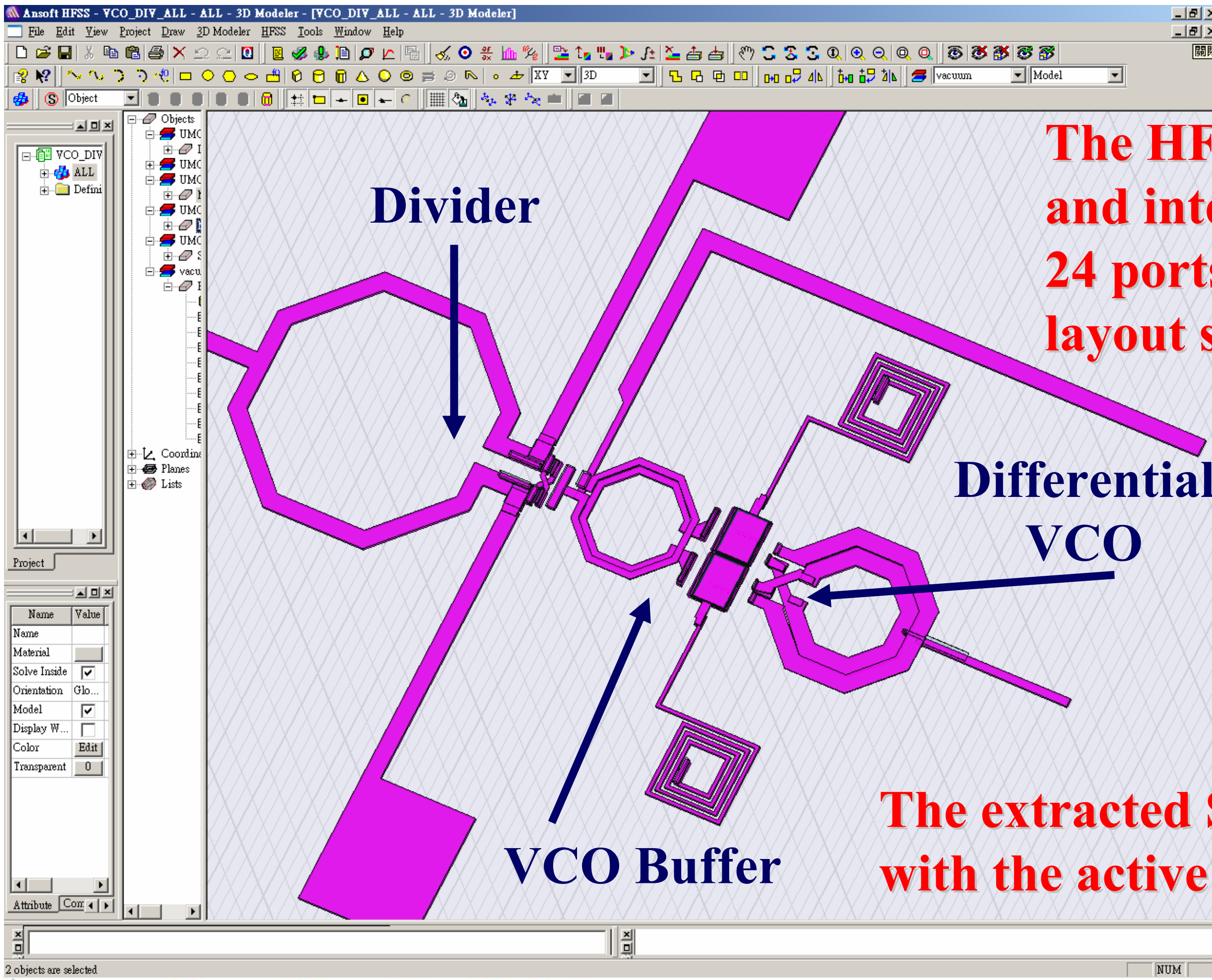
Case I : High Frequency VCO and Divider

■ **Whole circuit of VCO and Divider**



Case I : High Frequency VCO and Divider

- **Layout Diagram of VCO in HFSS 3-D view**

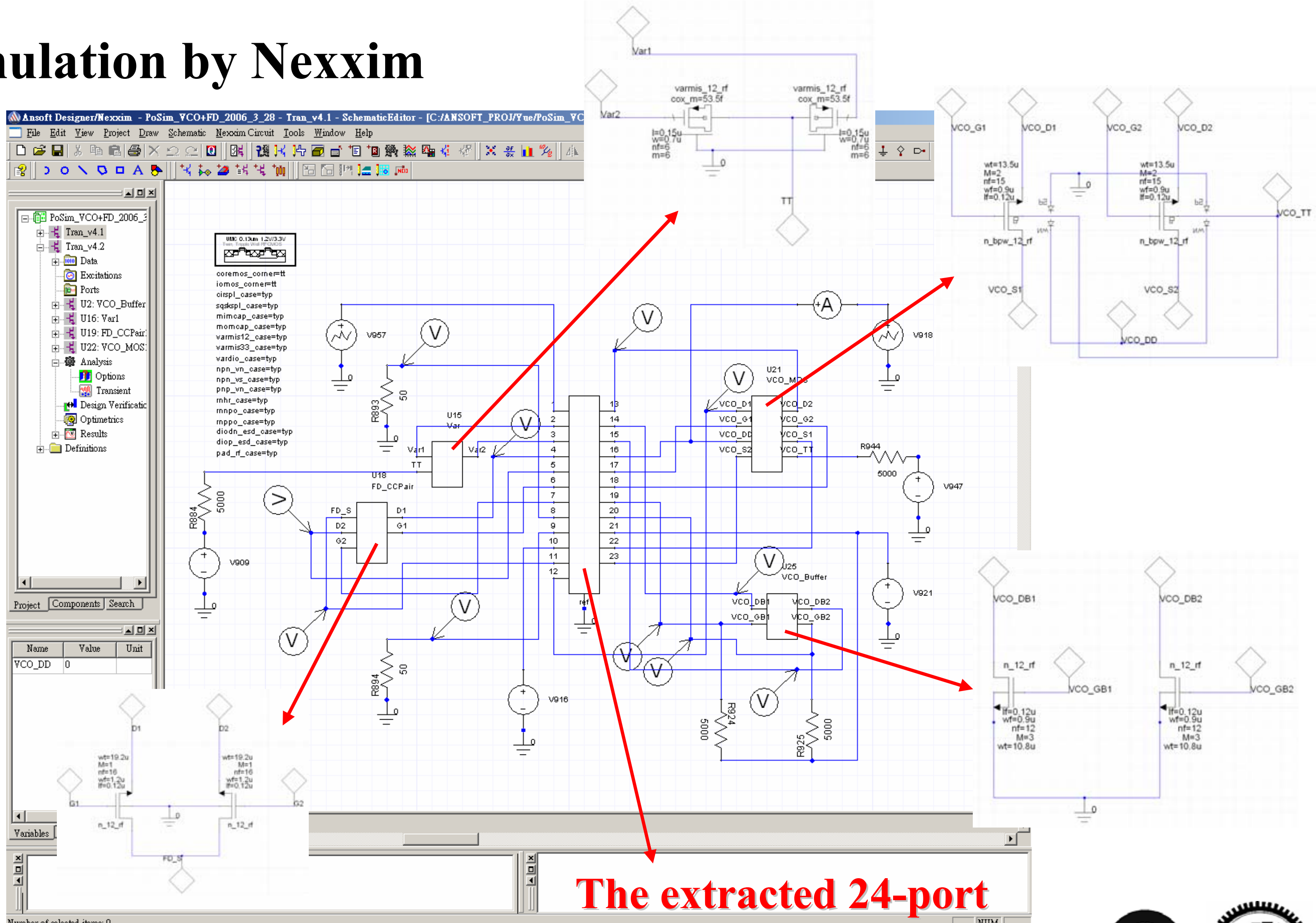


The HFSS extracts the parasitic and interconnection effect.
24 ports are considered in this layout structure

The extracted SNP file is co-simulated with the active devices by Ansoft Nexxim

Case I : High Frequency VCO and Divider

■ **Simulation by Nexxim**

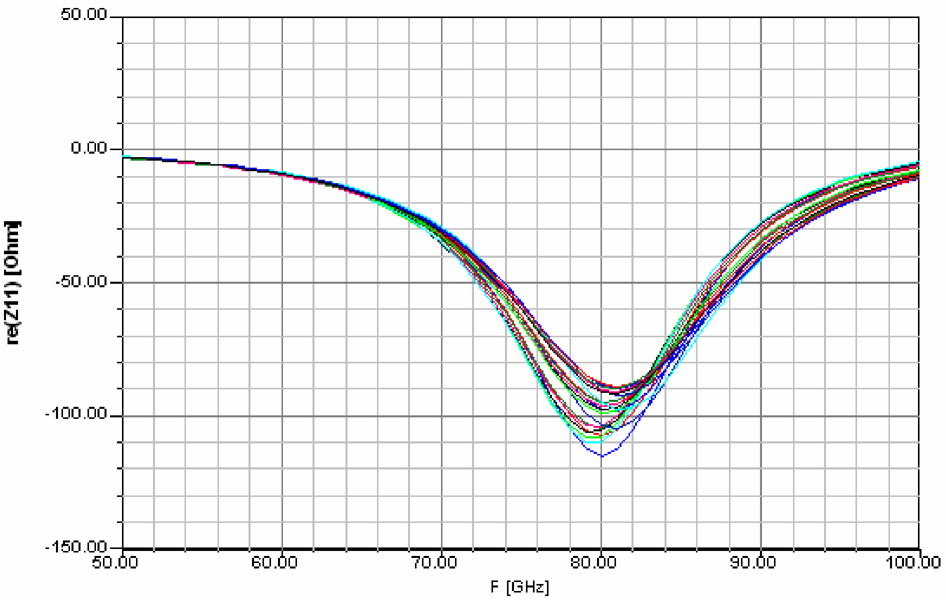


The extracted 24-port S-parameter from HFSS

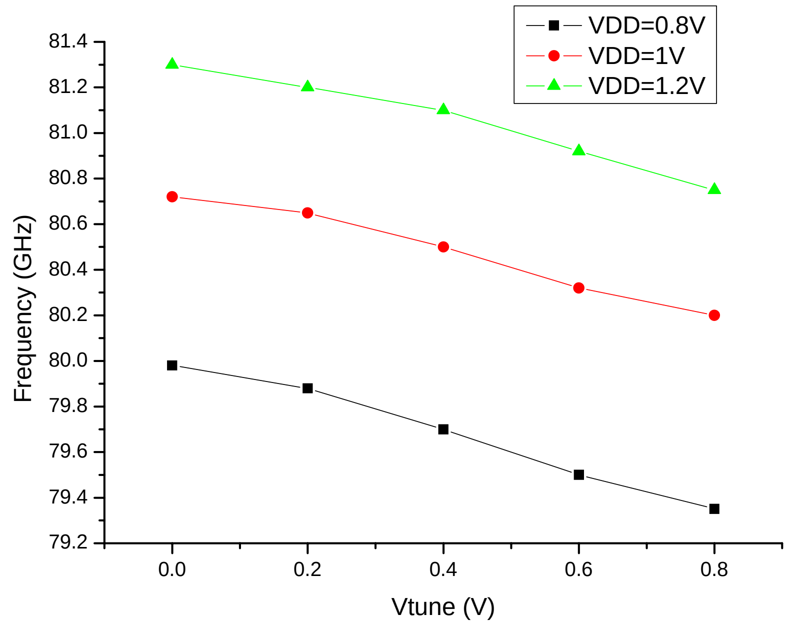
Case I : High Frequency VCO and Divider

- **Simulation results – (1) VCO**

Characteristics of negative-R

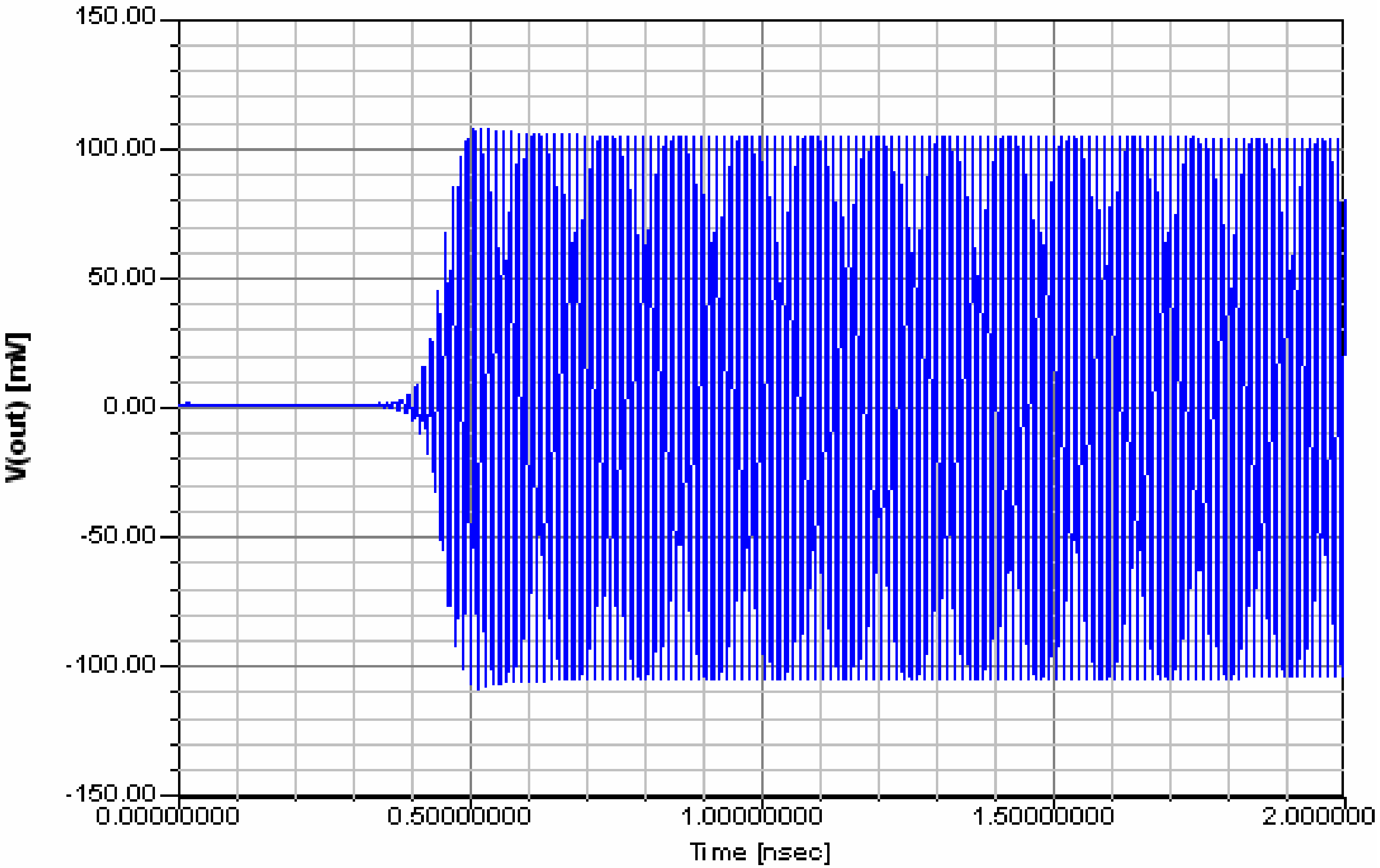


Tuning Range
From 79.4GHz to 81.4 GHz



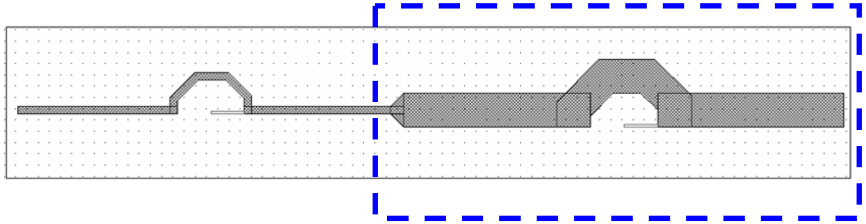
Case I : High Frequency VCO and Divider

- Simulation results – (2) VCO

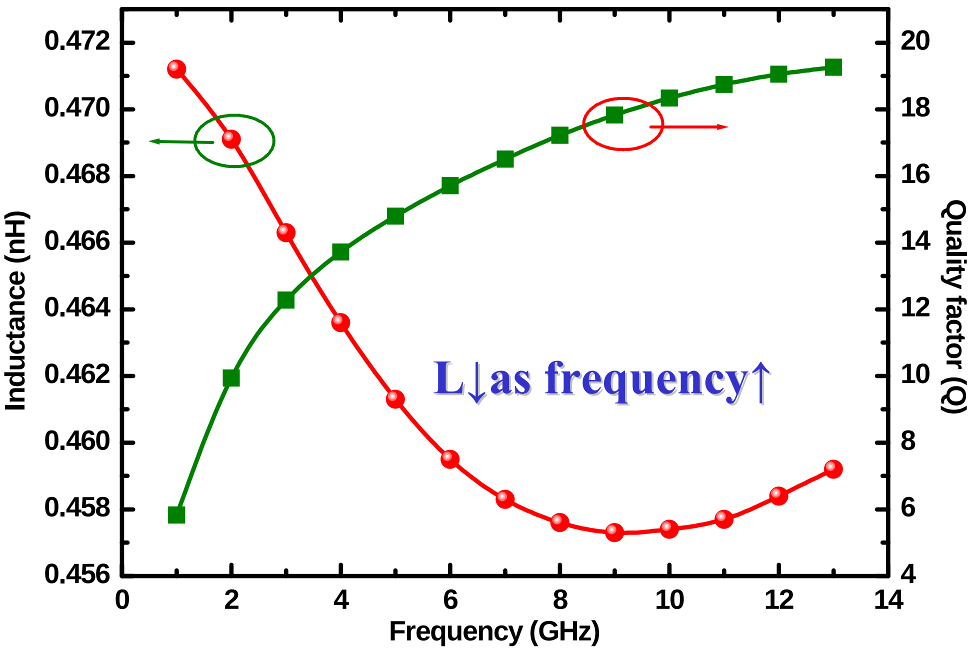


Case II : Wide Tuning Range VCO for UWB

- **Wide tuning range LC tank**
  - **Half-turn inductor**
    - **Inductance decreases before its self-resonate frequency. This characteristic can be used to increase the tuning range of VCO.**

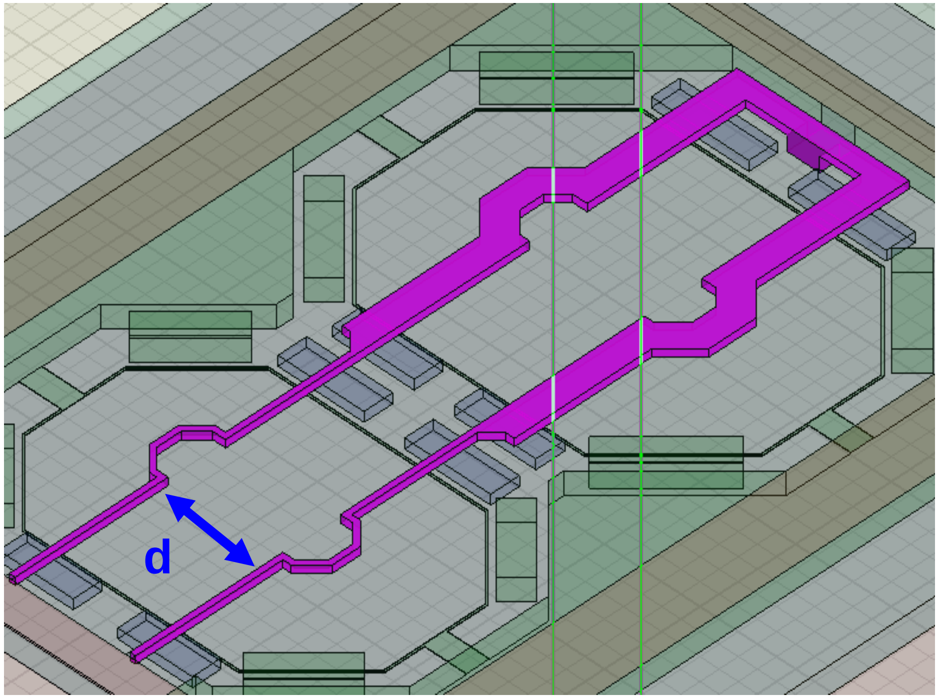


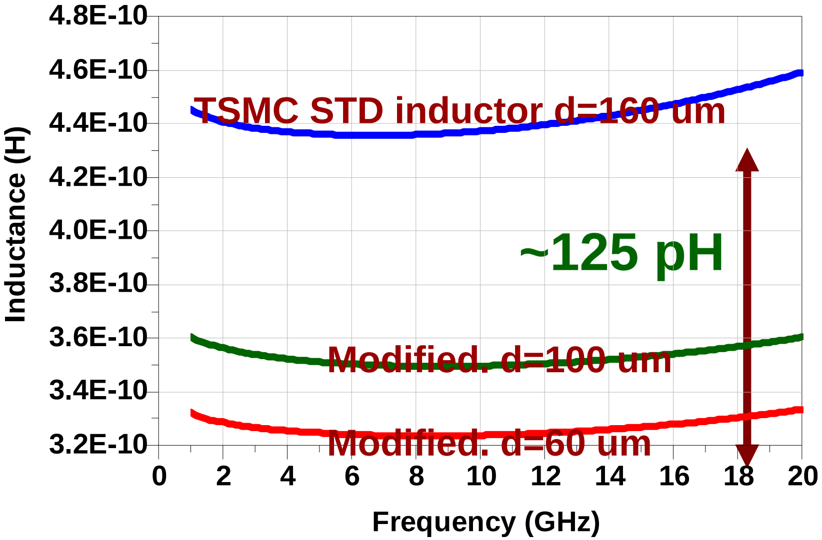
Wider metal width has higher Q but larger parasitic capacitance that decrease the tuning range. Therefore, 2 half-turn inductors are in series. The 2nd one is chosen wider metal to increase Q slightly.



Wide Tuning Range VCO for UWB

- **Wide tuning range LC tank**
  - **The half-turn inductors in series are slightly modified from the device provided by foundry to reduce active area . The HFSS is adopted to verify the inductors.**

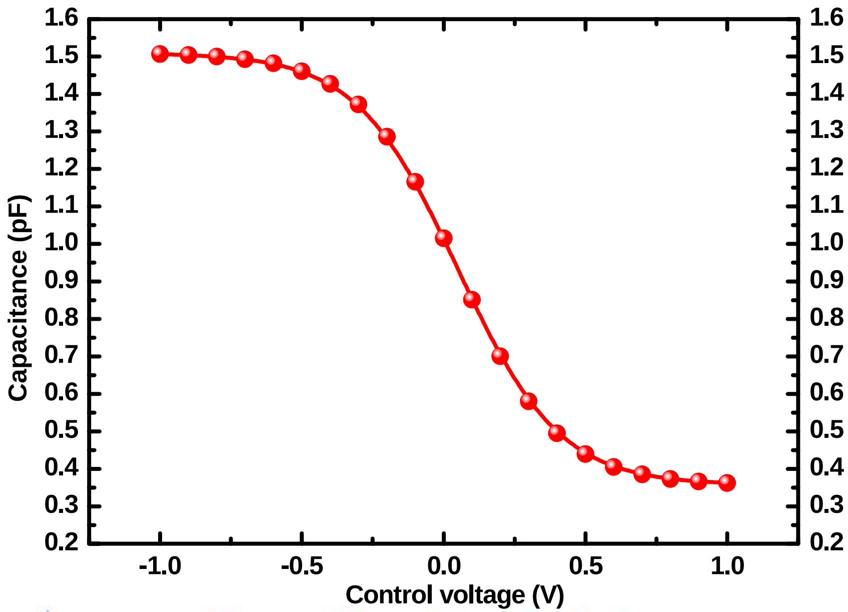


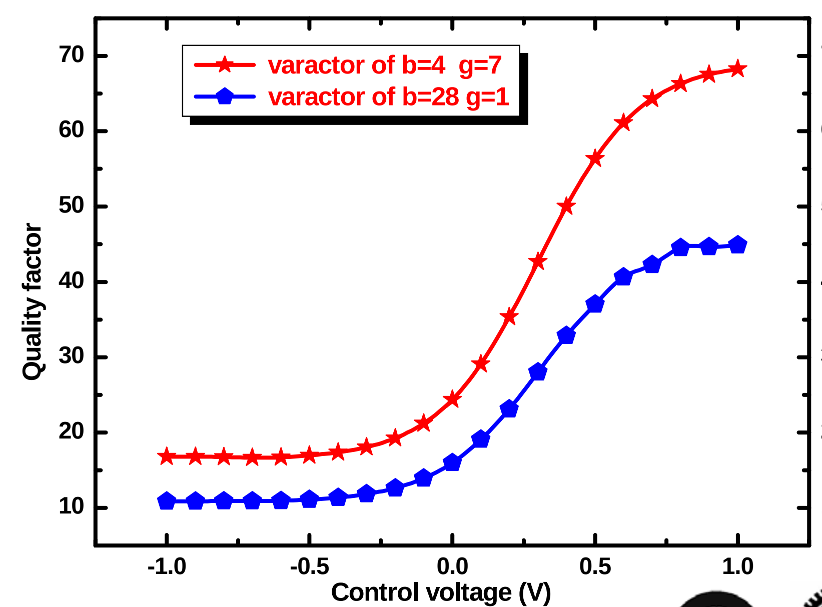


L↓as frequency↑
at the frequency below 10 GHz

Case II : Wide Tuning Range VCO for UWB

- **Wide tuning range LC tank**
  - **More group number reduce gate resistance that increase Q_{var}.**
  - **Gate is connected to VCO output and S/D are connected bias (ac ground point). This can result in wider tuning range and better phase noise.**
  - $Q_{var} \propto L^{-2}$ **. Tuning capability:** $\left(C_{max}/C_{min}\right) \propto \left(L/L_{min}\right)$

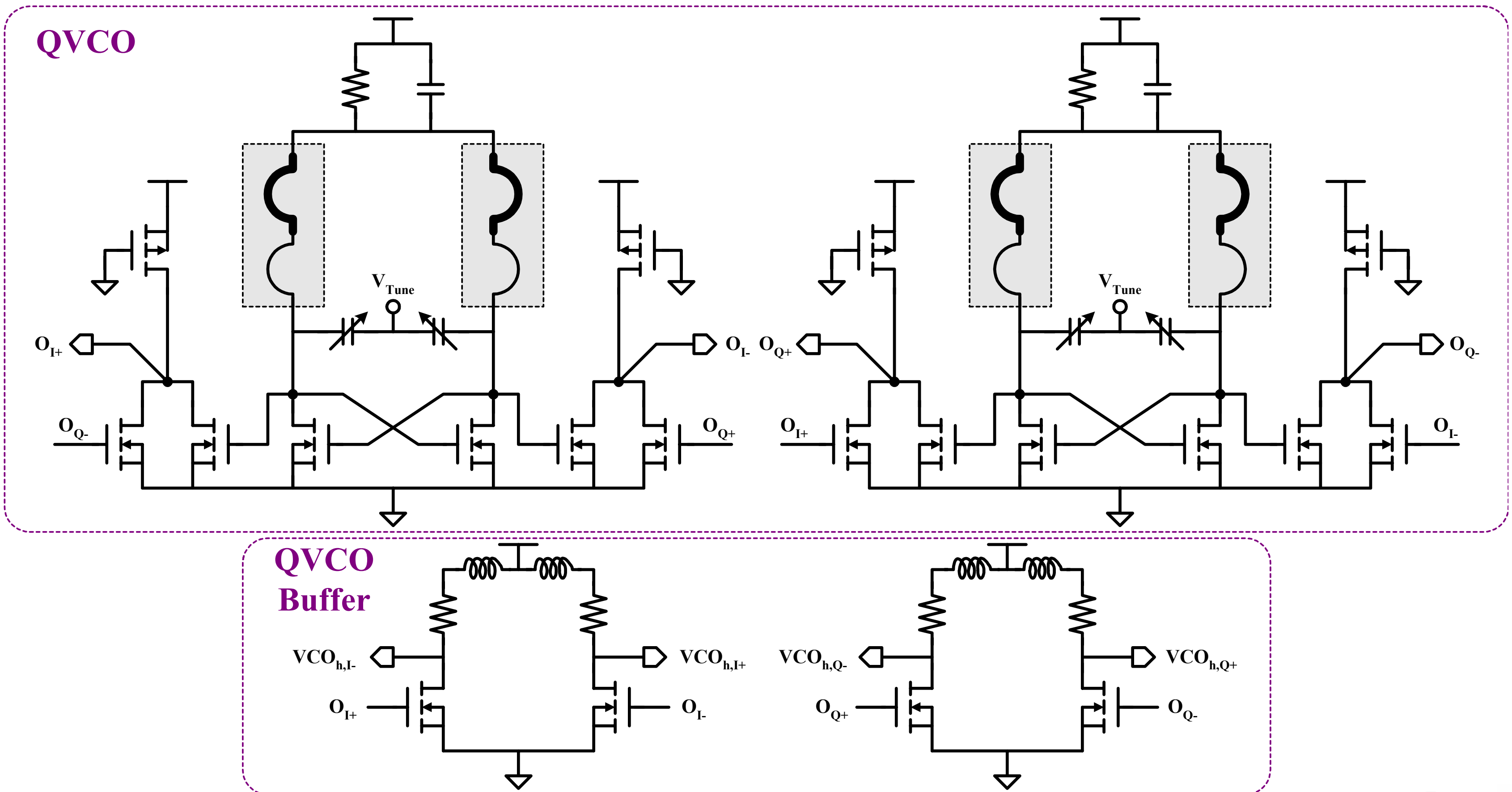




Case II : Wide Tuning Range VCO for UWB

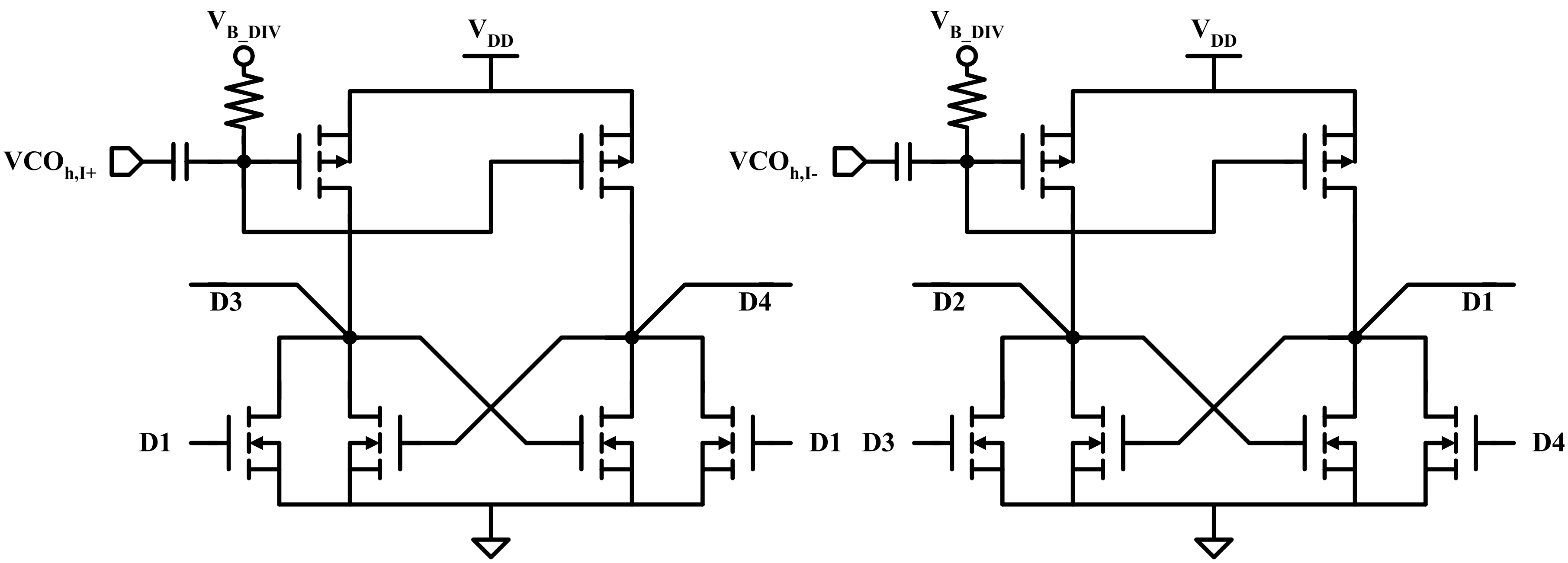
Circuit of the wide tuning range quadrature VCO

- The core quadrature VCO oscillates from 6 GHz to 10 GHz



Case II : Wide Tuning Range VCO for UWB

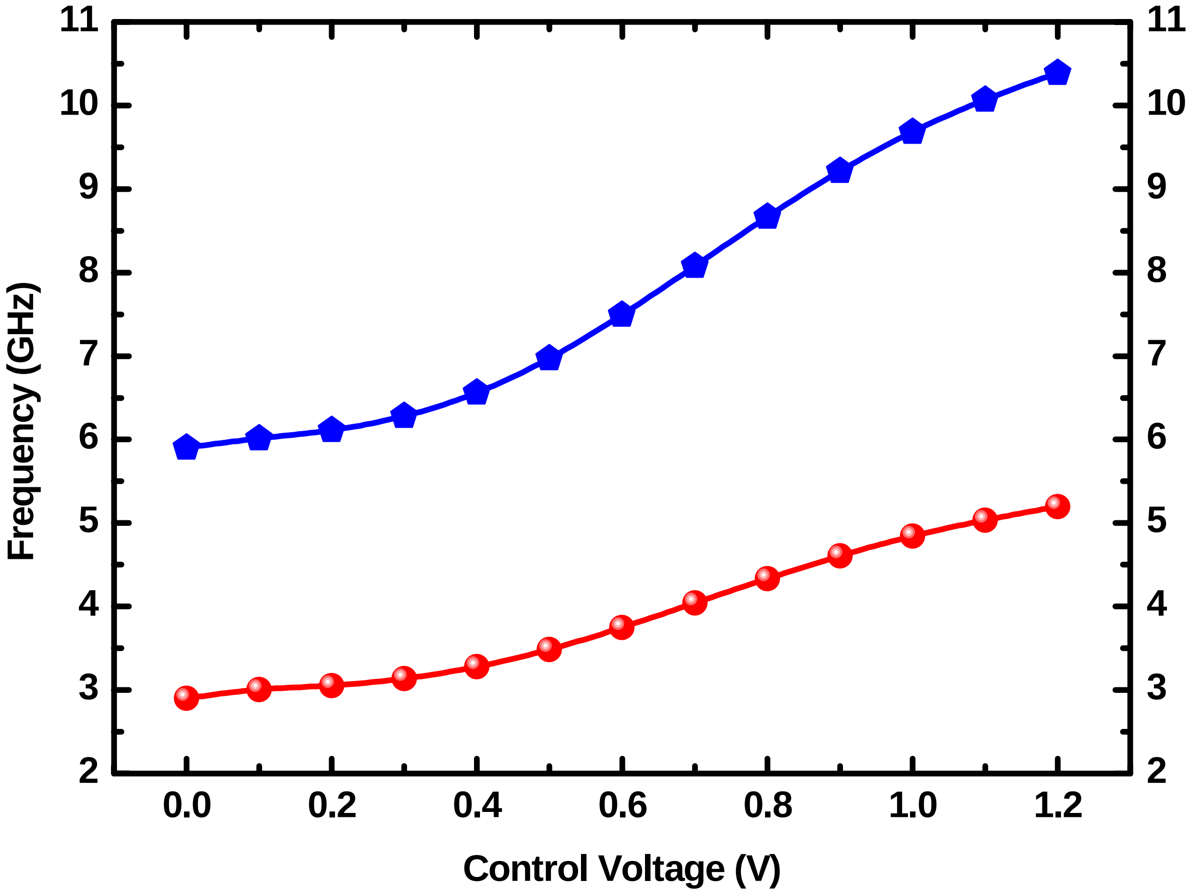
- **Circuit of the wide tuning range quadrature VCO**
  - Through a divided-by-2 circuit, the 3 GHz to 5 GHz can be designed
  - The frequency gap from 5 GHz to 6 GHz are going to be reduced.



  - Hence, oscillator operates from 3 GHz to 10 GHz can be realized.

Case II : Wide Tuning Range VCO for UWB

■ **Simulation results: VCO tuning curve**



Conclusions

- **Ansoft HFSS helps extract parasitic and consider inter-connection in detail.**

- **Ansoft Designer/Nexxim has much higher simulation speed and higher capacity to handle larger circuits including N-port S-parameters extracted from EM. More realistic design and faster design period can be achieved.**

- **Ansoft Designer/Nexxim + HFSS is promising for the CMOS RFIC design flow.**