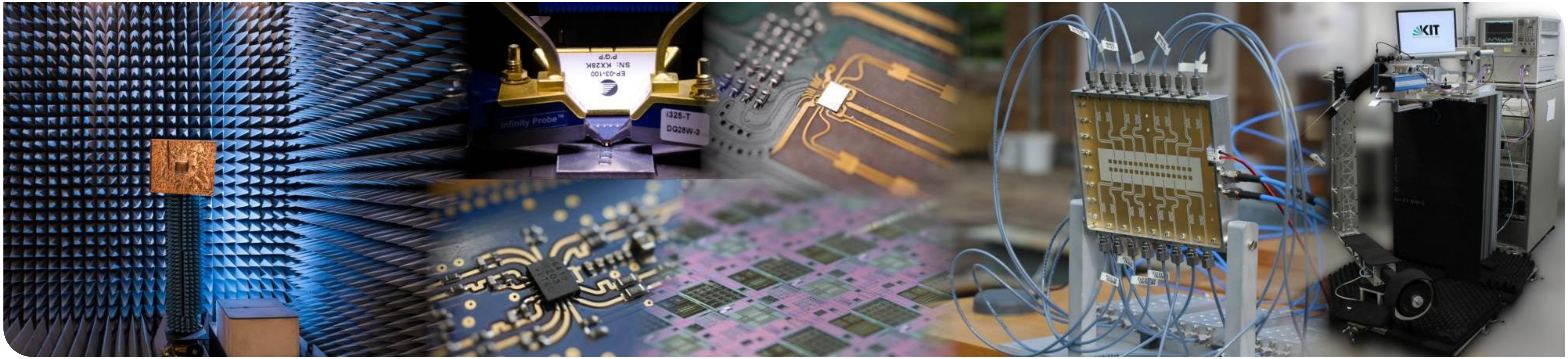
MMICDL – Up-conversion Mixer Design

2379568 Jiyun Kim



Contents

Contents

Ⅰ. Introduction

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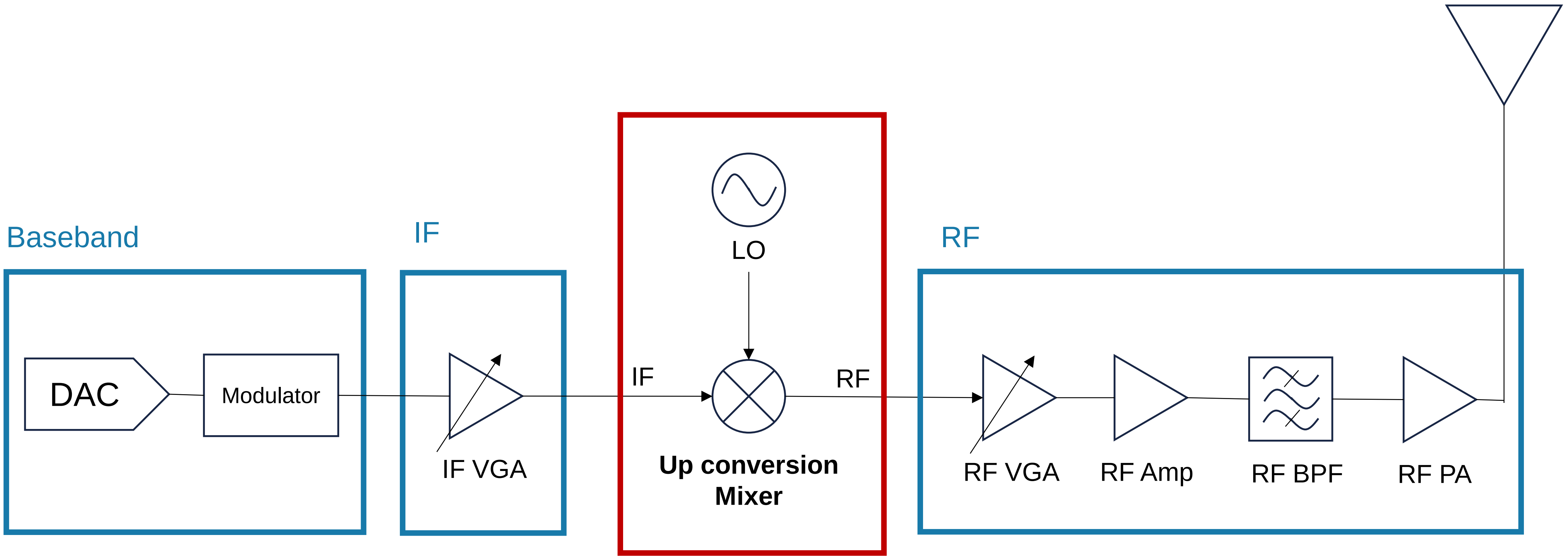
- MMIC (Monolithic microwave integrated circuits)
  - All circuits and components are fabricated directly on a single semiconductor
    - advantages
      - Compact size
      - low cost
      - Operates at high frequencies (K band and higher) reaching mmWave
    - challenges
      - waveguide effects have to be considered
      - Modelling and simulation have to be accurate to produce correctly
      - parasitics increases with frequency
      - Achievable output powers drop with frequency necessitating

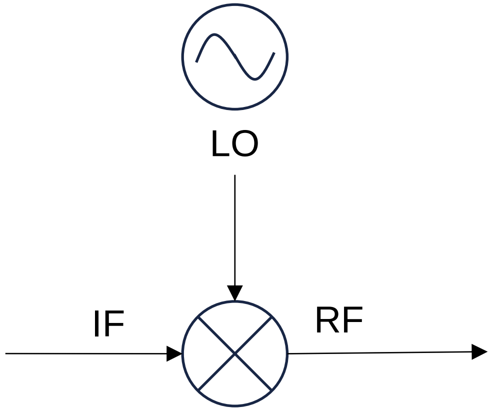
Ⅰ. Introduction

- RF Transmitter

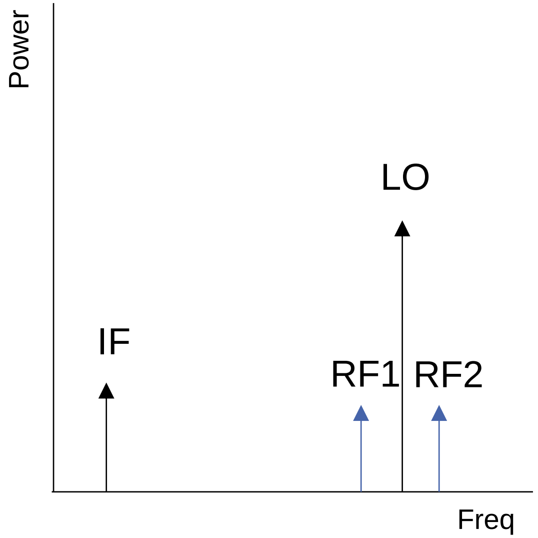


I. Introduction

- Up-conversion Mixer



Up conversion Mixer



RF1 = LO – IF
RF2 = LO + IF

- Design Goals
  - 1dB compression point > 0dBm
  - Gain > 10dB
  - IF Bandwidth > 200MHz
  - S11 < -15dB
  - S22 < -15dB

Ⅱ. Design Procedure

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- Schematic view and simulation
  - Single balance or Double balance
  - Core design (include transistor decision)
  - DC simulation
  - S-param simulation
  - output / input matching network
  - Design params check with HB simulation
- Layout view and simulation
  - Core Layout & EM simulation
  - S-param simulation
  - output / input matching network
  - Design params check with HB simulation
  - Inductor Layout design (Pcell) & EM simulation
  - Mixer Layout EM simulation
  - Design params check with HB simulation

Ⅱ. Design Procedure

- Schematic view and simulation
  - Single balance or Double balance
  - Core design (include transistor decision)
  - DC simulation
  - S-param simulation
  - output / input matching network
  - Design params check with HB simulation

Ⅱ. – 1. Schematic View and Simulation

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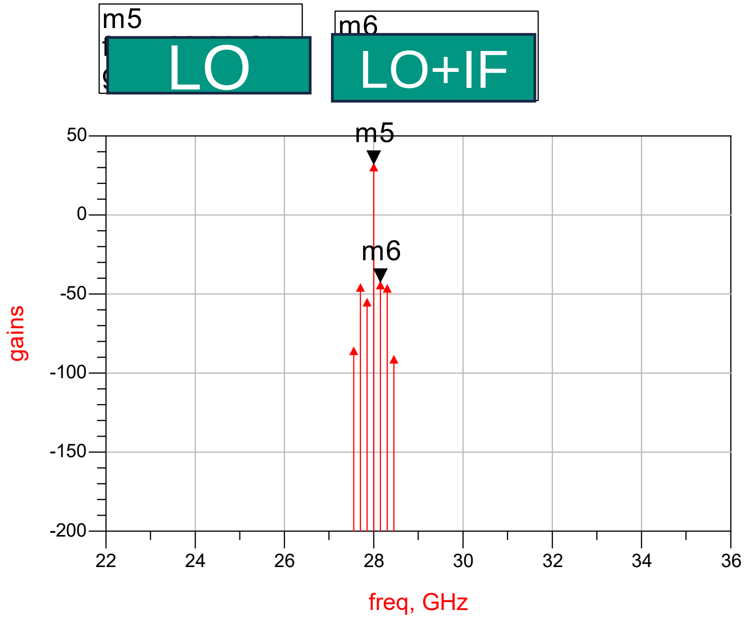
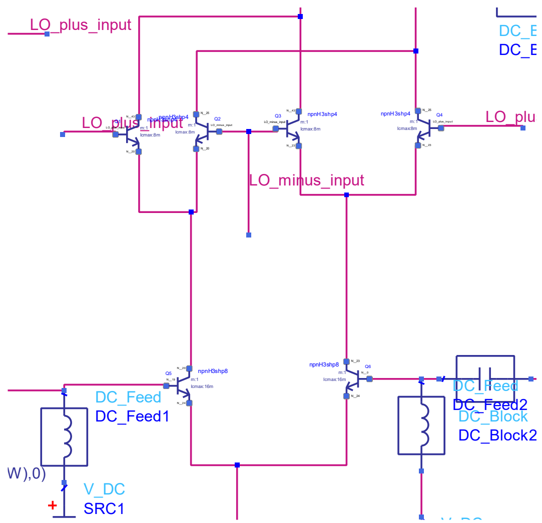
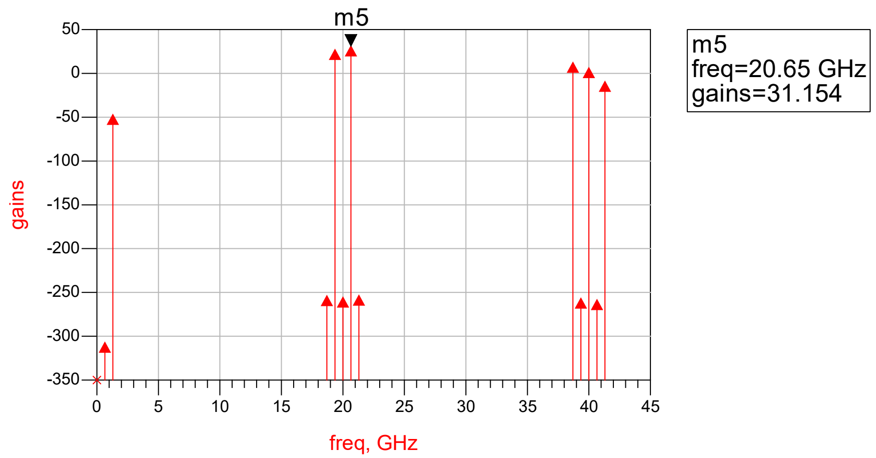
- Balance Mixer : improves isolation
- Single Balance vs Double Balance
  - Unwanted LO component in output in Single Balance

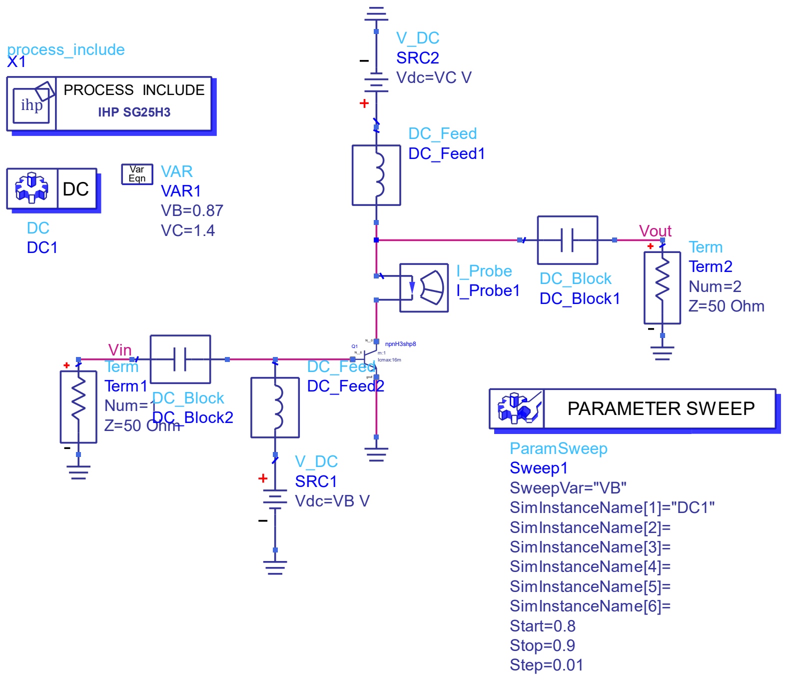


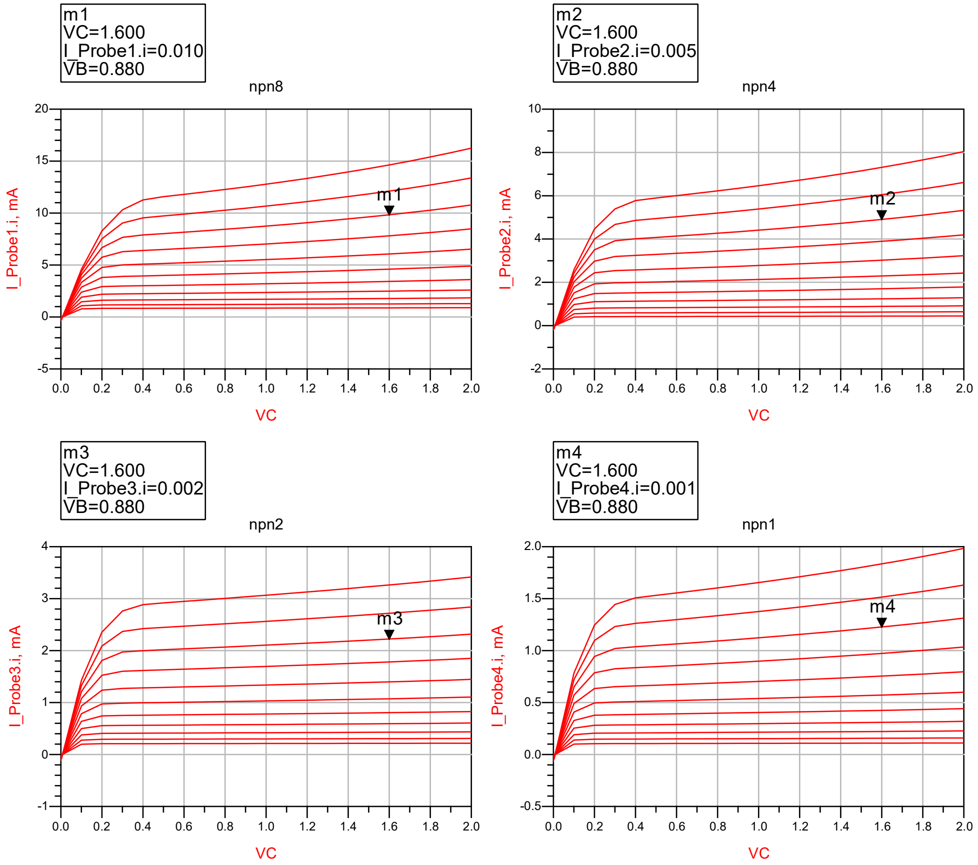




Ⅱ. – 1. Schematic View and Simulation

- Core Design – transistor analysis





Ⅱ. – 1. Schematic View and Simulation

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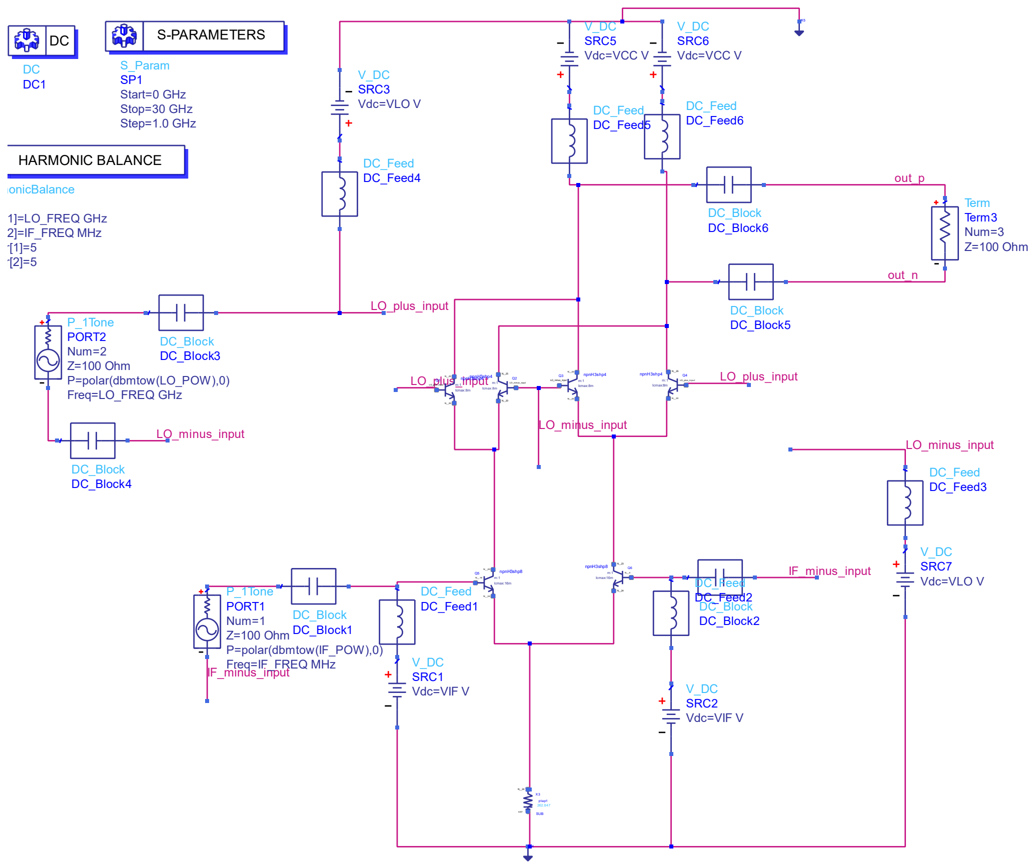
Core Design



Fixed Parameters

- VCC=3.6 V, VLO= 2.4V, VIF=0.89V
- Q0, Q1, Q2, Q3 : npnhp4 and Q4, Q5 : npnhp8 from SG25_dev library from IHP
- Initial value LO_POW=0dBm, LO_FREQ=20GHz, IF_POW=-30dBm, IF_FREQ=100MHz

Ⅱ. – 1. Schematic View and Simulation

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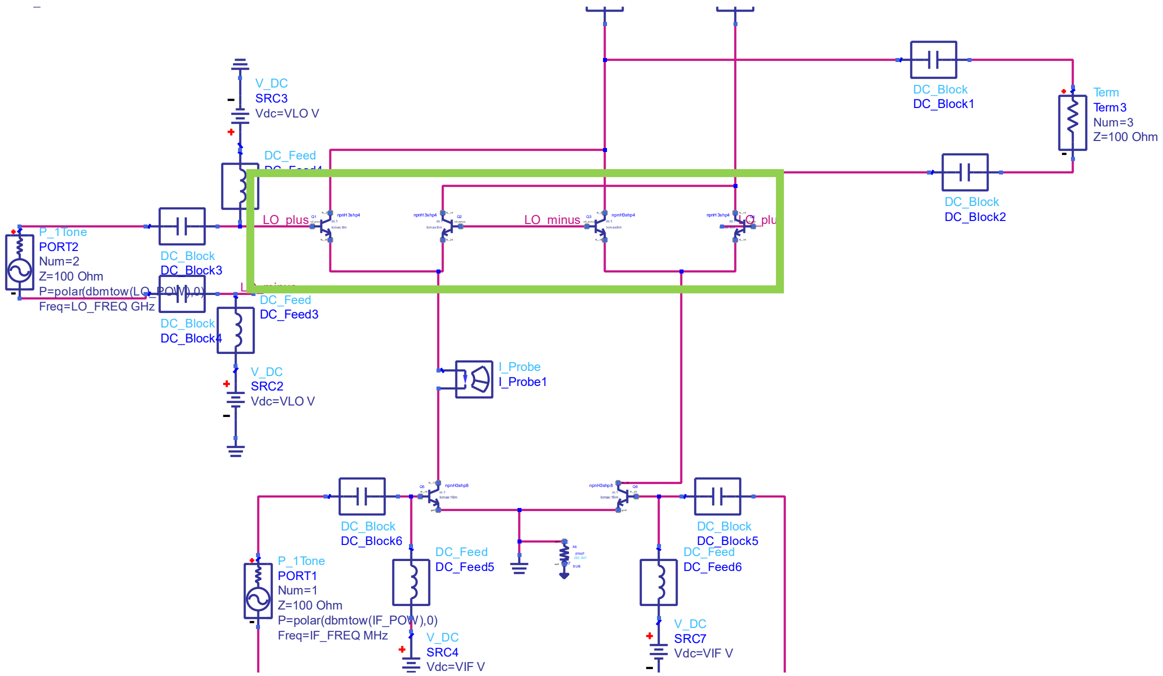
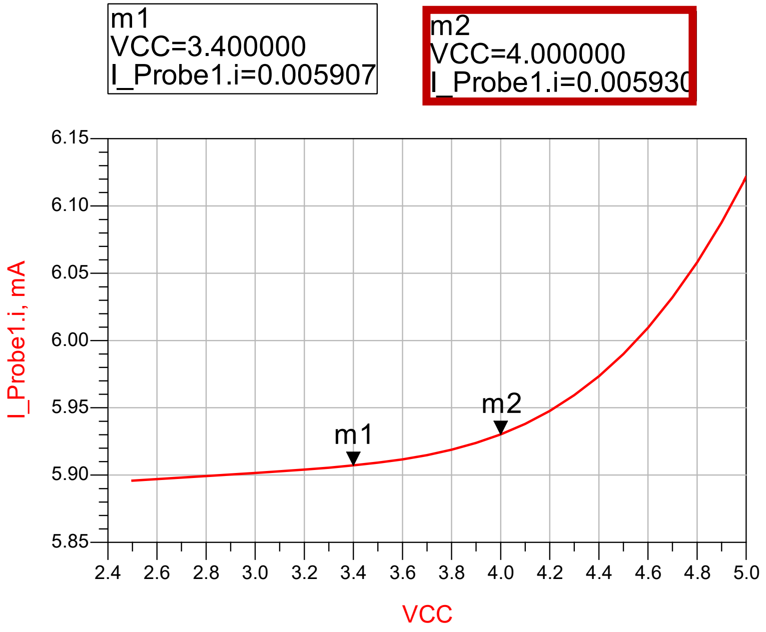
- DC Simulation

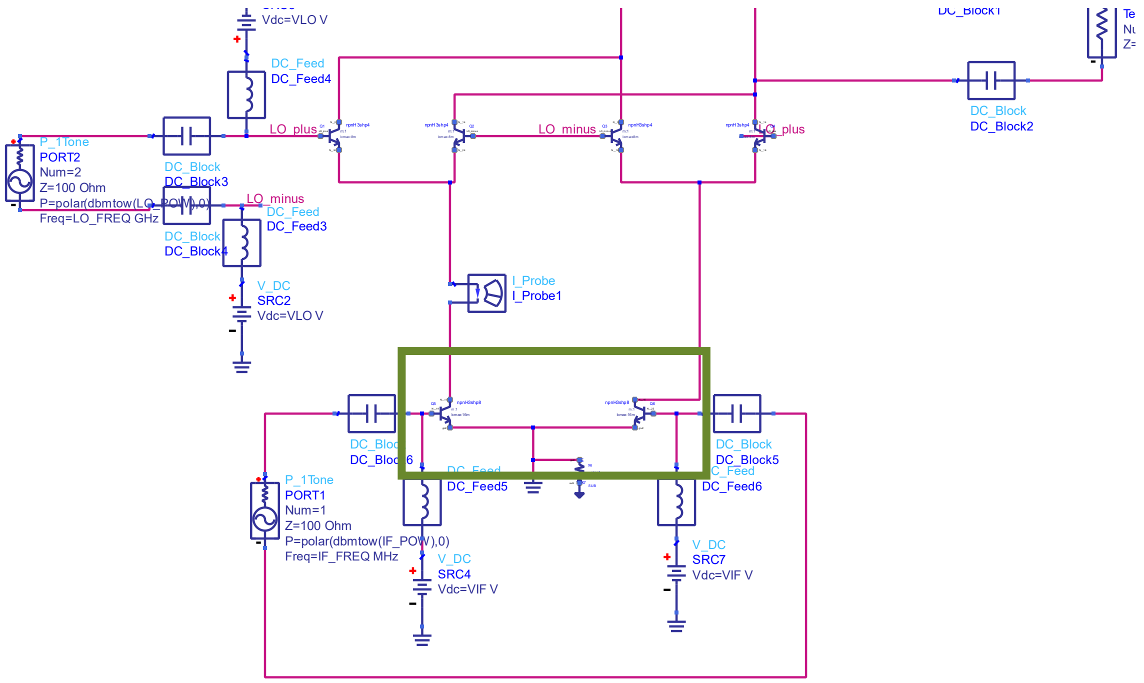


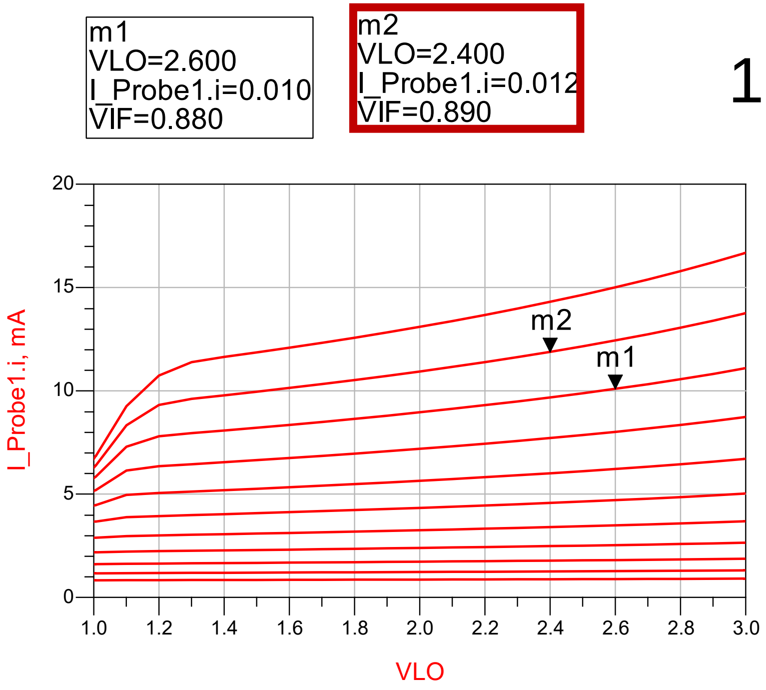


6mA

Ⅱ. – 1. Schematic View and Simulation

- DC Simulation

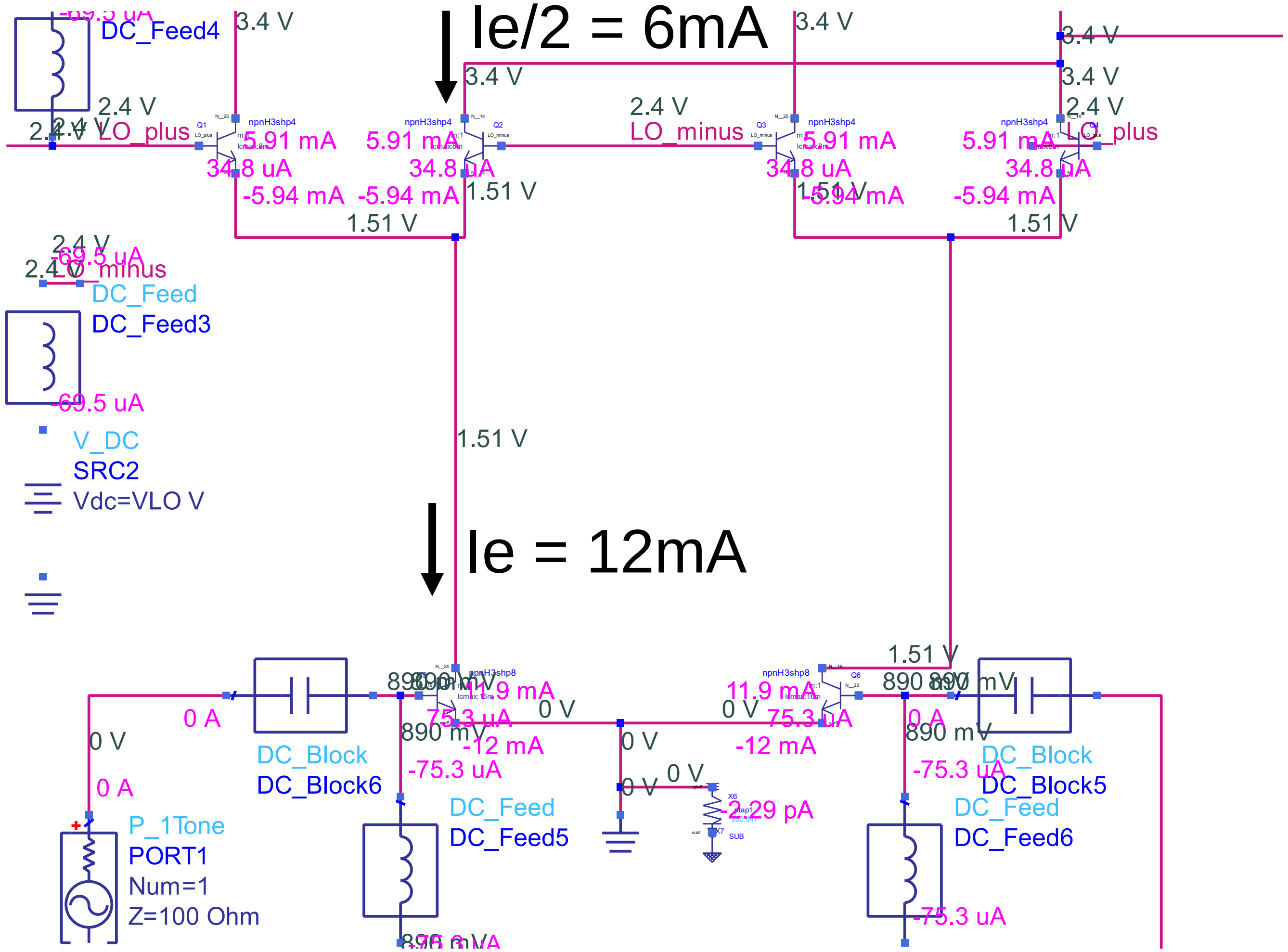




12mA

Ⅱ. – 1. Schematic View and Simulation

- DC Simulation with annotation



Ⅱ. – 1. Schematic View and Simulation

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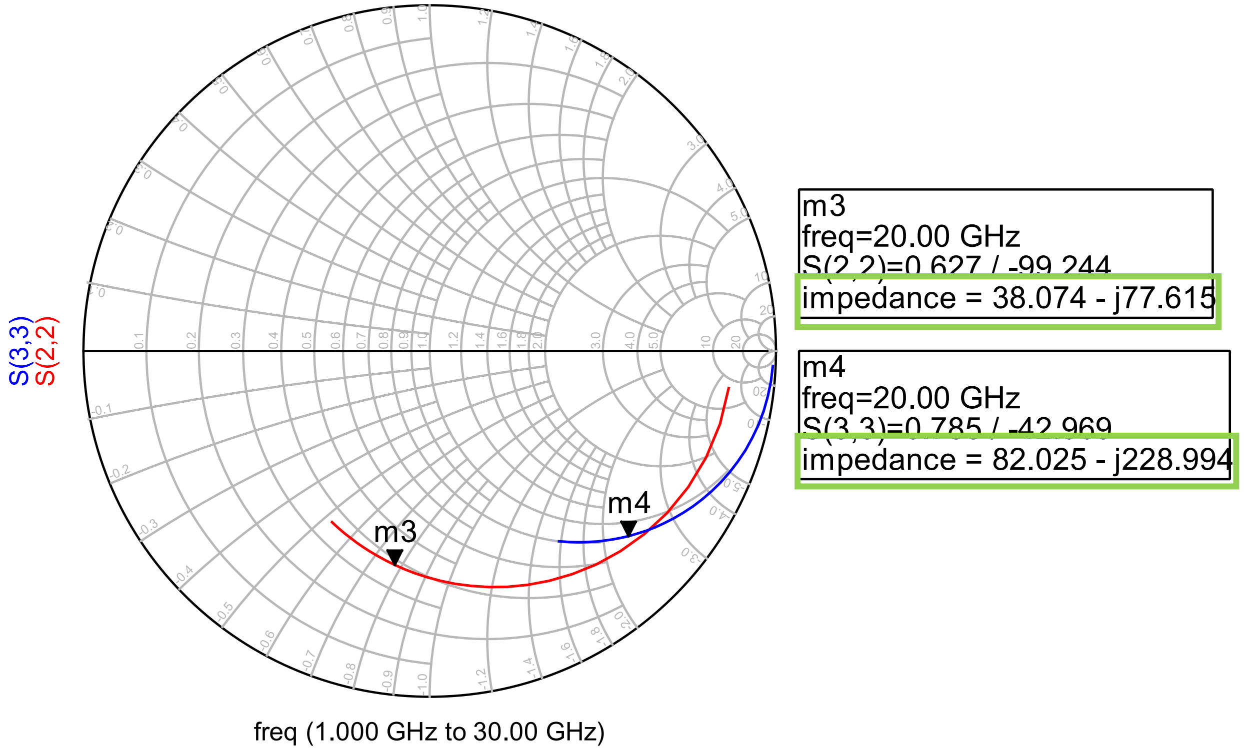
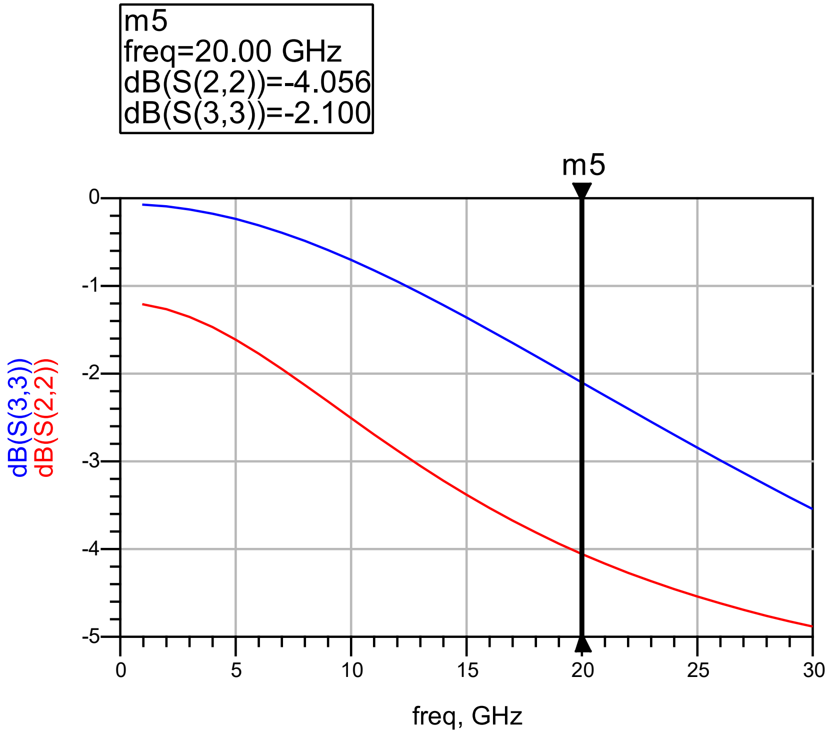
- S-parameter Simulation (Z0 = 100Ω)





Ⅱ. – 1. Schematic View and Simulation

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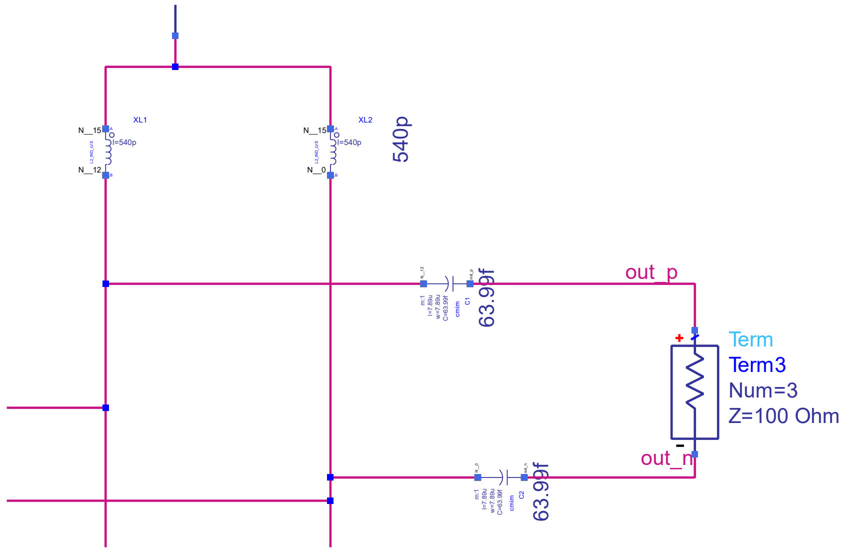
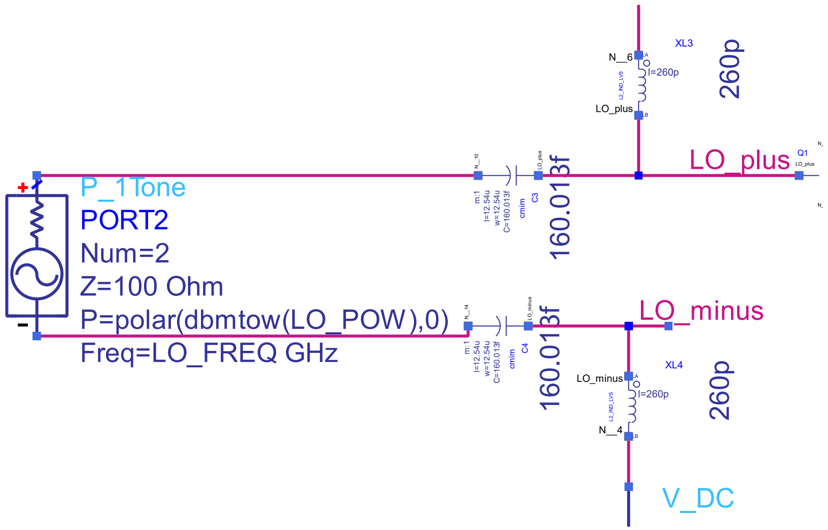
Output Matching

- (L=540pH, C=64fF)



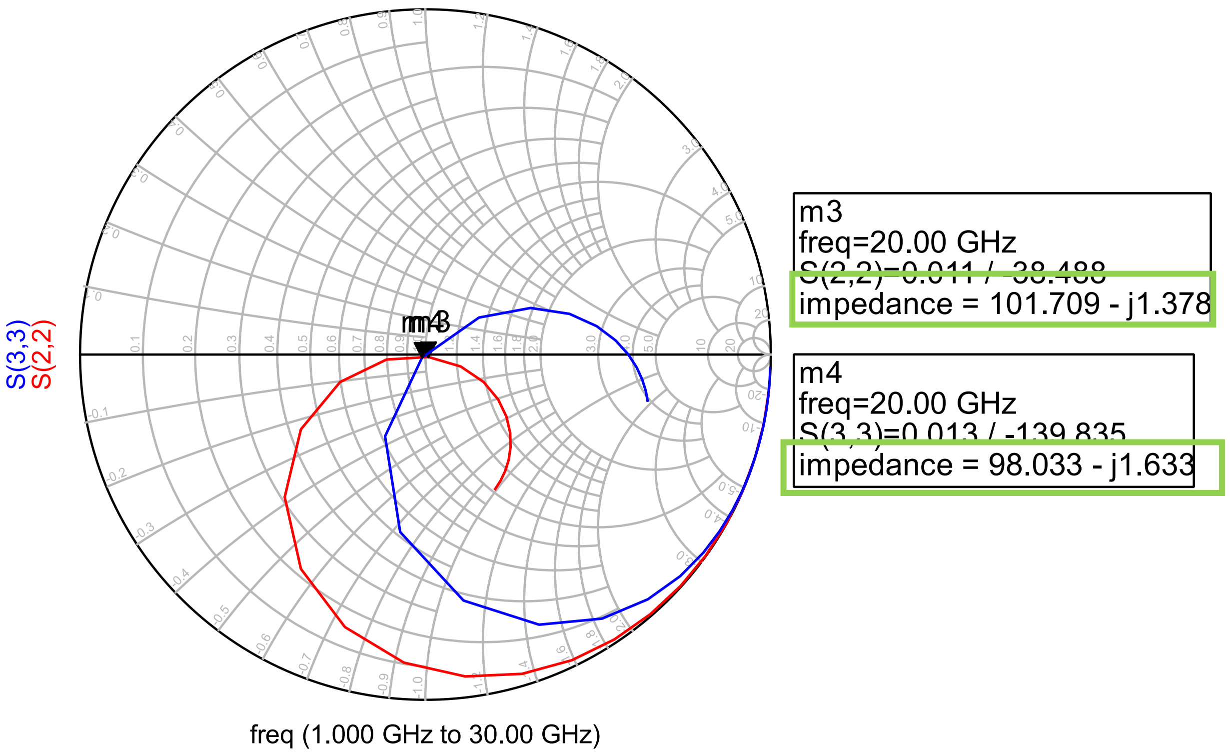
Input Matching

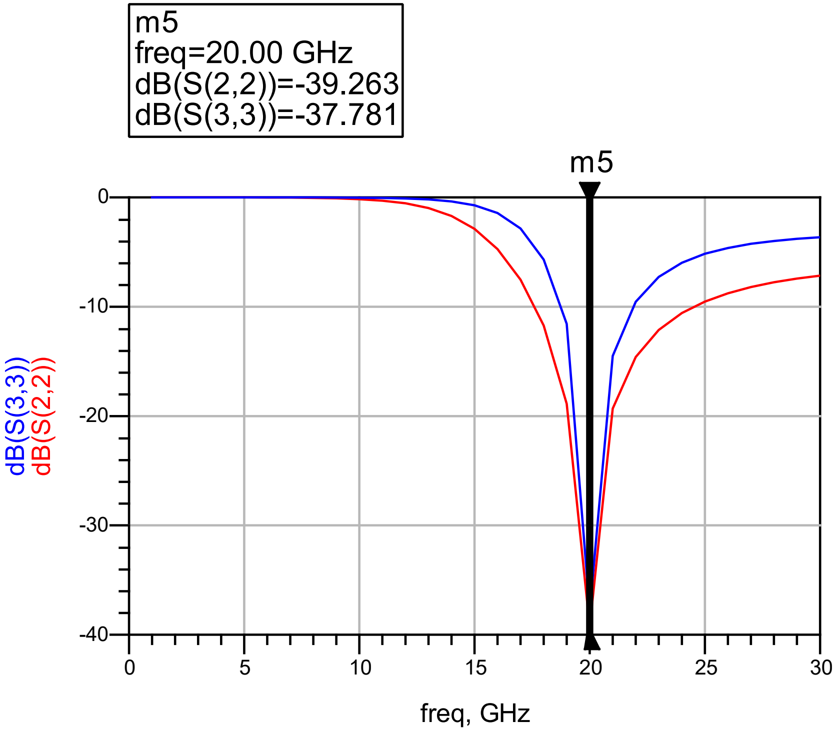
- (L=260pH, C=160fF)



Ⅱ. – 1. Schematic View and Simulation

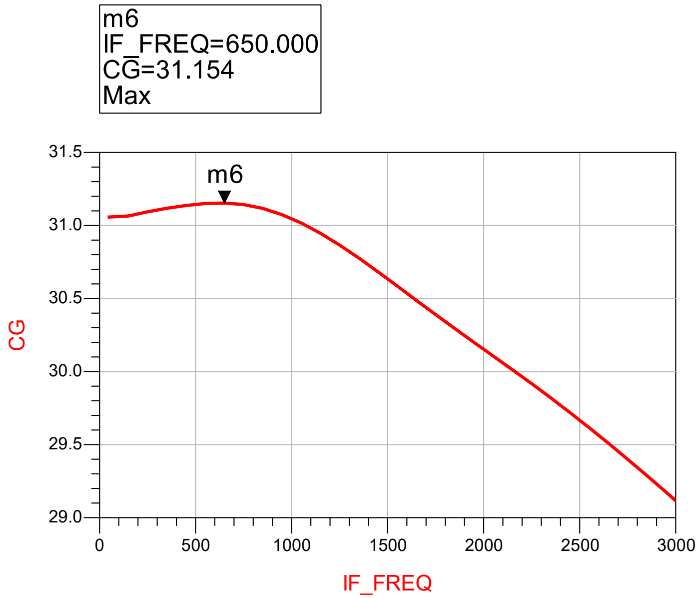
- Matched S-parameter Simulation (Z0 = 100Ω)

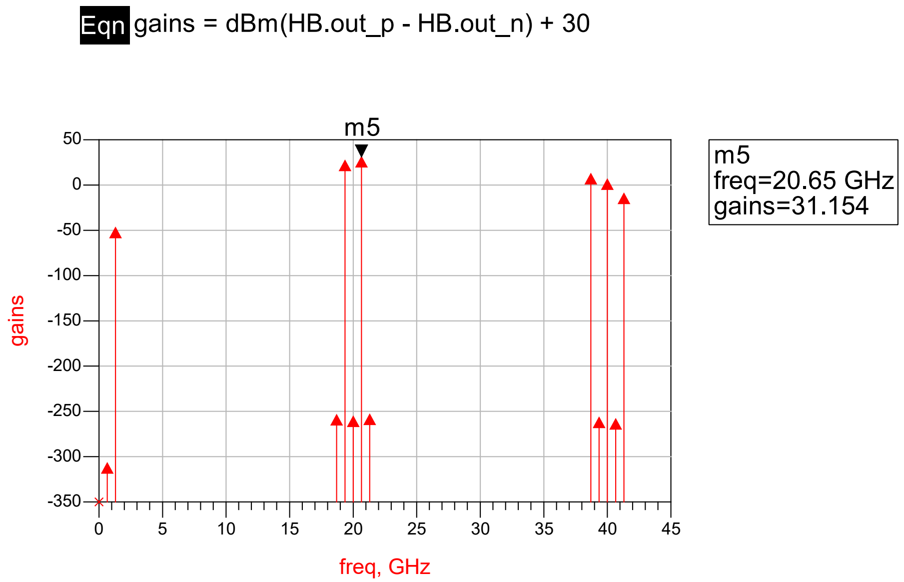




Ⅱ. – 1. Schematic View and Simulation

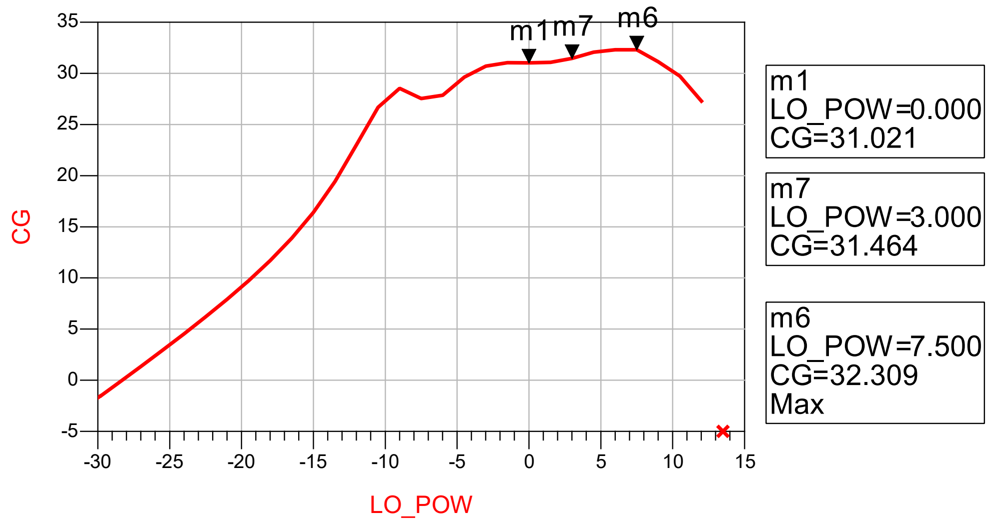
- Harmonic Balance (HB) Simulation – conversion gain vs IF frequency





Ⅱ. – 1. Schematic View and Simulation

- Harmonic Balance (HB) Simulation – conversion gain vs LO power



Ⅱ. – 1. Schematic View and Simulation

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Design goals

- 1dB compression point > 0dBm
- Gain > 10dB
- IF Bandwidth > 200MHz
- S11 < -15dB
- S22 < -15dB

Simulation Result

- 1dB compression point
- Gain= 31.154dB
- IF Bandwidth = more than 3GHz
- S11= -39.263dB
- S22= -37.781dB

Ⅱ. Design Procedure

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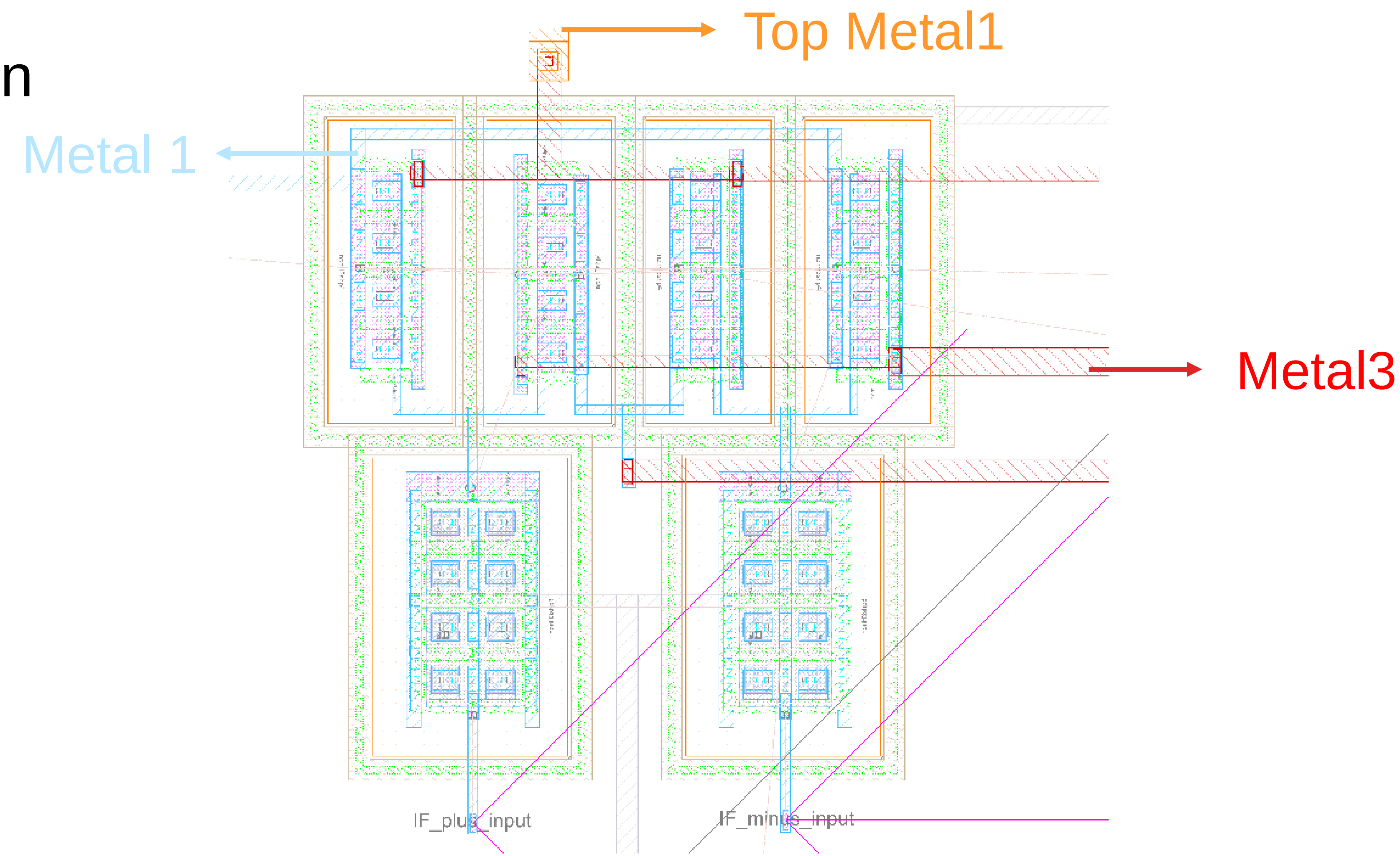
- Layout view and simulation
  - Core design
    - Core Layout & EM simulation
    - S-param simulation
    - output / input matching network
    - Design params check with HB simulation
  - Inductor Layout design (Pcell) & EM simulation
  - Mixer Layout EM simulation
    - Design params check with HB simulation

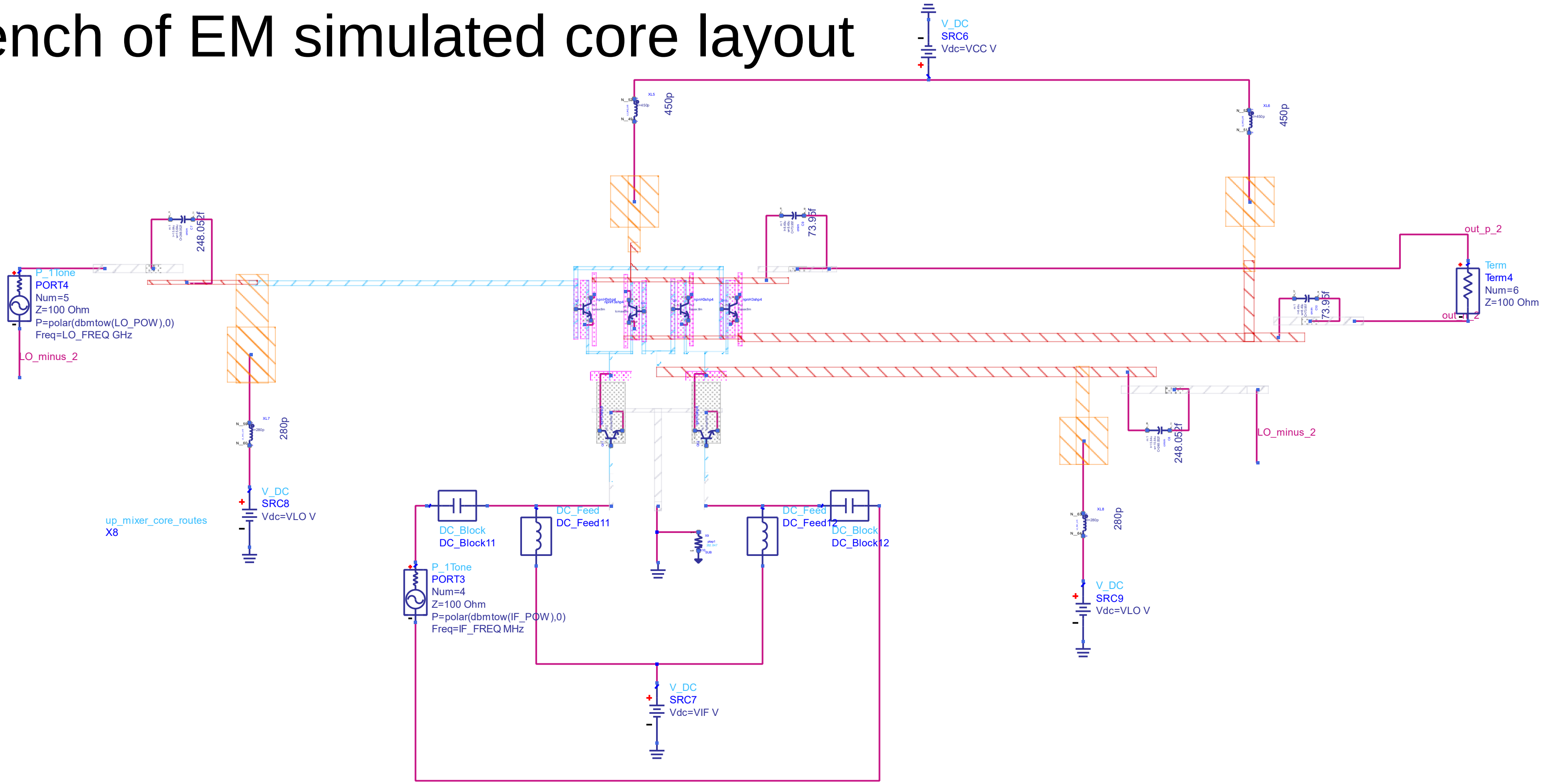
Ⅱ. – 2. Layout View and Simulation

- Core design



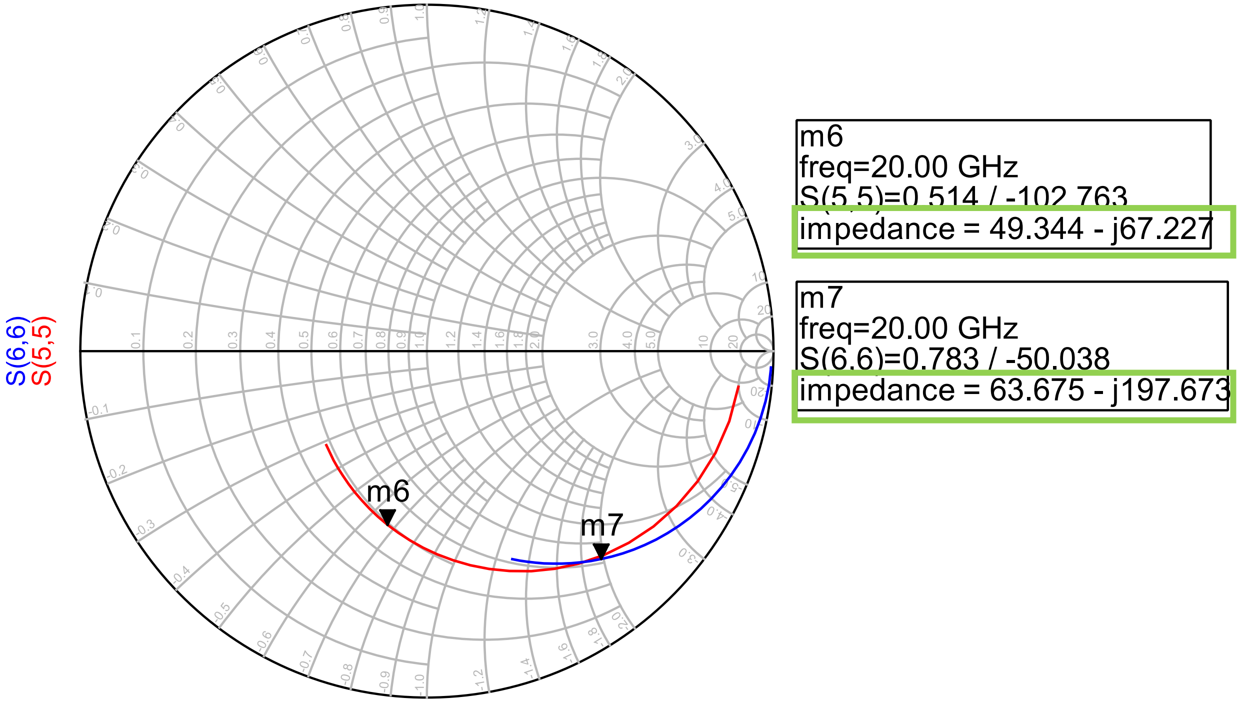
Ⅱ. – 2. Layout View and Simulation

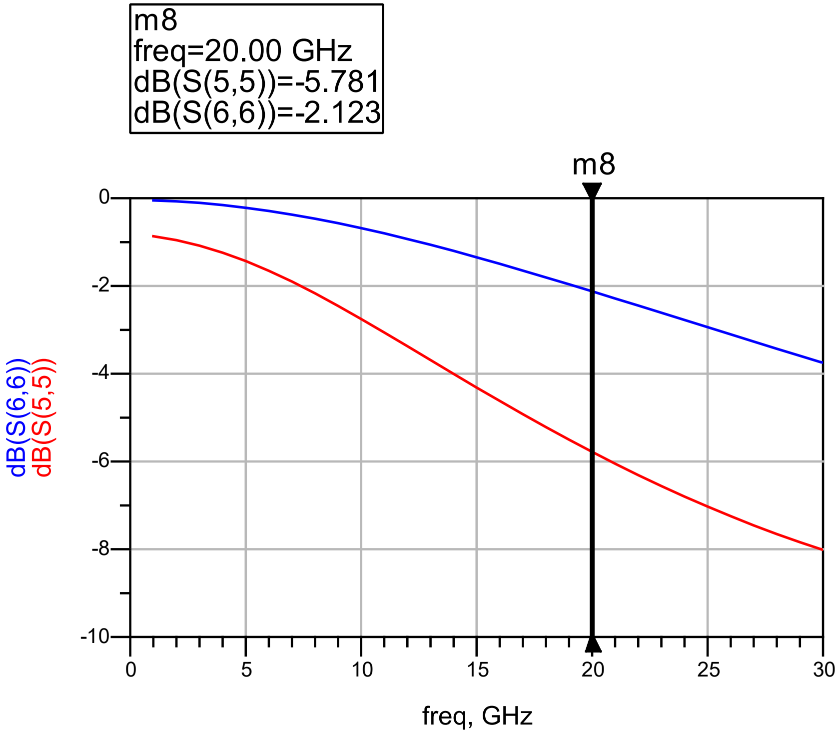
- Test bench of EM simulated core layout



Ⅱ. – 2. Layout View and Simulation

- EM simulated core – S-parameter simulation





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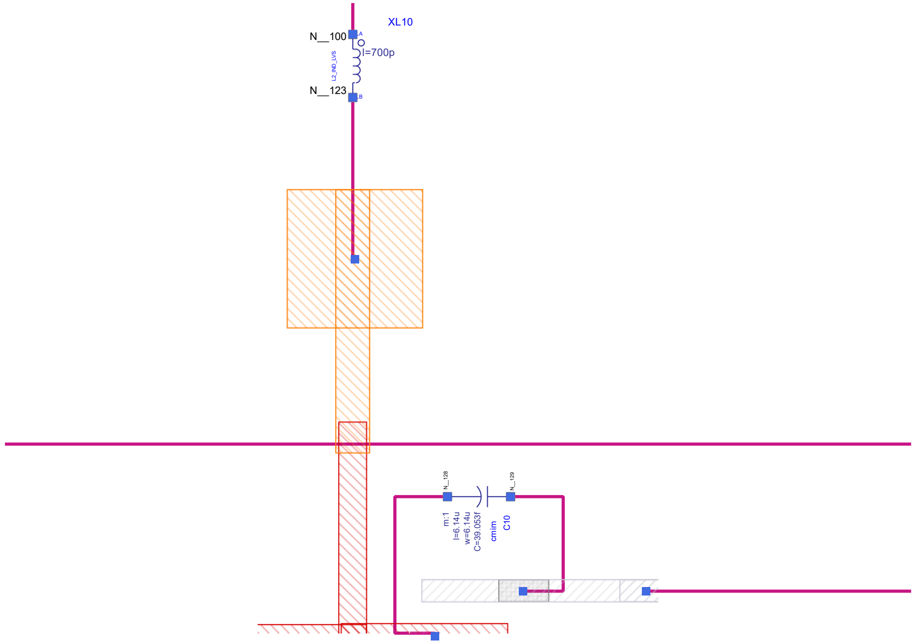
Ⅱ. – 2. Layout View and Simulation

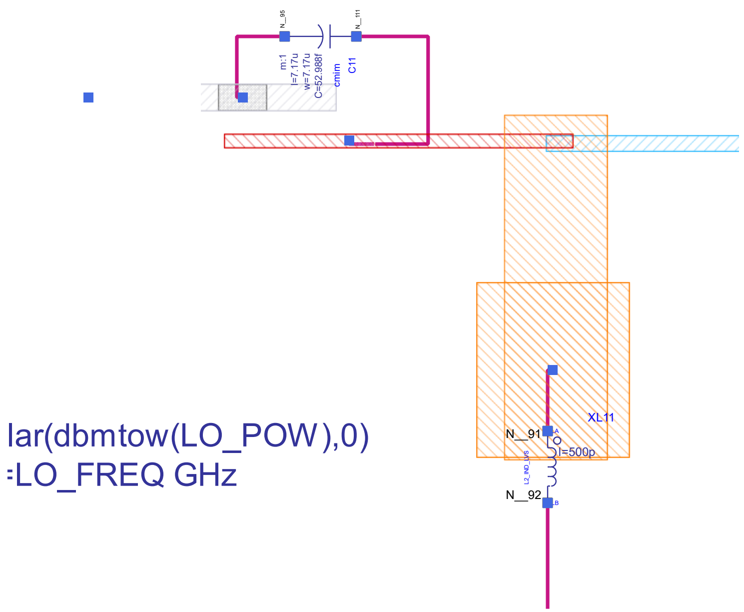
Output Matching

- (L=450pH, C=74fF)



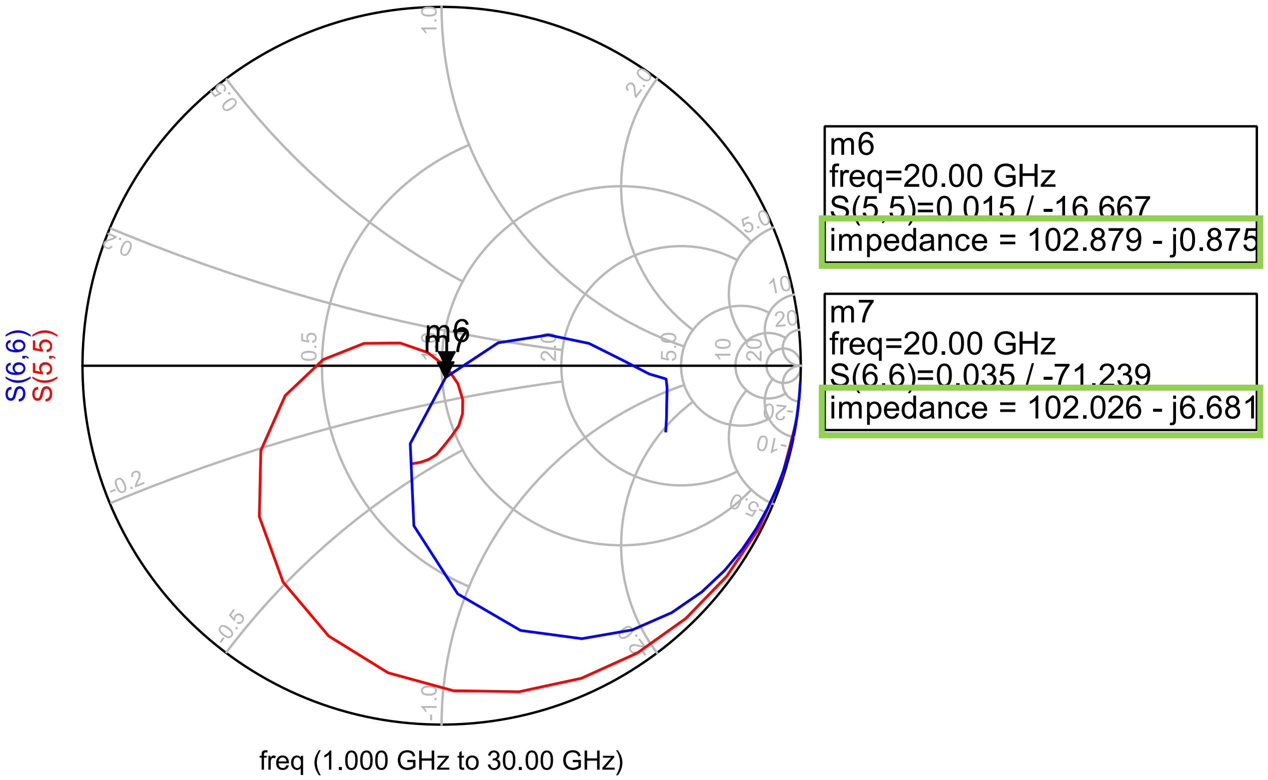
Input Matching

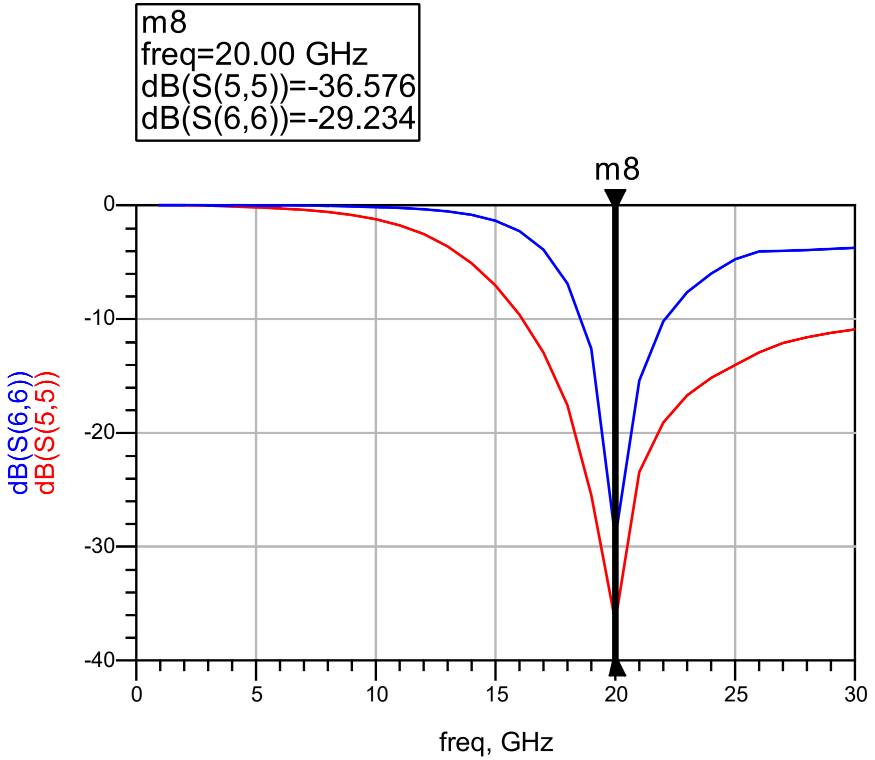
- (L=280p, C=248fF)



Ⅱ. – 2. Layout View and Simulation

- Matched S-parameter Simulation (Z0 = 100Ω)





Ⅱ. – 2. Layout View and Simulation

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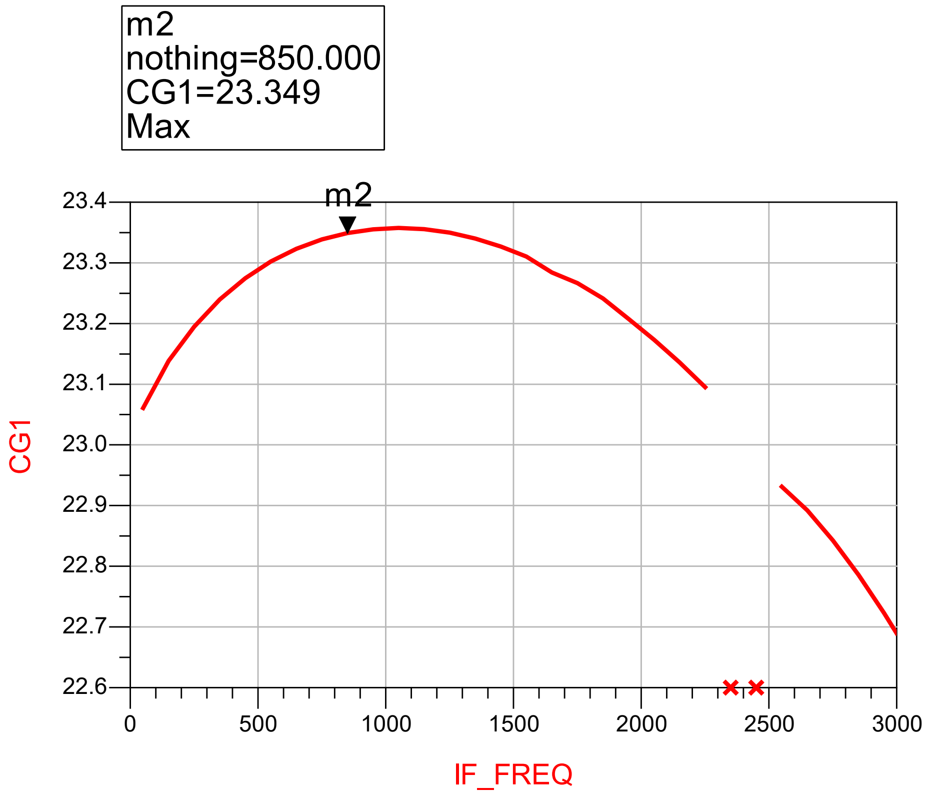
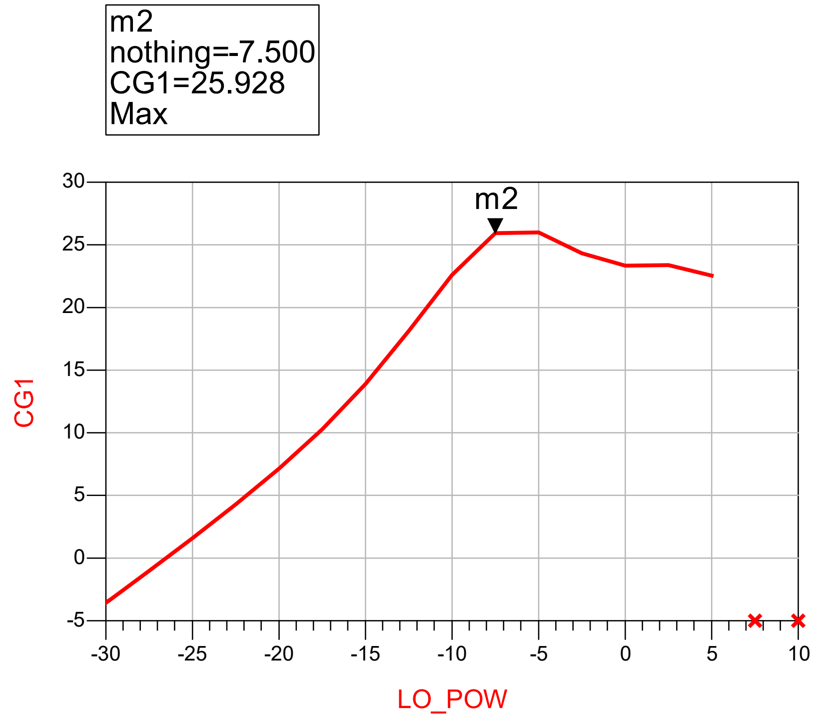
- Harmonic Balance (HB) Simulation – conversion gain vs IF frequency

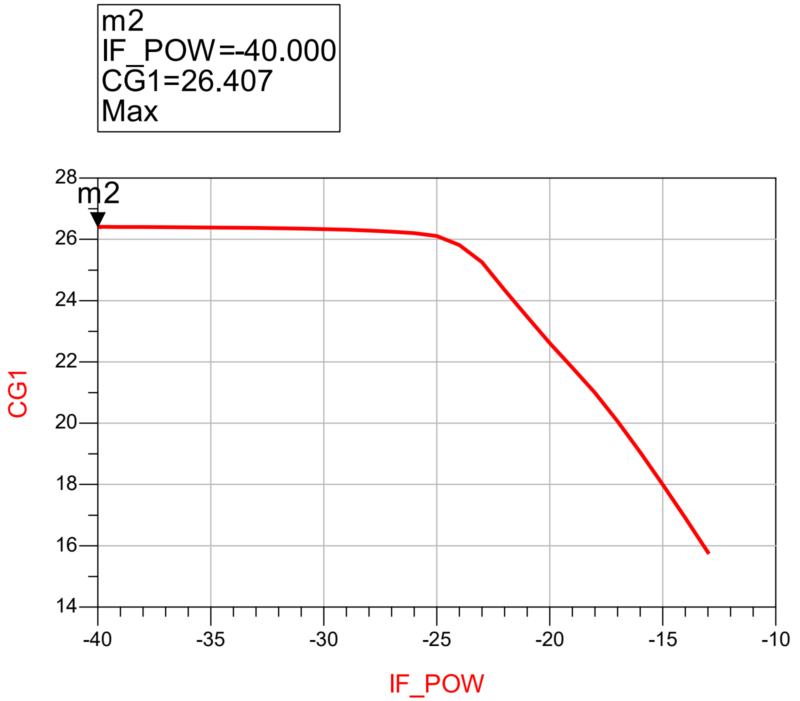


Ⅱ. – 2. Layout View and Simulation

Conversion gain vs LO power

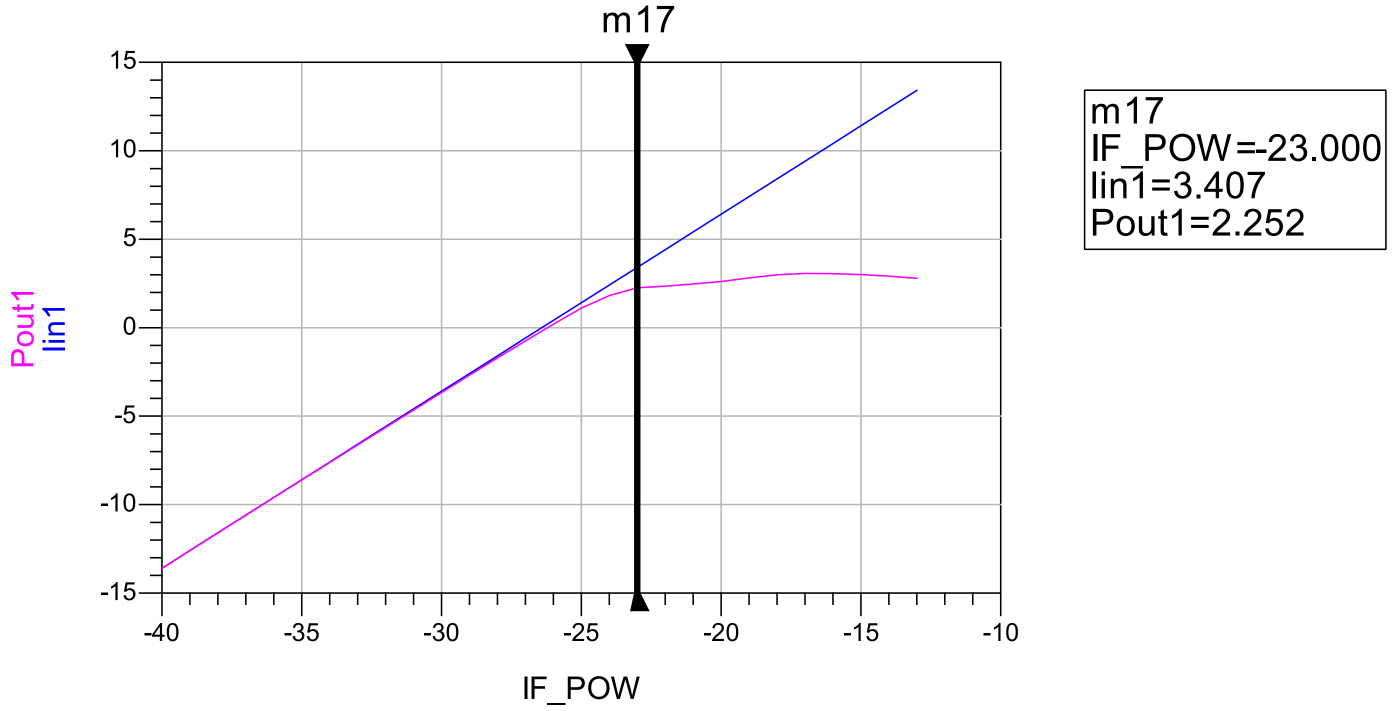


Conversion gain vs IF power



Ⅱ. – 2. Layout View and Simulation

- Harmonic Balance (HB) Simulation – 1dB compression point



Ⅱ. – 2. Layout View and Simulation

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Design goals

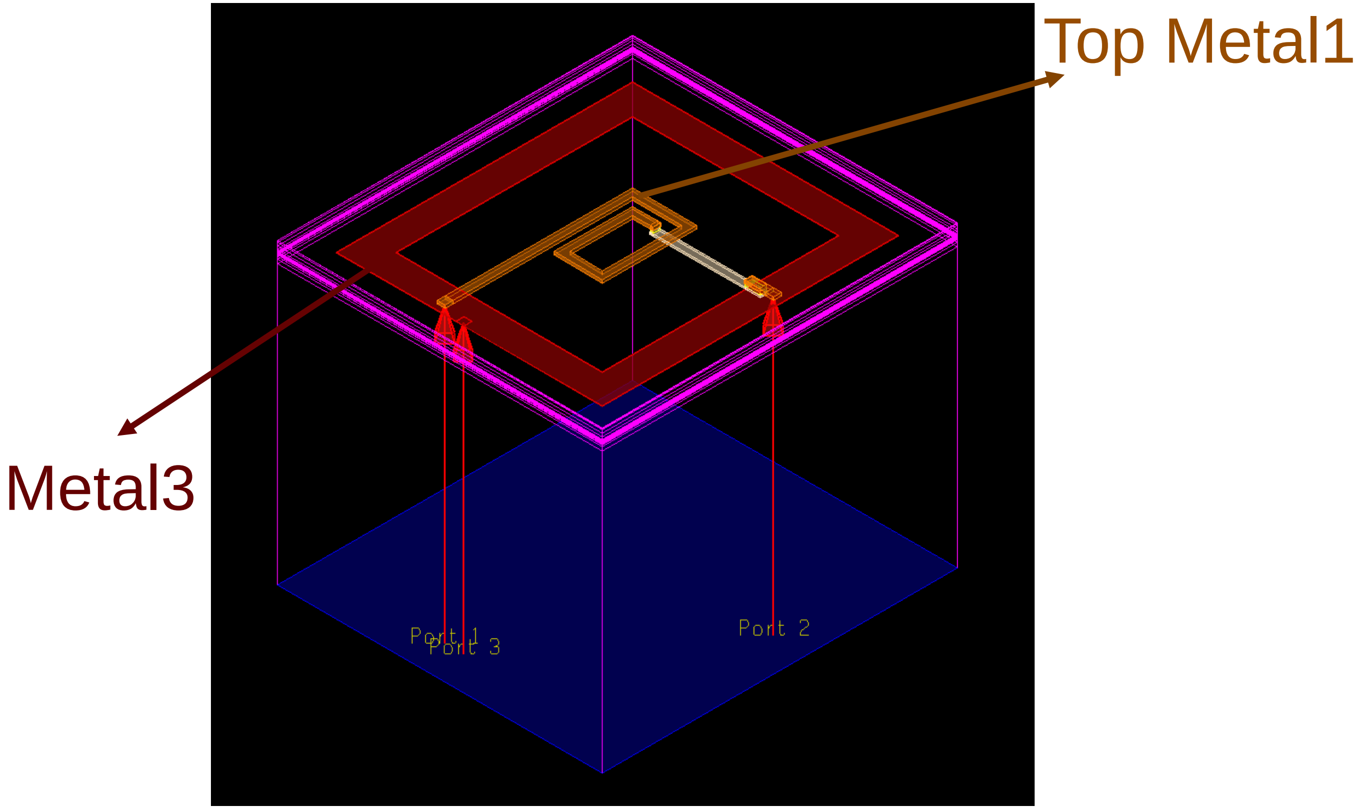
- 1dB compression point > 0dBm
- Gain > 10dB
- IF Bandwidth > 200MHz
- S11 < -15dB
- S22 < -15dB

Simulation Result

- 1dB compression point = 2.252dBm
- Gain = 23.349dB
- IF Bandwidth = more than 3GHz
- S11 = -36.576dB
- S22 = -29.234dB

Ⅱ. – 2. Layout View and Simulation

- Inductor design – LO port (L= 280.1pH with Q-factor value 17.863)



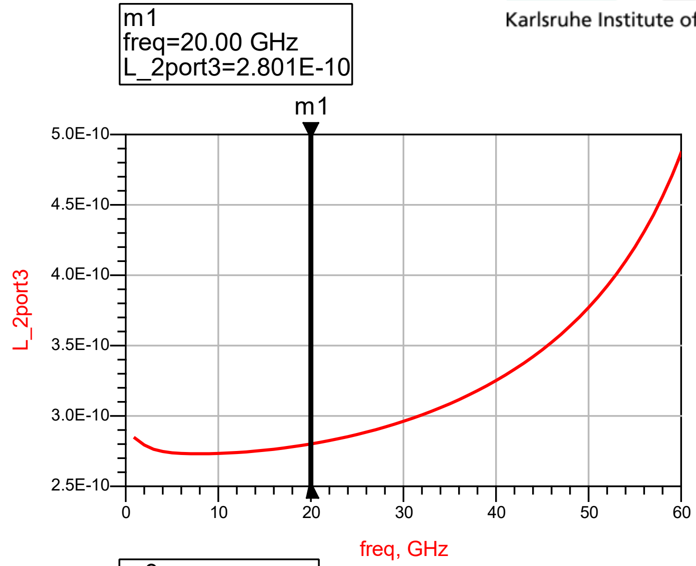
Pcell parameters defined in skill pcell IDE		
cond_width	TW(track width)	8.5u
coil_length		87u
width	ID(inner-turn diameter)	57u
sep	D(Distance between tracks)	8.5u
gnd_sep	GPS(Ground path side)	75u
gnd_size	GPW(Ground path width)	30u
turns	N (Number of turns)	1.5
coil_exit		2

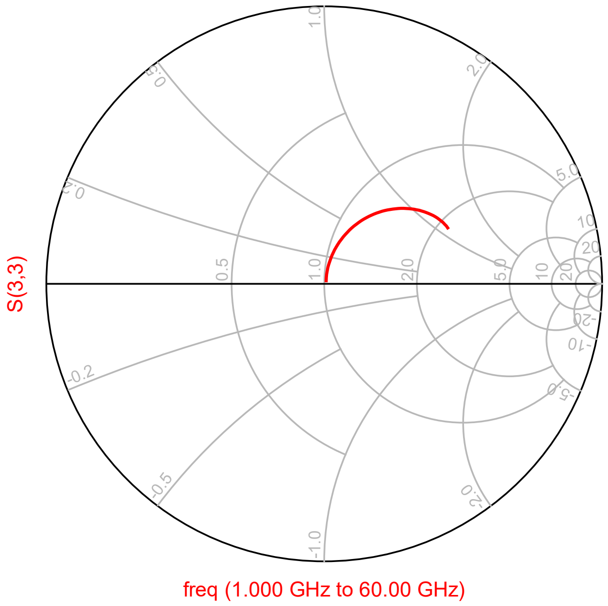
Ⅱ. – 2. Layout View and Simulation

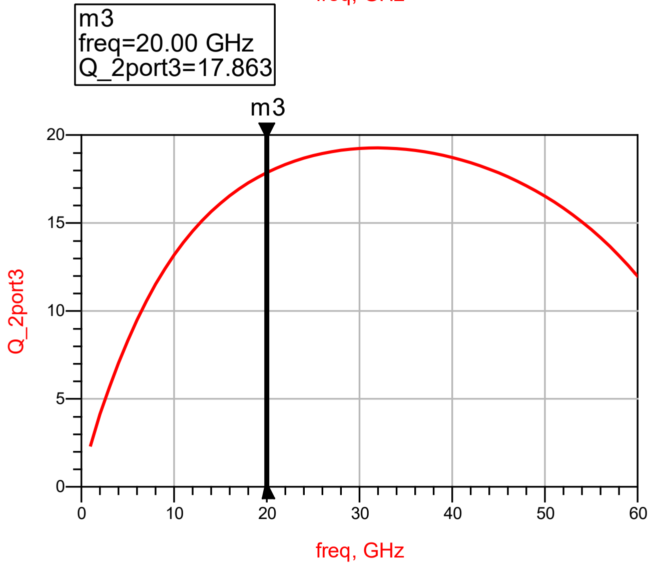
- Inductor design – LO port
  - L= 280.1pH
  - Q-factor = 17.863

Eqn L_2port3=imag(1/Y(3,3)) / omega

Eqn Q_2port3=imag(1/Y(3,3)) / real(1/Y(3,3))

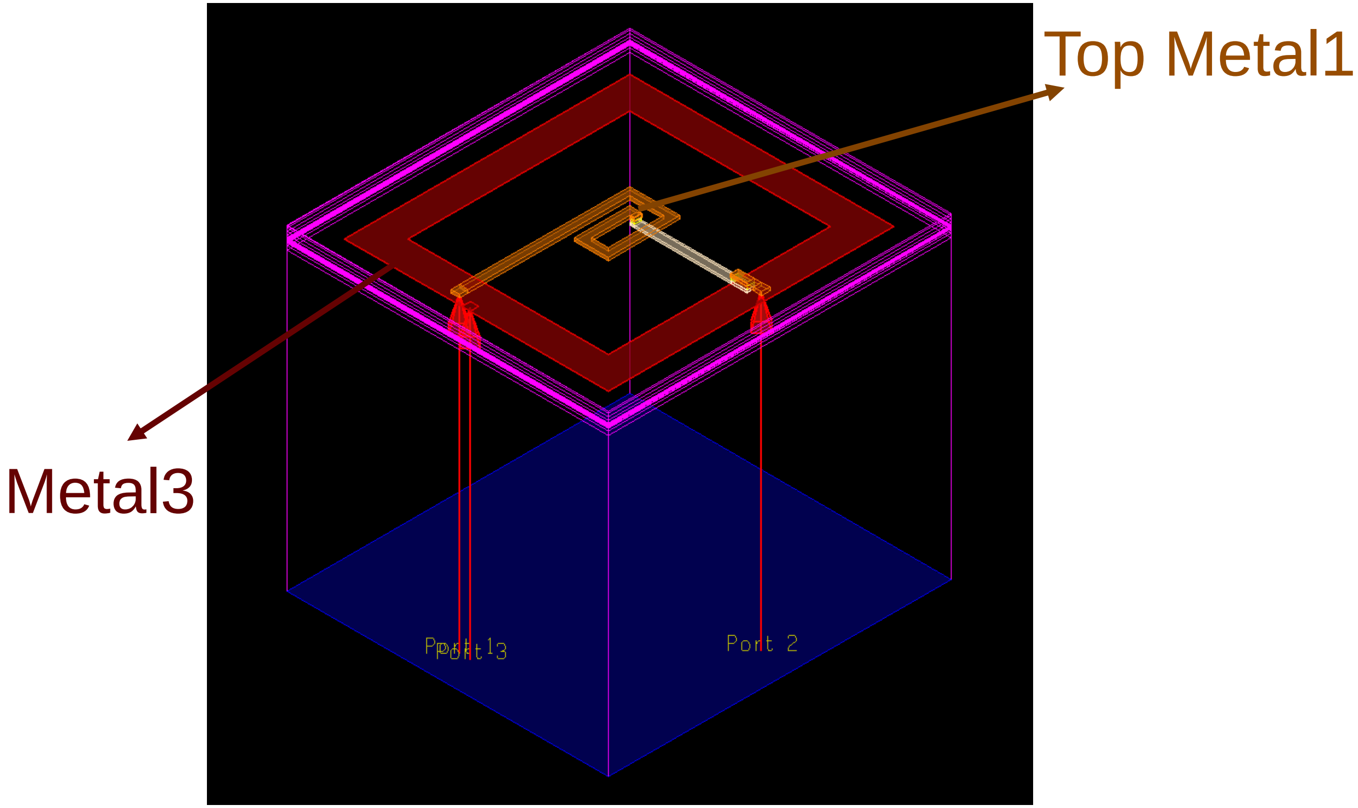






Ⅱ. – 2. Layout View and Simulation

- Inductor design – RF port (L = 422.1pH with Q-factor value 19.574)



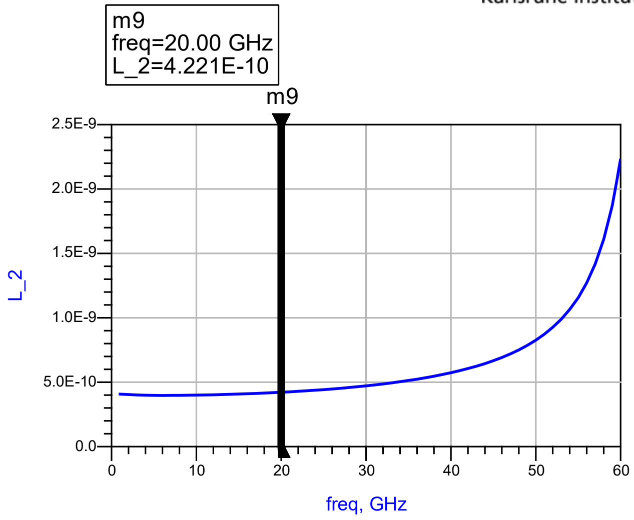
Pcell parameters defined in skill pcell IDE		
cond_width	TW(track width)	8u
coil_length		60u
width	ID(inner-turn diameter)	40u
sep	D(Distance between tracks)	8u
gnd_sep	GPS(Ground path side)	75u
gnd_size	GPW(Ground path width)	30u
turns	N (Number of turns)	1.5
coil_exit		2

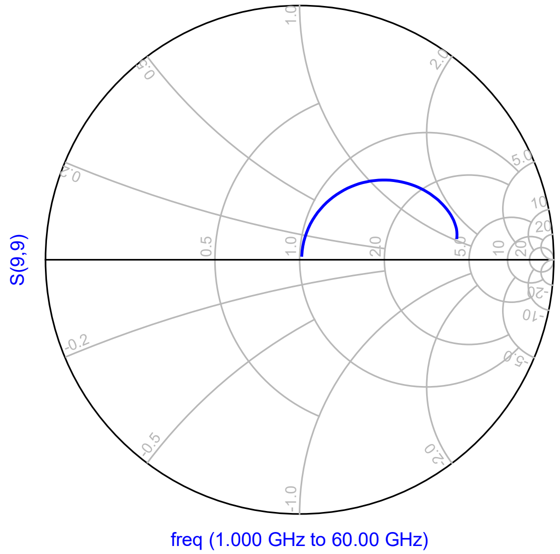
Ⅱ. – 2. Layout View and Simulation

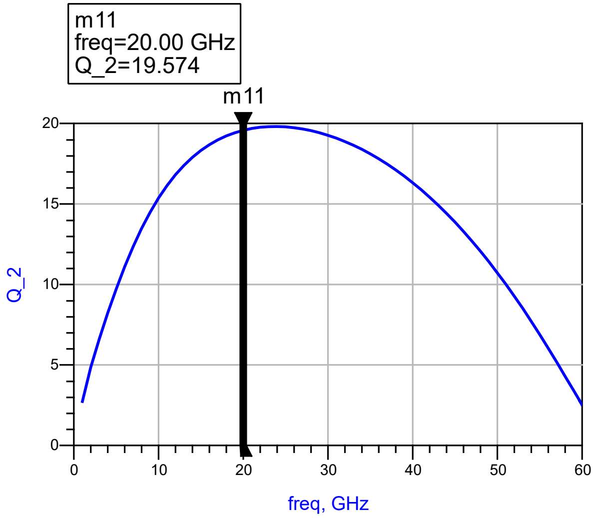
- Inductor design – LO port
  - L= 422.1pH
  - Q-factor = 19.574

Eqn L_2=imag(1/Y(9,9)) / omega

Eqn Q_2=imag(1/Y(9,9)) / real(1/Y(9,9))

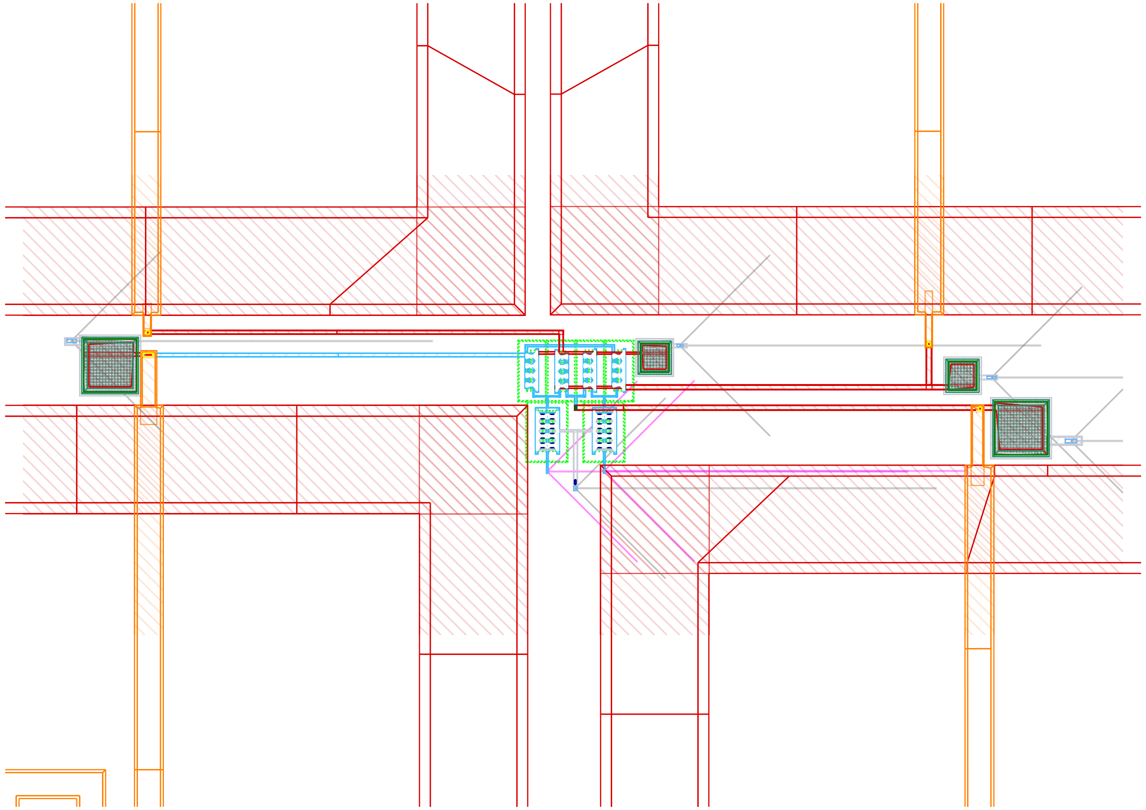


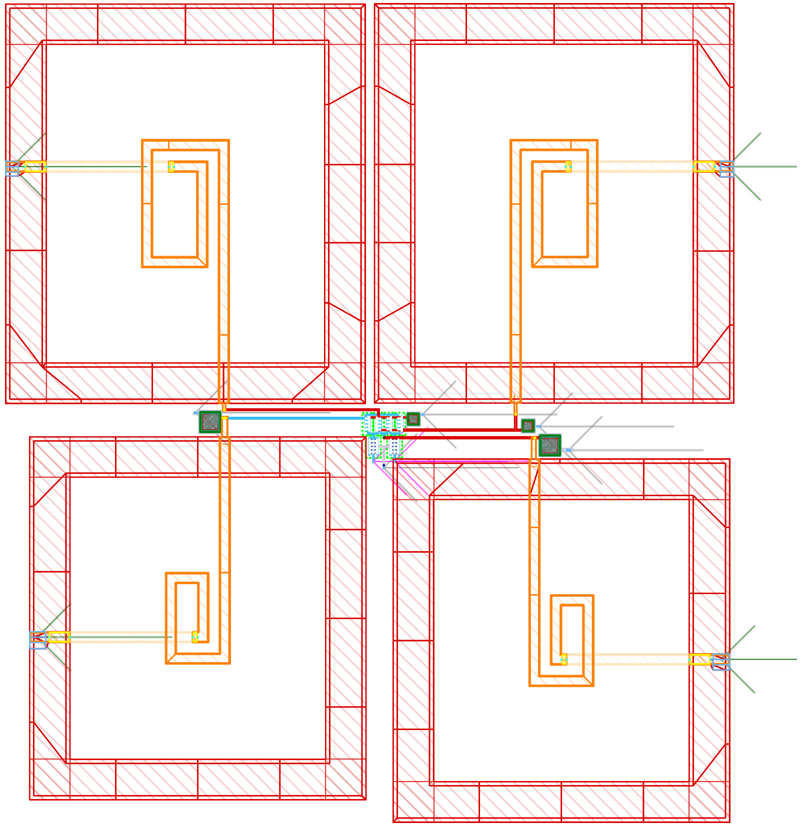




Ⅱ. – 2. Layout View and Simulation

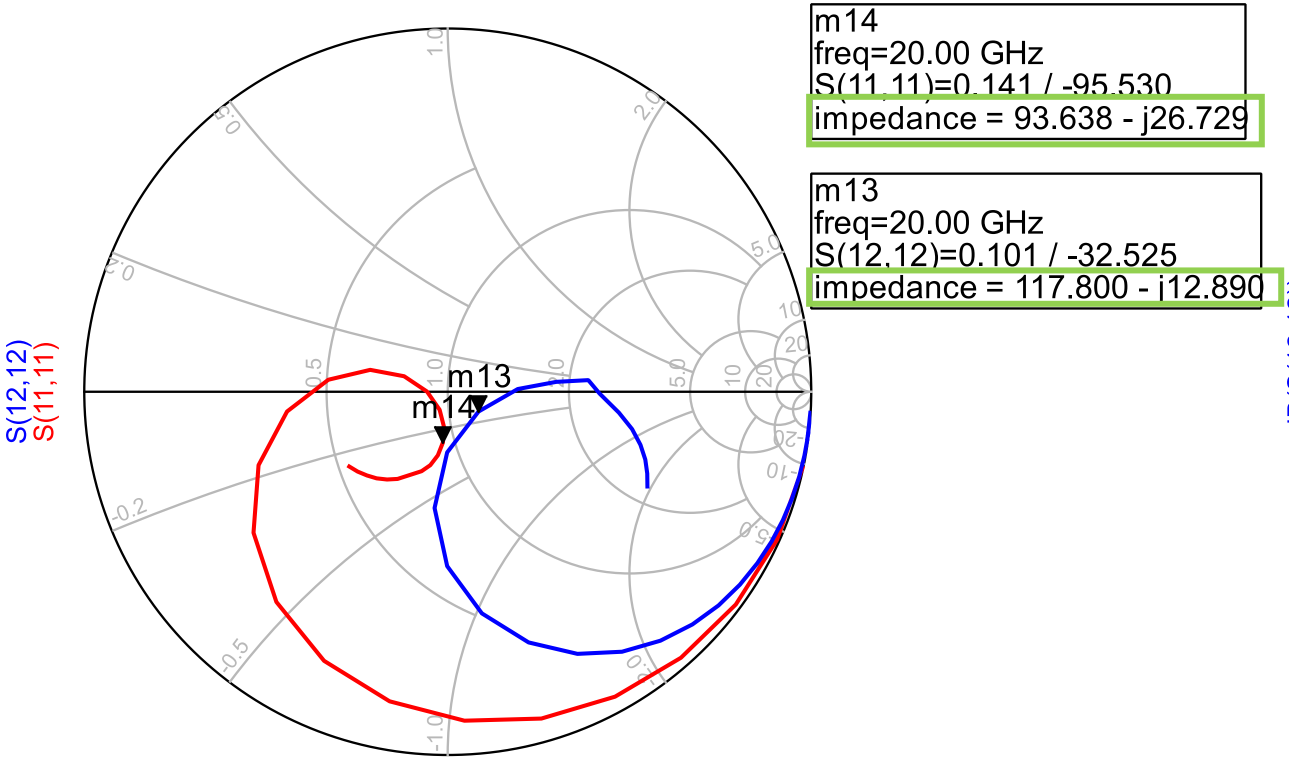
- EM simulated final layout with inductors and capacitors

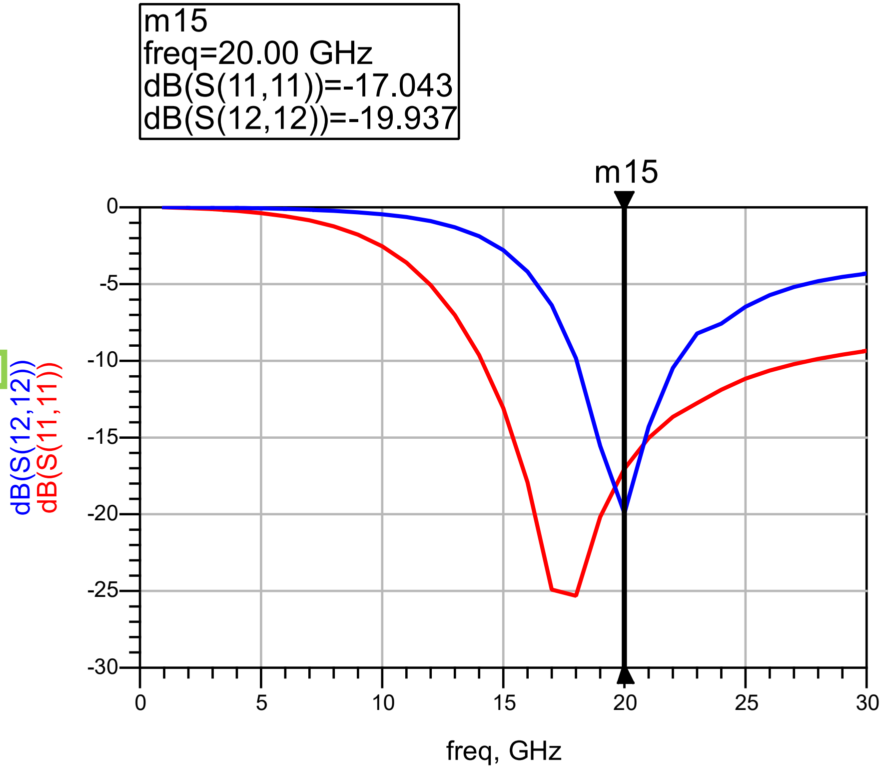




Ⅱ. – 2. Layout View and Simulation

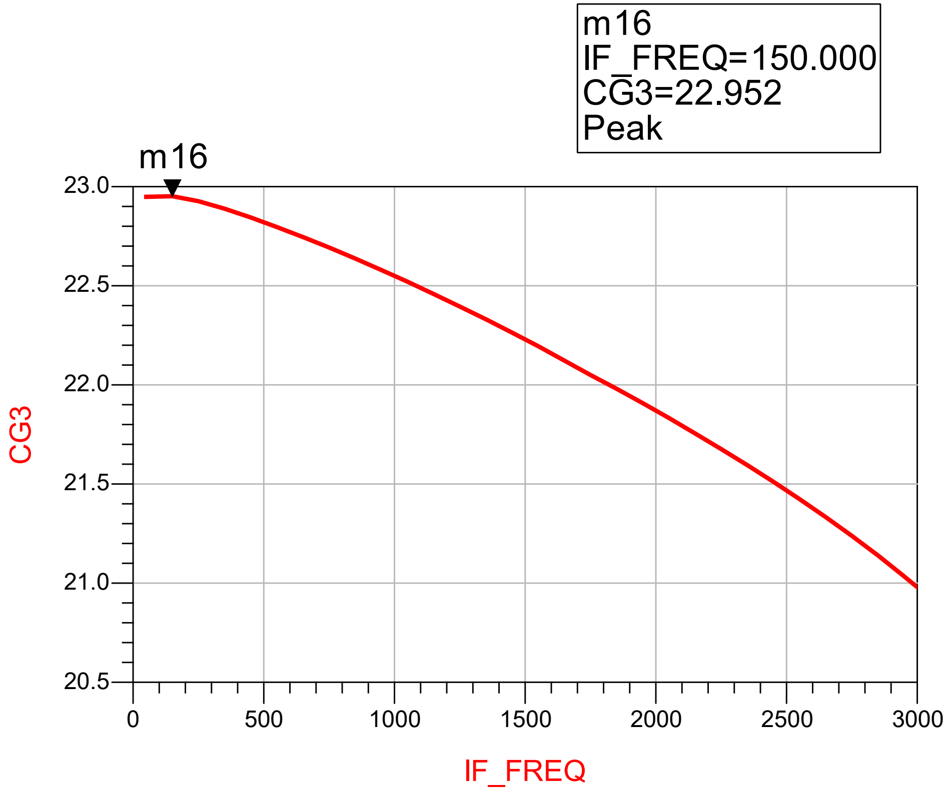
- S-parameter simulation





Ⅱ. – 2. Layout View and Simulation

- Harmonic Balance (HB) Simulation – conversion gain vs IF frequency



Ⅱ. – 2. Layout View and Simulation

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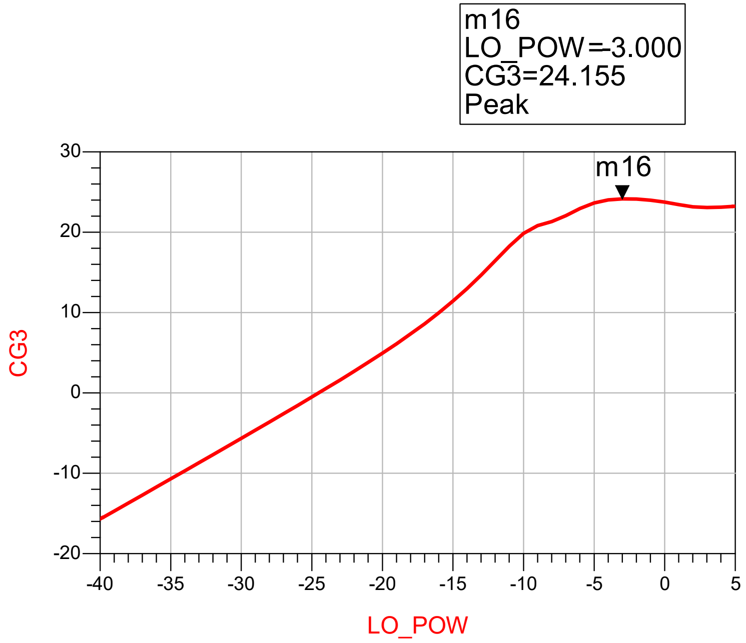
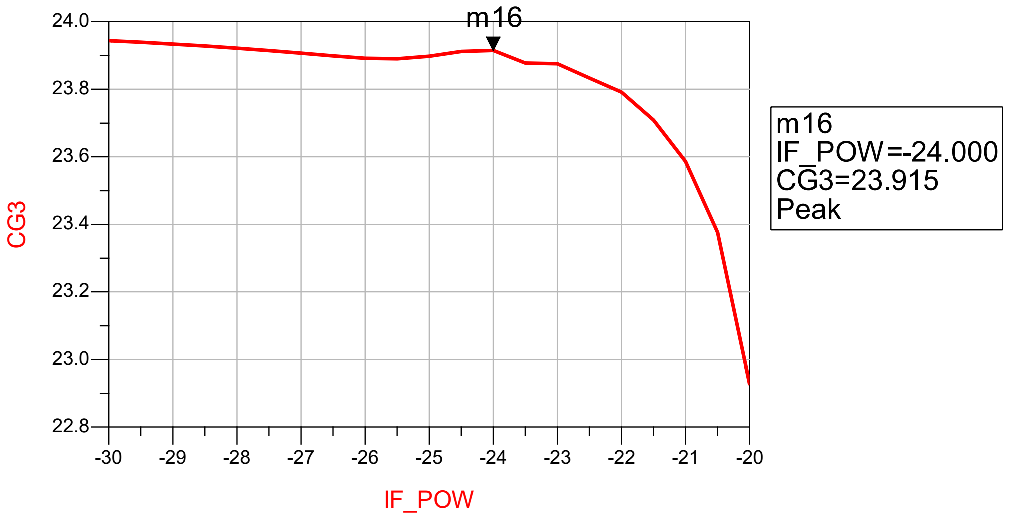
Conversion gain vs LO power

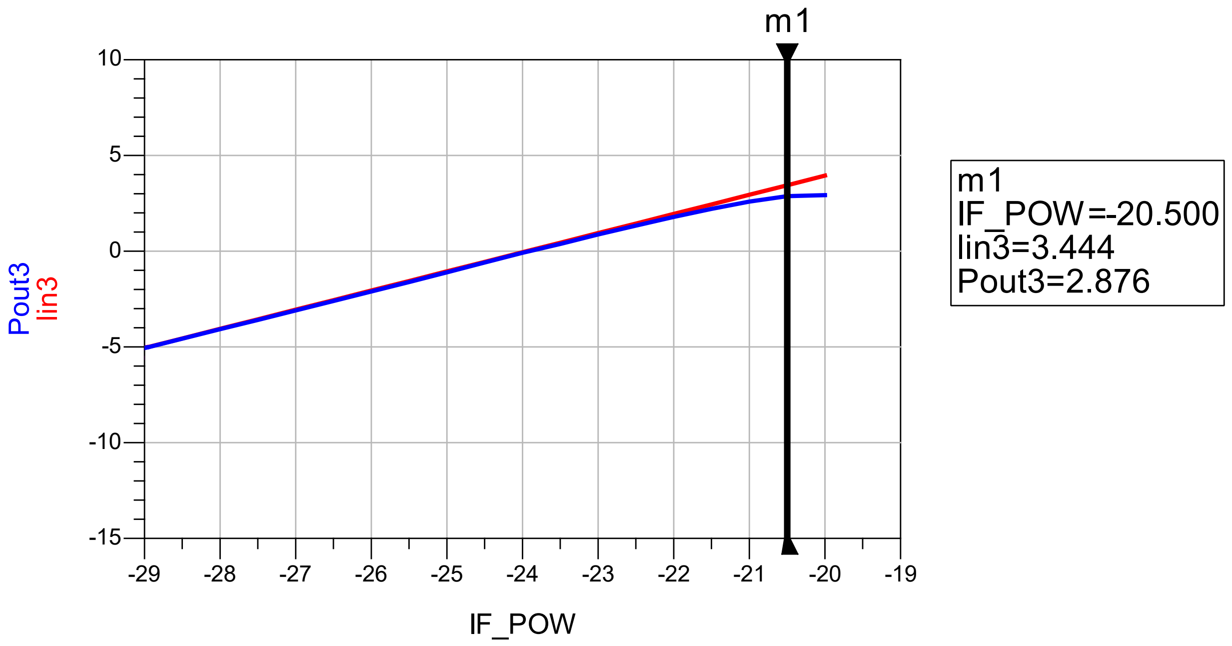


Conversion gain vs IF power



Ⅱ. – 2. Layout View and Simulation

- Harmonic Balance (HB) Simulation – 1dB compression point



Ⅱ. – 2. Layout View and Simulation

Design goals

- 1dB compression point > 0dBm
- Gain > 10dB
- IF Bandwidth > 200MHz
- S11 < -15dB
- S22 < -15dB

Simulation Result

- 1dB compression point = 2.876dBm
- Gain = 22.952dB
- IF Bandwidth = more than 3GHz
- S11 = -17.043dB
- S22 = -19.937dB

Ⅲ. Conclusion

- IF frequency = 150MHz , LO frequency= 20GHz, RF frequency = 20.15GHz, BW > 3GHz
- Application
  - Broadband application
    - High quality
    - Large amount of data transmission

Ⅲ. Conclusion

- RF frequency = 20.15GHz
- Application
  - SHF band
    - Modern communications technologies
    - modern radars
    - DTH services
    - 5GHz Wi-Fi channel
    - radio astronomy
    - mobile networks
    - TV broadcasting satellites
    - microwave devices
    - broadcasting satellites
    - amateur radio

Frequency Band	ITU band number	Frequency
Extremely low frequency (ELF)	1	3 Hz-30 Hz
Super low frequency (SLF)	2	30 Hz-300 Hz
Ultra low frequency (ULF)	3	300 Hz-3 kHz
Very low frequency (VLF)	4	3–30 kHz
Low frequency (LF)	5	30–300 kHz
Medium frequency (MF)	6	300–3,000 kHz
High frequency (HF)	7	3–30 MHz
Very high frequency (VHF)	8	30–300 MHz
Ultra high frequency (UHF)	9	300–3,000 MHz
Super high frequency (SHF)	10	3–30 GHz
Extremely high frequency (EHF)	11	30–300 GHz
Terahertz or tremendously high frequency (THF)	12	300–3,000 GHz

ITU classification of frequency bands (https://resources.pcb.cadence.com/blog/2022-an-overview-of-frequency-bands-and-their-applications)

Ⅲ. Conclusion

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- RF frequency = 20.15GHz
- Application
  - K-band(Radar waves)
    - police radars operate in USA
    - short-range communication
      - automatic door openers
      - collision avoidance systems
      - blind spot monitoring systems in vehicles
  - K-band MMIC
    - local-multipoint distribution services (LMDS)
    - digital point-to-point radio services
    - fixed satellites

Frequency	Band designation
3-30 MHz	HF
30-300 MHz	VHF
300-1000 MHz	ULF
1-2 GHz	L
2-4 GHz	S
4-8 GHz	C
8-12 GHz	X
12-18 GHz	Ku
$\boxed{\text{18-27 GHz}}$	$\boxed{\text{K}}$
27–40 GHz	Ka
40-75 GHz	V
75-110 GHz	W
110 -300 GHz	mm or G

IEEE classifications of frequency bands(https://resources.pcb.cadence.com/blog/2022-an-overview-of-frequency-bands-and-their-applications)