Self-Mixing Amplifier for CW Sensors

Master thesis presentation

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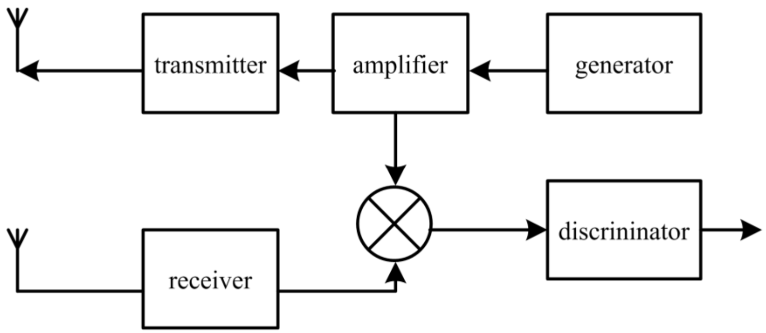
- Motivation
- 10 MHz Single Stage Amplifier Analysis
- Design and Measurement of 10 GHz Self-Mixing Amplifier
- Conclusion

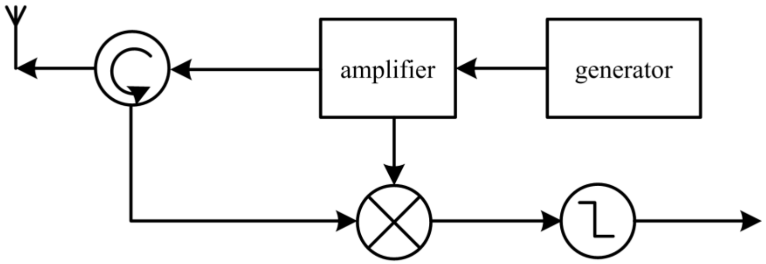
Motivation

- Background
- Nonlinear Fundamentals
- Mixer Fundamentals

Motivation - Background

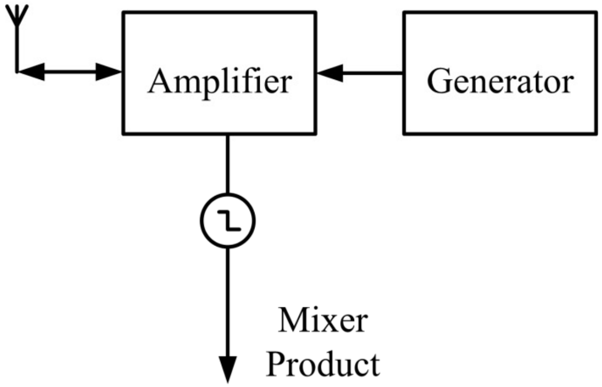
- CW Sensor
- Traditional transmitter and receiver designs

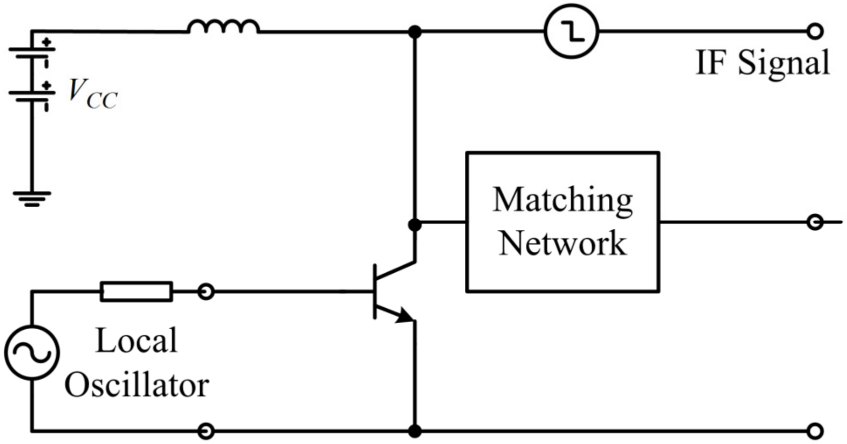




Motivation - Background

- **New concept**





Motivation – Nonlinear Fundamentals

- Nonlinear network analysis

$$v_{out} = a_0 + a_1 v_{in} + a_2 v_{in}^2 + a_3 v_{in}^3 + \ldots$$

$$a_0 = v_{out}(0)$$

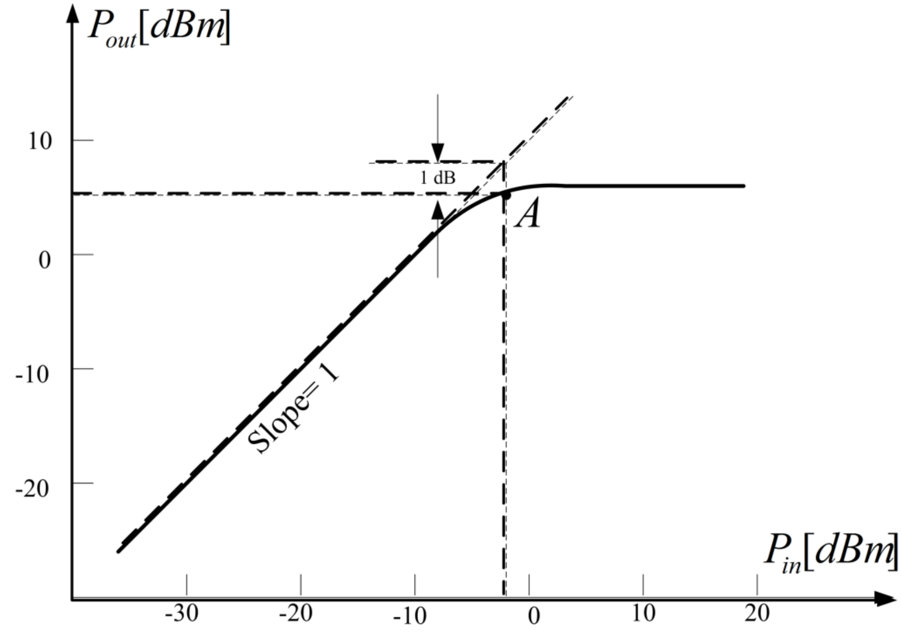
$$a_1 = \left.\frac{dv_{out}}{dv_{in}}\right|_{v_{in}=0} \qquad a_2 = \left.\frac{d^2 v_{out}}{dv_{in}^2}\right|_{v_{in}=0} \qquad a_3 = \left.\frac{d^3 v_{out}}{dv_{in}^3}\right|_{v_{in}=0}$$

If $v_{in} = V_0 \cos\omega_0 t$, the output voltage is

$$v_{out} = (a_0 + \frac{1}{2} a_2 V_0^2) + (a_1 V_0 + \frac{3}{4} a_3 V_0^3)\cos\omega_0 t + \frac{1}{2} a_2 V_0^2 \cos 2\omega_0 t + \ldots$$

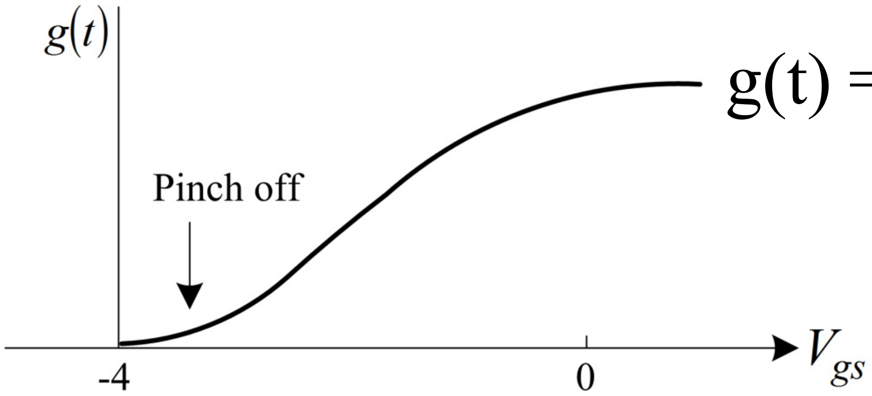
Motivation – Nonlinear Fundamentals

- Voltage gain (retained to the third order) $G_v = a_1 + \frac{3}{4} a_3 V_0^{\ 2}$
- 1 dB-Compression Point



Motivation – Mixer Fundamentals

- Down conversion $$f_{IF} = f_{RF} - f_{LO}$$
- Conversion Loss $$L_c = 10\log\frac{P_{RF}}{P_{IF}} > 0\text{dB}$$
- Variation of FET Output Conductance



$$g(t) = g_0 + 2\sum_{n=1}^{\infty} g_n \cos n\omega_{LO}\, t$$

Motivation – Mixer Fundamentals

- Drain current

$$i(t) = g(t)\, v_{RF}(t) = V_{RF}\,[g_0 \cos\omega_{RF} t + 2\sum_{n=1}^{\infty} g_n \cos n\omega_{LO} t \cos\omega_{RF} t]$$

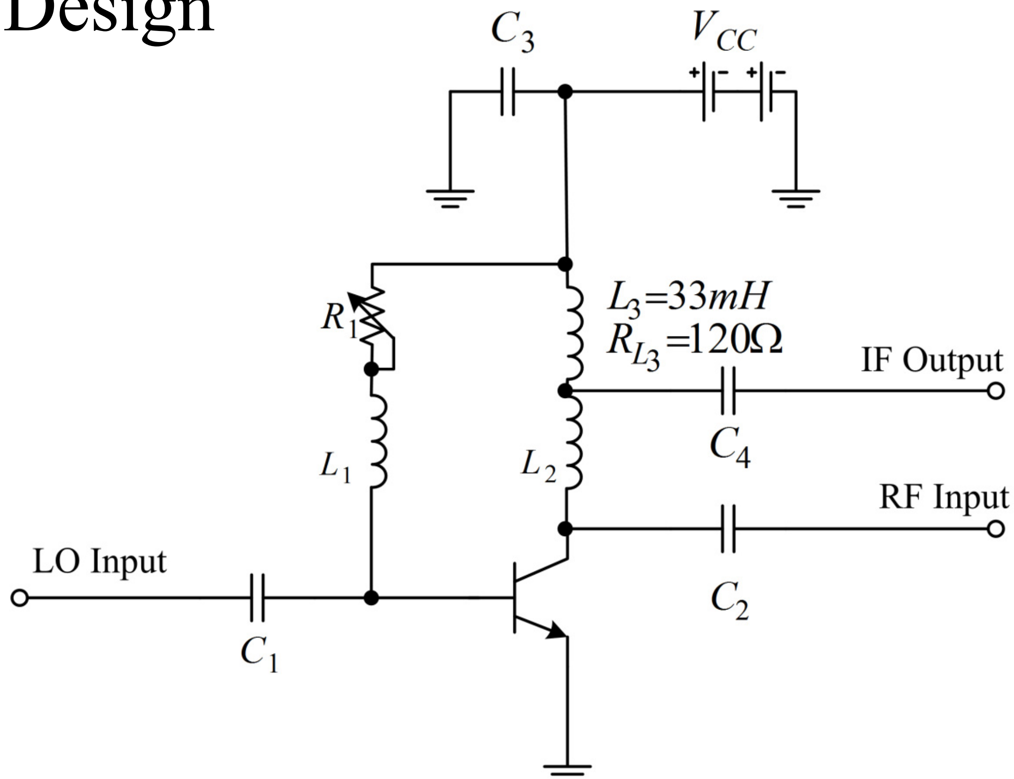
$$= V_{RF}\,[g_0 \cos\omega_{RF} t + 2\sum_{n=1}^{\infty} g_n [\cos n(\omega_{RF} + n\omega_{LO})\, t + \cos n(\omega_{RF} - n\omega_{LO})\, t]]$$

10 MHz Single Stage Amplifier Analysis

- Simulation
- Measurement

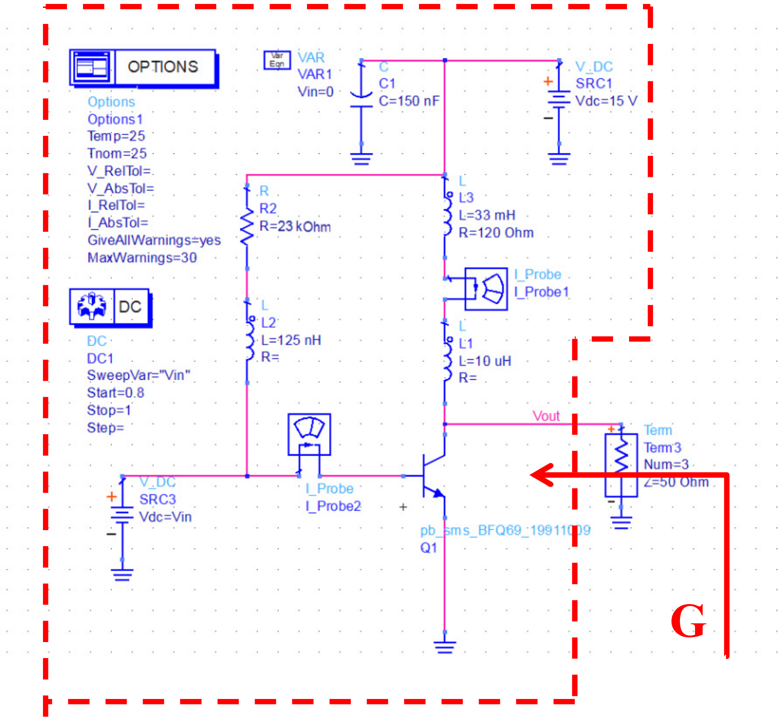
10 MHz Single Stage Amplifier Analysis – Simulation

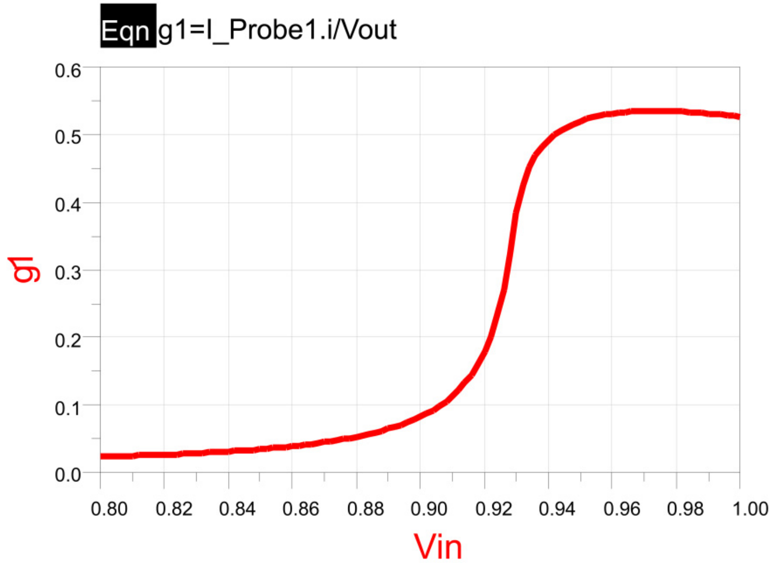
- Circuit Design



10 MHz Single Stage Amplifier Analysis – Simulation

- Amplifier output Conductance





10 MHz Single Stage Amplifier Analysis – Simulation

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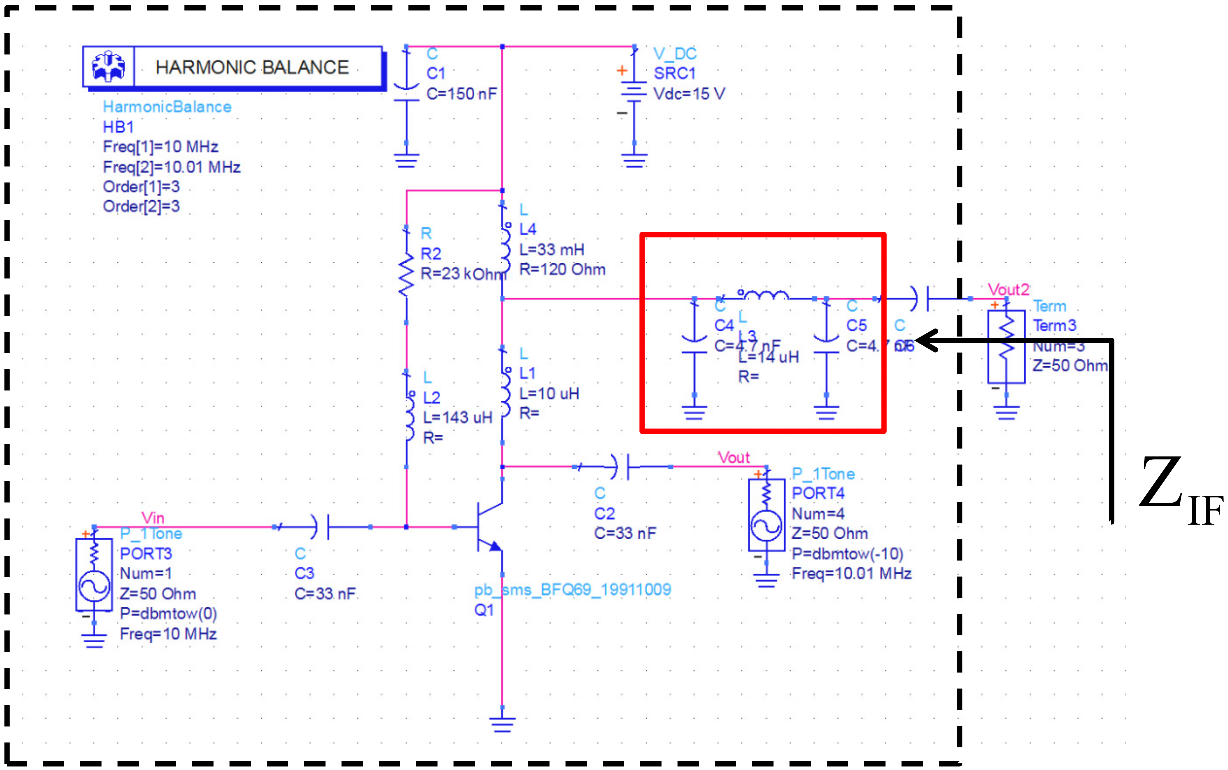
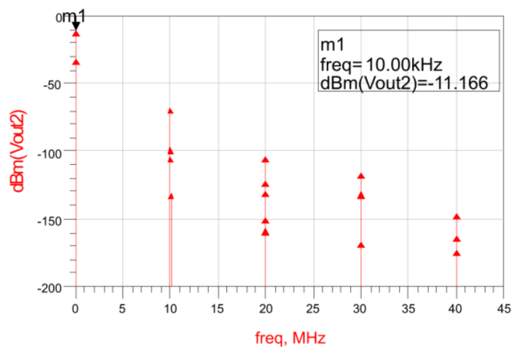
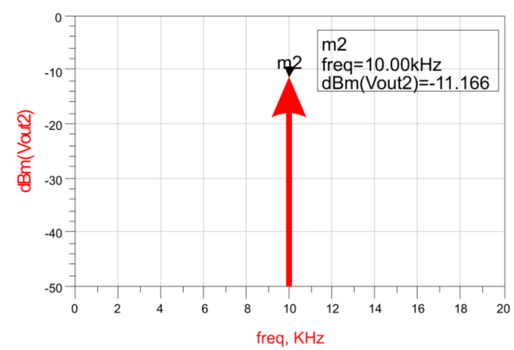
- Mixer Characteristics



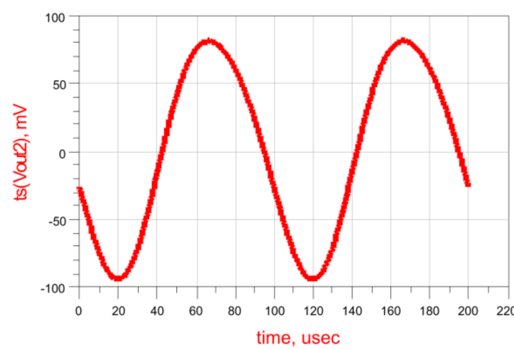
10 MHz Single Stage Amplifier Analysis – Simulation

- Mixer Characteristics





freq	Mix(1)	Mix(2)
0.0000 Hz	0	0
10.00 kHz	-1	1
20.00 kHz	-2	2
9.990 MHz	2	-1
10.00 MHz	1	0
10.01 MHz	0	1
10.02 MHz	-1	2
19.99 MHz	3	-1
20.00 MHz	2	0
20.01 MHz	1	1
20.02 MHz	0	2
20.03 MHz	-1	3
30.00 MHz	3	0
30.01 MHz	2	1
30.02 MHz	1	2
30.03 MHz	0	3
40.01 MHz	3	1
40.02 MHz	2	2
40.03 MHz	1	3



10 MHz Single Stage Amplifier Analysis – Measurement

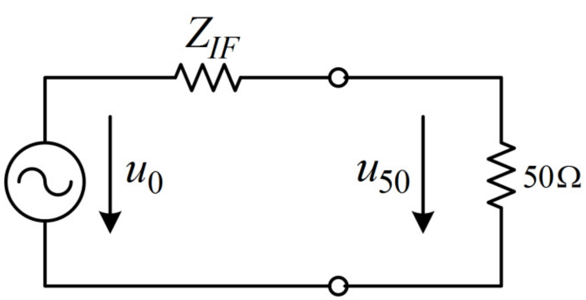
- Methods of Measurement

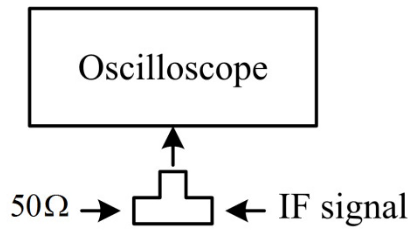
- Spectrum Analyzer
- Oscilloscope

$$P_{out}\,[\mathrm{dBm}] = 10\log\frac{P_{out}}{1\mathrm{mW}}$$

$$P_{out} = \frac{u_{50rms}^{2}}{50\,\Omega}$$

$$Z_{IF} = \frac{u_0}{u_{50}}\,50\,\Omega - 50\,\Omega$$





10 MHz Single Stage Amplifier Analysis – Measurement

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- Measurement with a Spectrum Analyzer

Unit	LO, RF and IF signal [dBm]							Conversion Loss [dB]
RF signal	LO signal							
	0		5		10		15	
	IF signal	Conversion Loss	IF signal	Conversion Loss	IF signal	Conversion Loss	IF signal	Conversion Loss
-10	-34.2	24.2	-26.4	16.4	-23.2	13.2	-21.0	11.0
-15	-39.4	24.4	-32.2	17.2	-28.3	13.3	-26.3	11.3
-20	-44.9	24.9	-37.3	17.3	-33.3	13.3	-31.3	11.3
-25	-47.8	22.8	-41..3	16.3	-38.2	13.2	-36.3	11.3
-30	-52.3	22.3	-46.7	16.7	-43.3	13.3	-41.5	11.5
-40	-		-		-53.5	13.5	-51.5	11.5

10 MHz Single Stage Amplifier Analysis – Measurement

- Measurement with an Oscilloscope

LO Signal [dBm]	RF Signal [dBm]			
	-10			
	Open[mV]	50Ω [mV]	Impedance[Ω]	Output Power[dBm]
0	9.84	4.52	58.85	-33.88
5	22.77	10.90	54.45	-26.24
10	31.91	15.51	52.87	-23.18
15	40.98	19.95	52.63	-20.10

10 MHz Single Stage Amplifier Analysis – Measurement

- Measurement of the Amplifier Output Conductance (RF Input Conductance)

Input Power[dBm]	**v_in[mV]**	**v_out[mV]**	**v_out_50Ω [mV]**	***Z*[Ω]**	***G*[mS]**
-30	15	332	147	62.98	15.9
-25	26	580	258	62.33	16.0
-20	49	990	453	59.38	16.8
-15	86	1.54 *10^3	707	59	16.9
-10	155	2.03 *10^3	1.00 *10^3	51.5	19.4
-5	271	2.70 *10^3	1.26 *10^3	57.14	17.5
-3	336	2.77 *10^3	1.28 *10^3	58.20	17.2

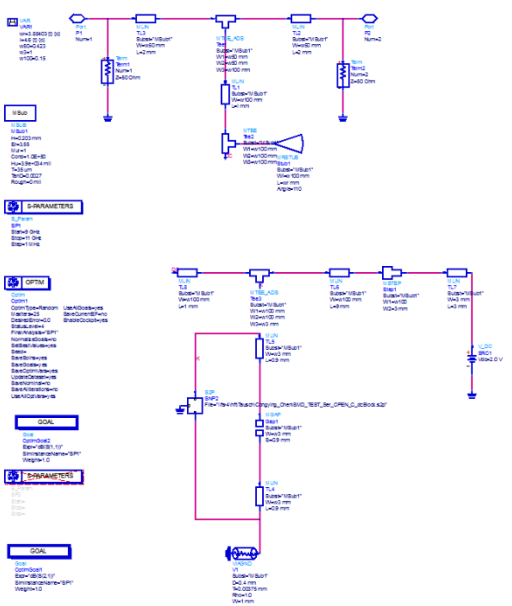
Design and Measurement of 10 GHz Self-Mixing Amplifier

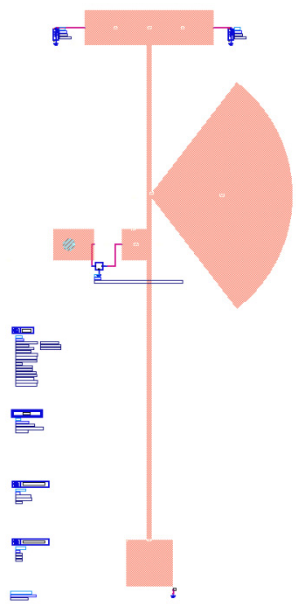
- Design and Simulation
- Measurement

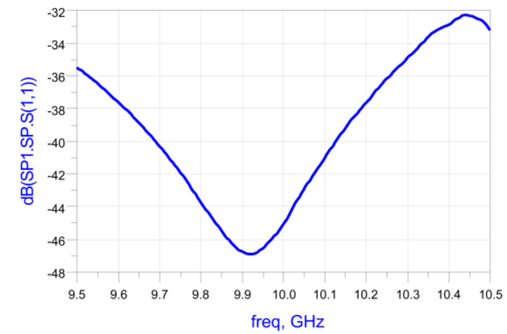
Design and Measurement of 10 GHz Self-Mixing Amplifier

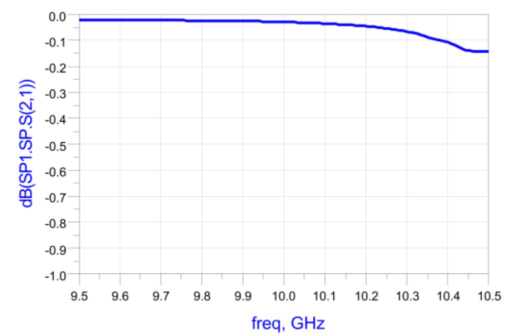
– Design and Simulation

- Transistor Selection & Operating Point
- Bias network Design









Design and Measurement of 10 GHz Self-Mixing Amplifier

– Design and Simulation

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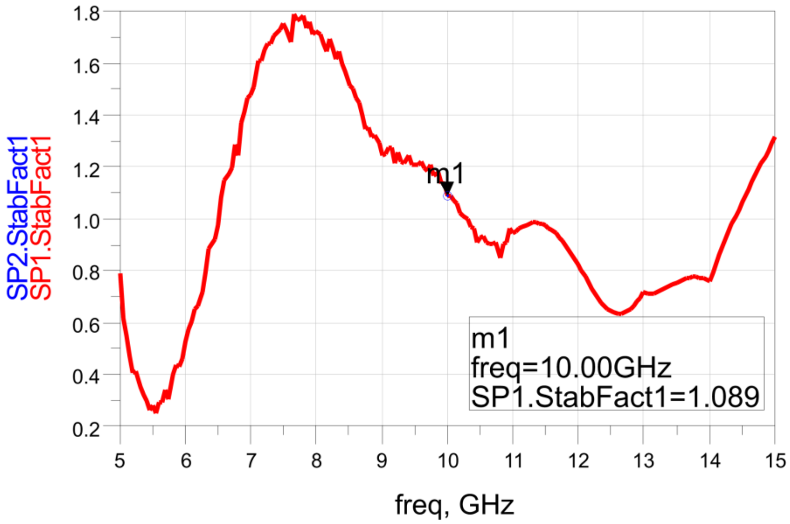
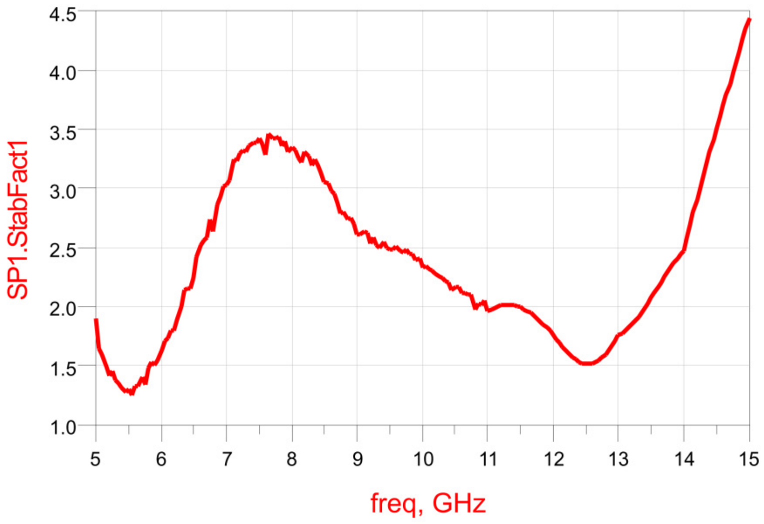
- Stability Analysis

$$K = \frac{(1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2)}{2|S_{12}S_{21}|} > 1$$

$$|\Delta| = |S_{11}S_{22} - S_{12}S_{21}| < 1$$

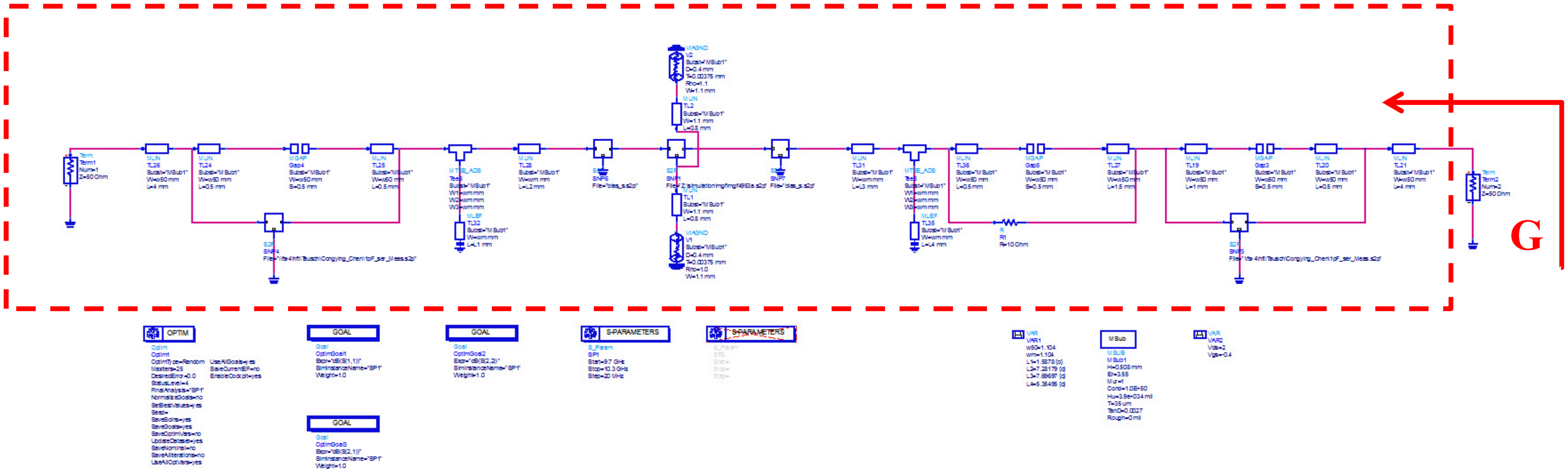




Design and Measurement of 10 GHz Self-Mixing Amplifier

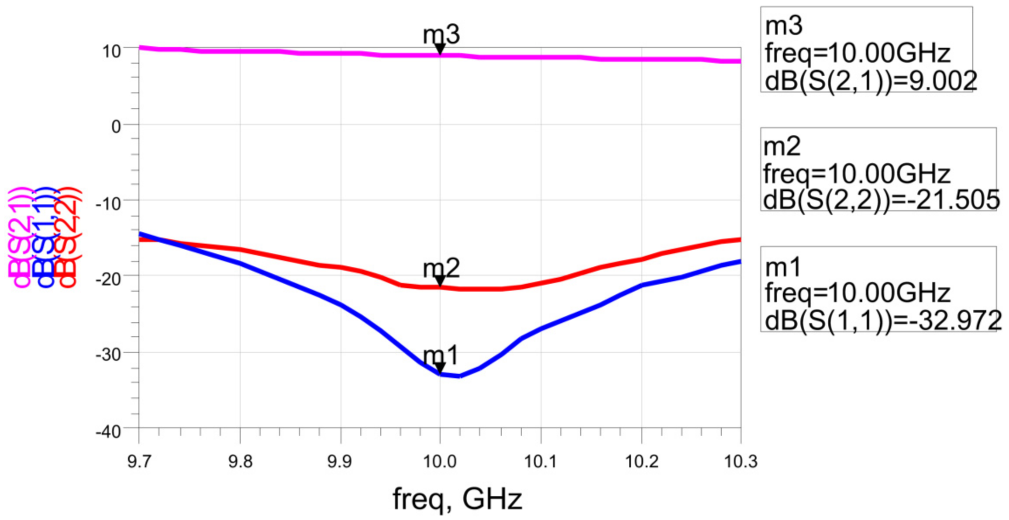
– Design and Simulation

- Input and output matching and Overall Amplifier



Design and Measurement of 10 GHz Self-Mixing Amplifier
– Design and Simulation

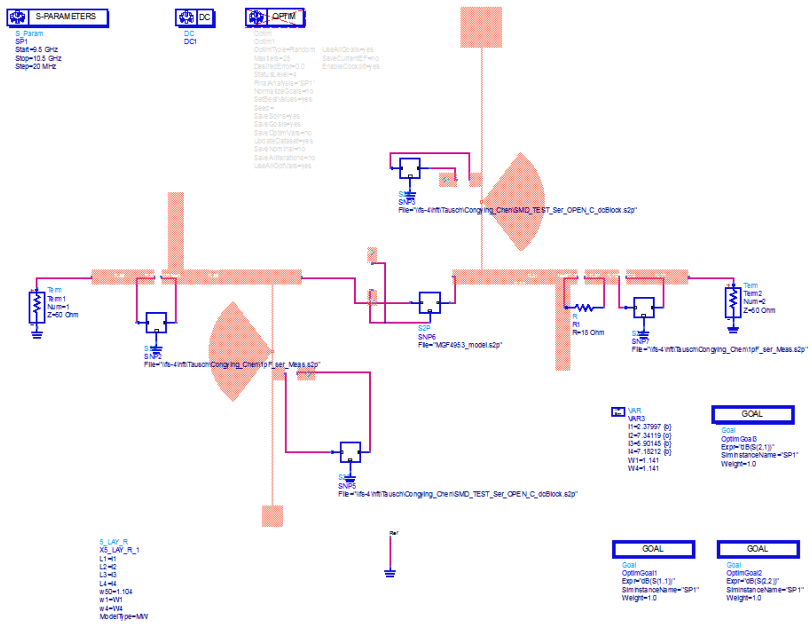
- Input and output matching and Overall Amplifier



Design and Measurement of 10 GHz Self-Mixing Amplifier

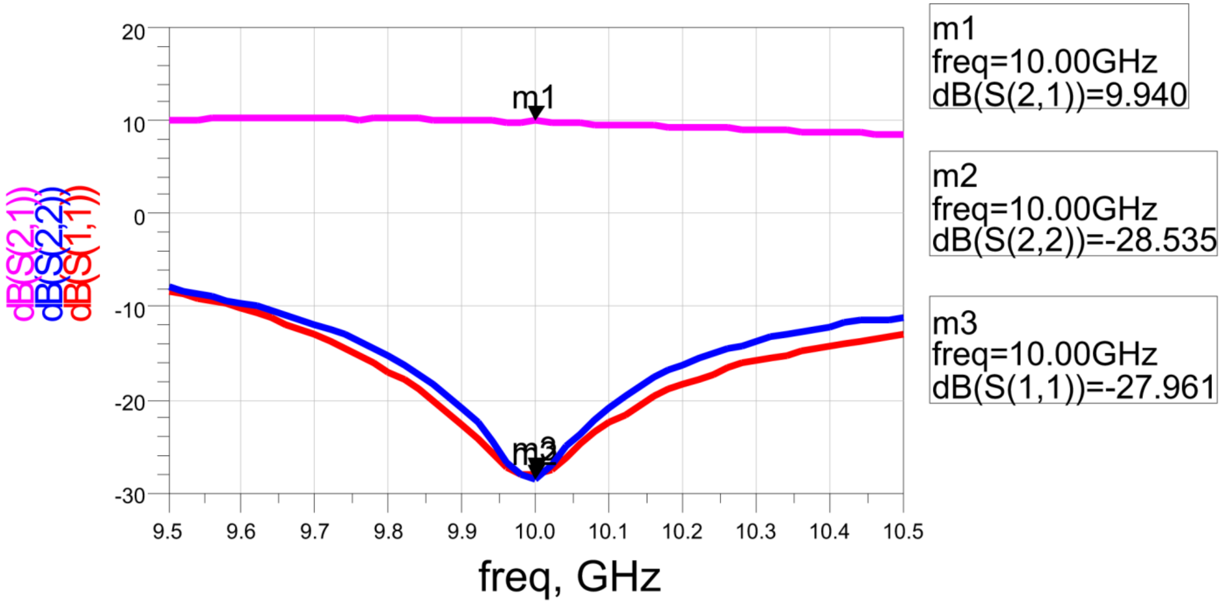
– Design and Simulation

- Input and output matching and Overall Amplifier



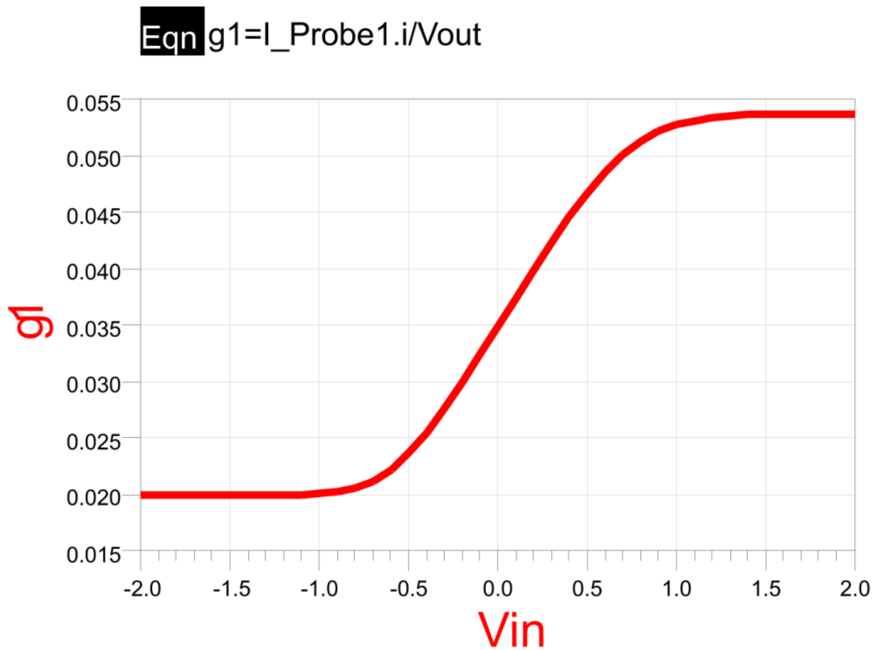
Design and Measurement of 10 GHz Self-Mixing Amplifier – Design and Simulation

- Input and output matching and Overall Amplifier



Design and Measurement of 10 GHz Self-Mixing Amplifier
– Design and Simulation

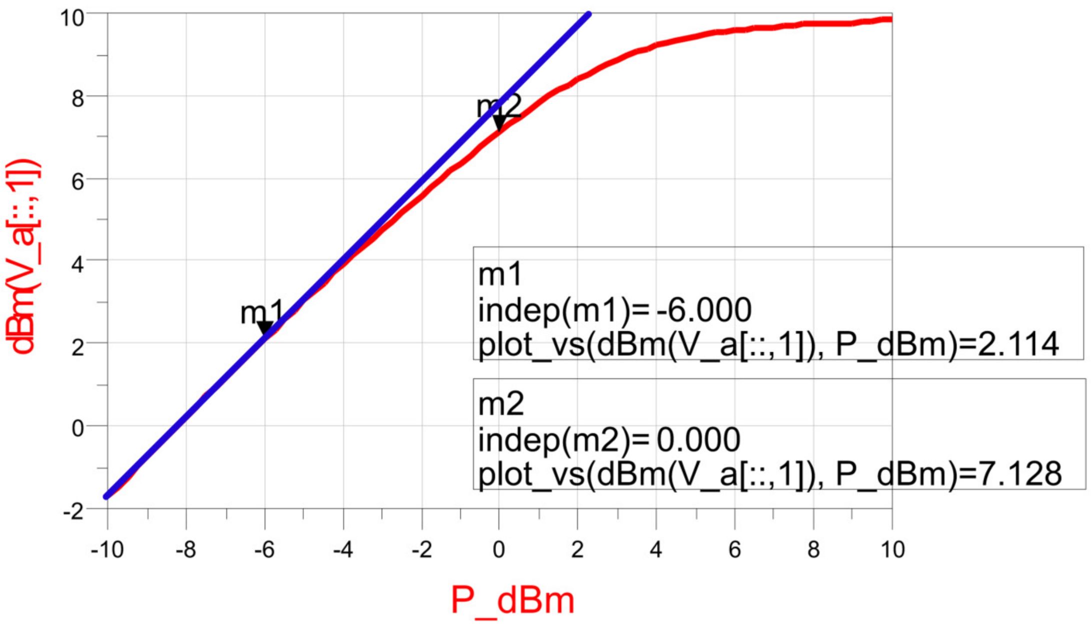
- RF Input Conductance



Design and Measurement of 10 GHz Self-Mixing Amplifier

– Design and Simulation

- 1 dB Compression Point



Design and Measurement of 10 GHz Self-Mixing Amplifier

– Design and Simulation

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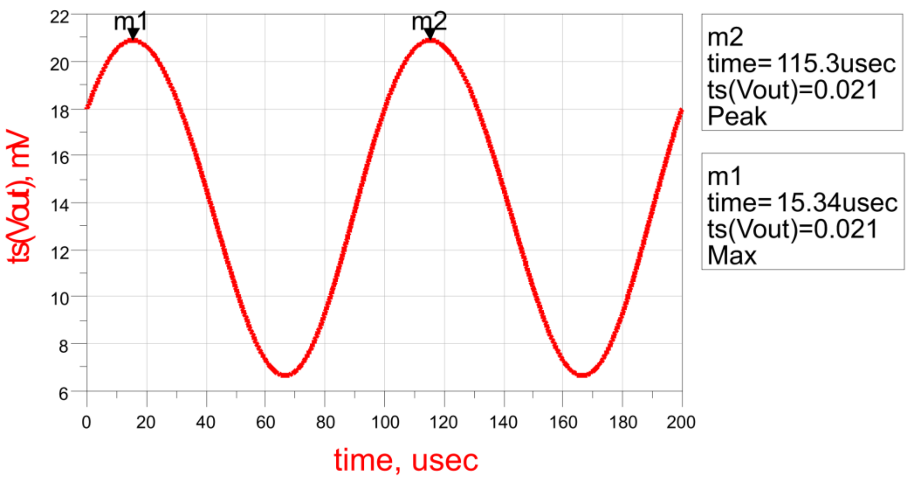
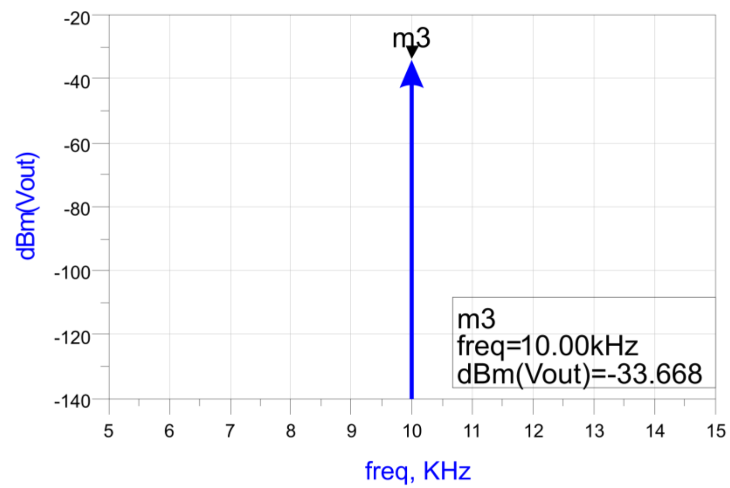
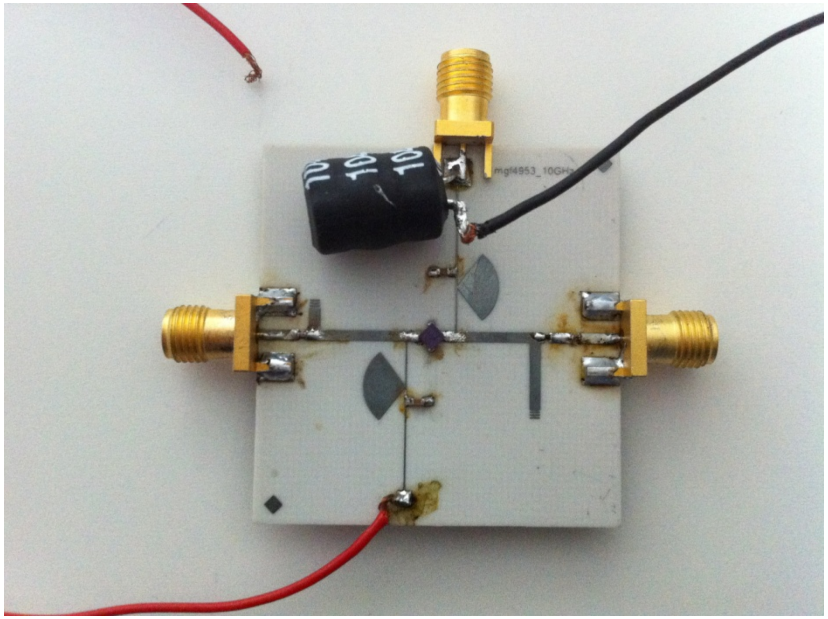
- IF Signal





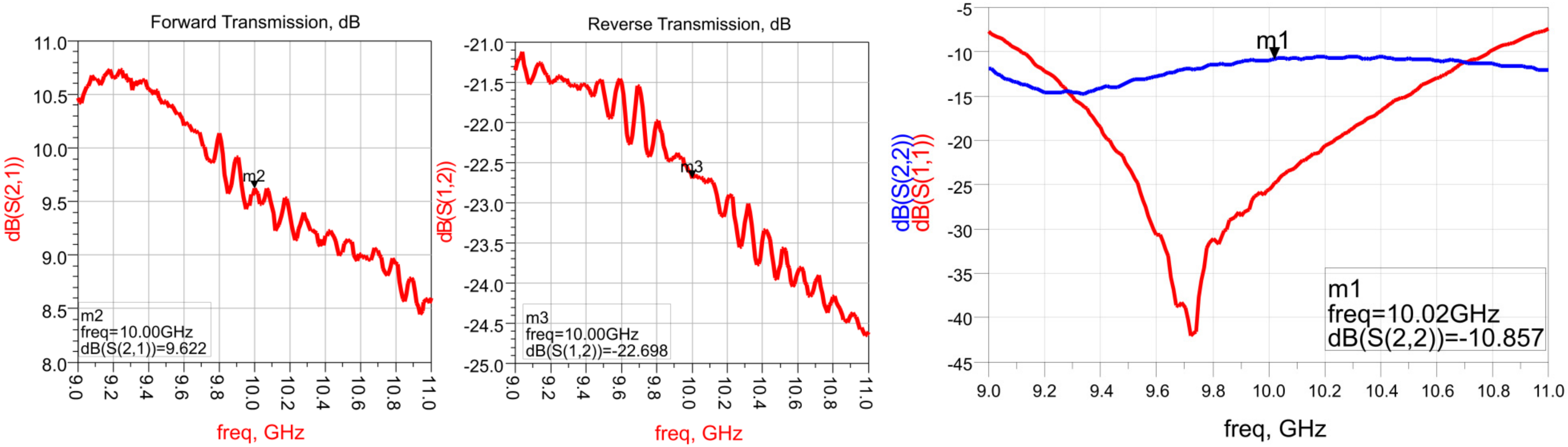
Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Implementation



Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Measurement of the S Parameters



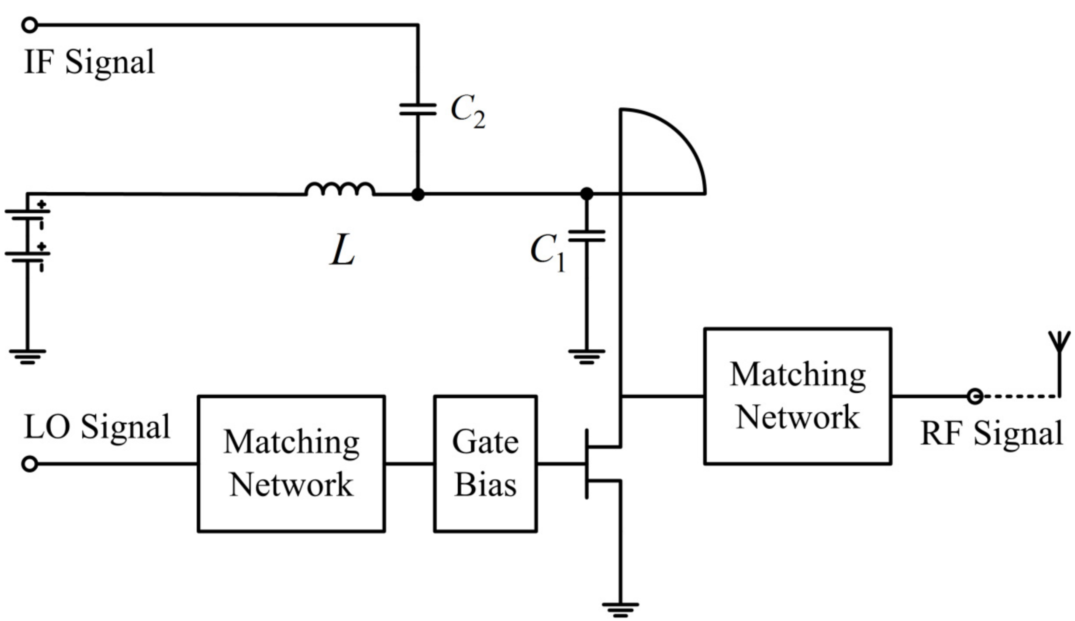
Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Measurement of 1 dBm-Compression Point

Input Power[dBm]	-10	-8	-6	-4	-2	0	2
Output Power[dBm]	-0.49	1.51	3.51	5.40	7.17	8.50	9.50

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Measurement of the Mixer Conversion Loss



$$L = 100\ \text{mH}$$

$$C_2 = 1.5\ \mu\text{F}$$

$$C_2 > \frac{1}{2\pi f_{IF}}$$

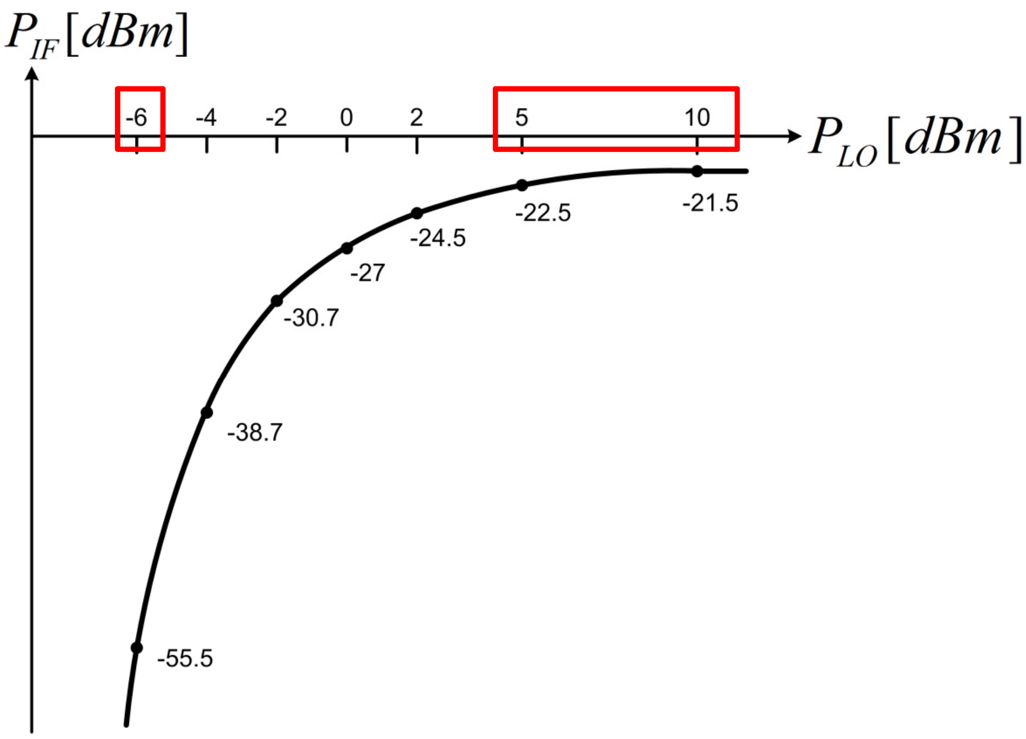
Design and Measurement of 10 GHz Self-Mixing Amplifier
– Measurement

- Mixer Products (Spectrum Analyzer)

RF Signal [dBm]	LO Signal[dBm]					
	-2		0		2	
	IF Signal [dBm]	Conversion Loss[dB]	IF Signal [dBm]	Conversion Loss[dB]	IF Signal [dBm]	Conversion Loss[dB]
-10	-30.79	20.79	-27.00	17.00	-24.50	14.50
-15	-36.99	21.99	-32.10	17.10	-29.97	14.97
-20	-40.51	20.51	-38.52	18.52	-35.10	15.10
-25	-45.70	20.70	-43.00	18.00	-39.03	14.03

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Mixer Products (Spectrum Analyzer)



$P_{RF} = -10dBm$

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

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- Mixer Products (Oscilloscope) without C_2

LO Signal [dBm]	RF Signal [dBm]			
	-10			
	Open[mV]	50Ω[mV]	Impedance[Ω]	Output Power[dBm]
-2	68	40	35.00	-23.98
0	98	60	31.66	-20.46
2	104	64	31.25	-19.89

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

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- Mixer Products (Oscilloscope) with C_2

LO Signal [dBm]	RF Signal [dBm]			
	-10			
	Open[mV]	50Ω [mV]	Impedance[Ω]	Output Power[dBm]
-2	35	20	37.50	-30.00
0	52	31	33.87	-26.19
2	70	42	33.33	-23.55

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

- Calculation of Impedance in Imagine Part

Impedance[Ω] Measured without C_2	Impedance[Ω] Measured with C_2	Impedance[Ω] of C_2
35.00	37.50	13.46
31.66	33.87	12.03
31.25	33.33	11.58

Design and Measurement of 10 GHz Self-Mixing Amplifier – Measurement

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- Conversion Loss

LO Signal[dBm]	Conversion Loss[dB]
-2	13.98
0	10.46
2	9.89

Conclusion

- Larger LO Signal $\rightarrow$ Larger Output Signal
  Lower Output Impedance

- The LO Signal depends on 1 dB-compression point

- Feasibility of Self-Mixing Amplifier

Thank You for Your Attention