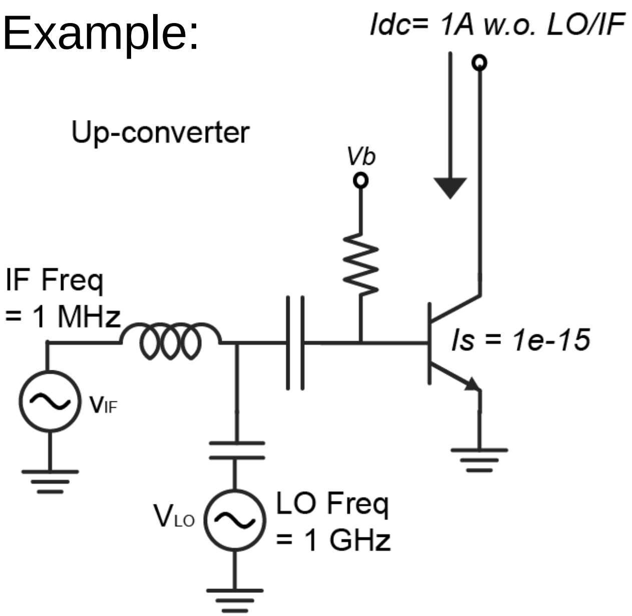
Mixer Analysis and Simulation Examples

Nov. 15 2017

Simple Example (1/3)

Example:



Small-signal distortion power series not applicable

$$i_{out} = I_{c0}/V_T * v_{in} + I_{c0}/(2V_T^2) * v_{in}^2 + I_{c0}/(6V_T^3) * v_{in}^3$$

Restart from the large-signal equation

$$I_c = I_s \exp\{ [V_b + V_{LO}\cos(f_{LO}t) + v_{IF}\cos(f_{IF}t)]/V_T \}$$

$$= I_{c0} \times \exp[V_{LO}\cos(f_{LO}t)/V_T] \times \exp[v_{IF}\cos(f_{IF}t)/V_T]$$

1A *Cannot use power series* *Use power series*

if $V_{LO} = 10V_T$

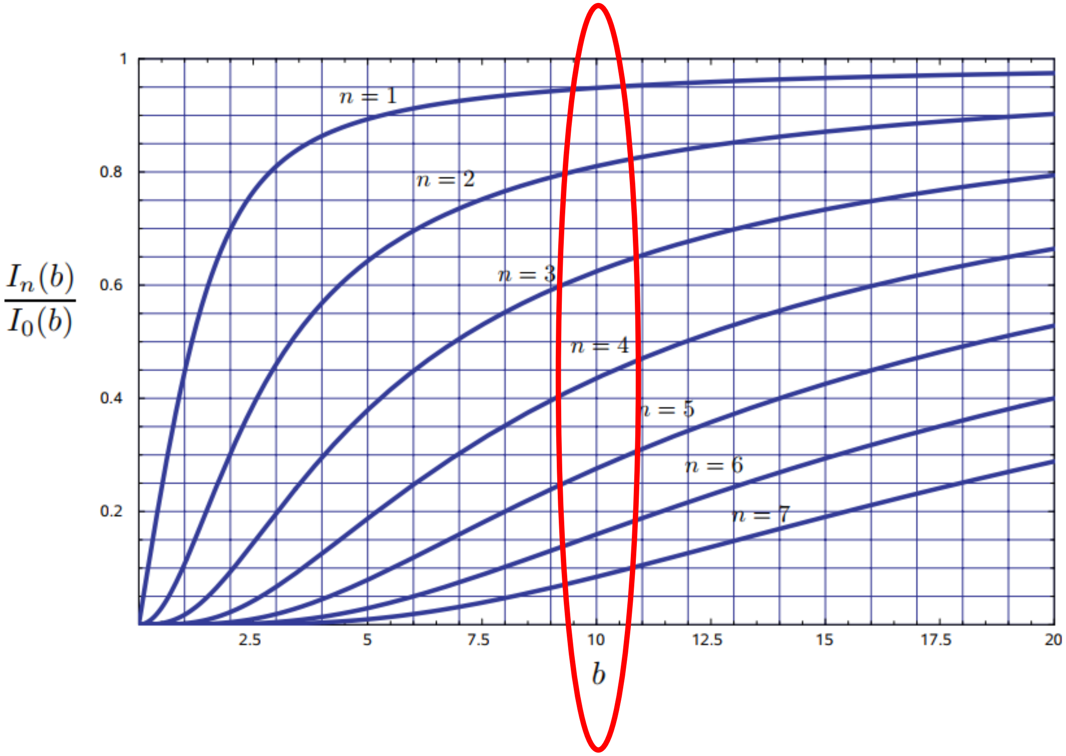
$\exp[V_{LO}/V_T \times \cos(f_{LO}t)] \approx dc \times [1 + 1.9\cos(f_{LO}t) + 1.6\cos(2f_{LO}t) + \ldots]$

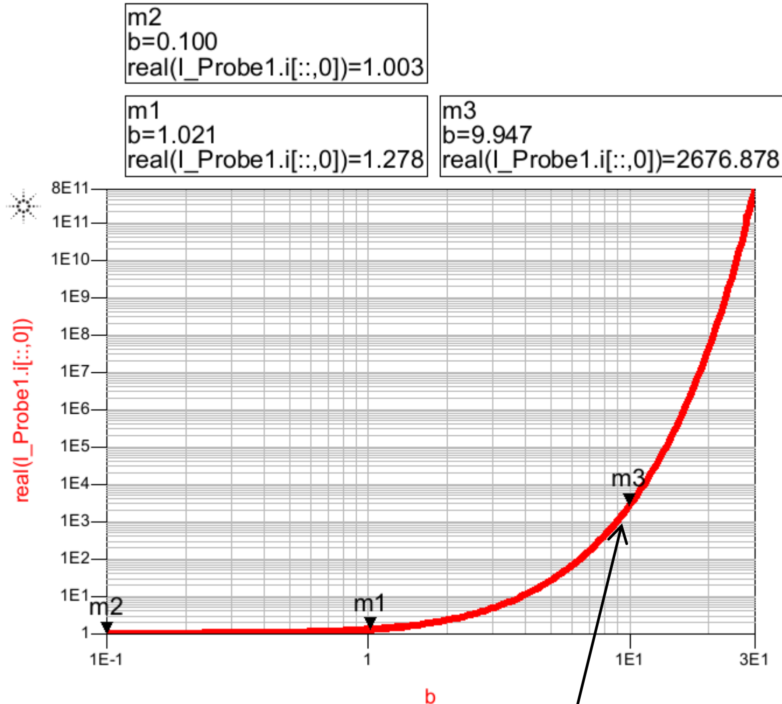
$\exp[v_{IF}\cos(f_{IF}t)/V_T] \approx 1 + v_{IF}\cos(f_{IF}t)/V_T + v_{IF}^2\cos^2(f_{IF}t)/2V_T^2 + v_{IF}^3\cos^3(f_{IF}t)/6V_T^3$

1. Voltage-to-current conversion gain: $[I_{c0} \times v_{IF}/V_T \times dc \times 1.9/2]/v_{IF} = [I_{c0}/V_T \times dc \times 1.9/2]$
2. Mixer IIP3 = $\mathrm{sqrt}((4a_1)/(3a_3)) = \mathrm{sqrt}((4 \times 1/V_T)/(3 \times 1/6V_T^3)) = 2.8V_T$
3. Mixer IP1dB = $\mathrm{sqrt}(|4a_1|/|3a_3| \times 0.11) = 0.33 \times 2.8V_T$
4. LO to RF leakage: $(I_{c0} \times dc \times 1.9)/(10V_T)$

Simple Example (2/3)

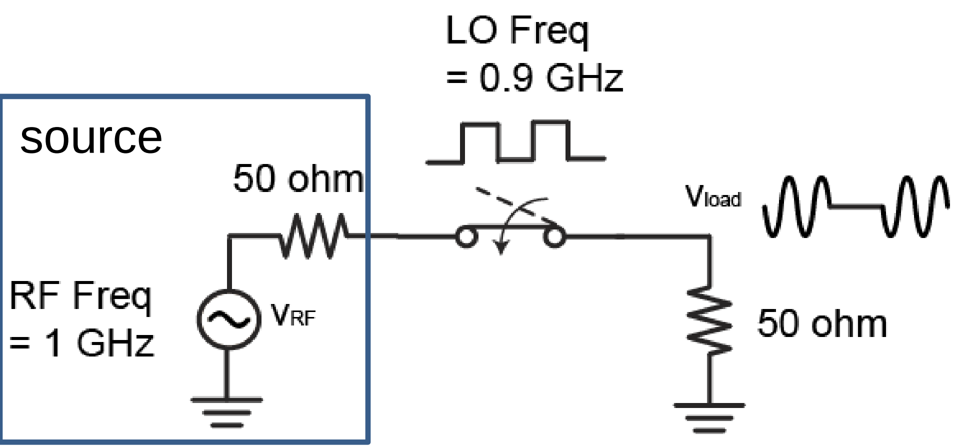
$$e^{b\cos\omega t} = I_0(b) + 2I_1(b)\cos\omega t + 2I_2(b)\cos 2\omega t + \cdots$$





The dc current explodes when $V_{LO} = 10V_T$

Simple Example (3/3)



0-1-0-1-0-1

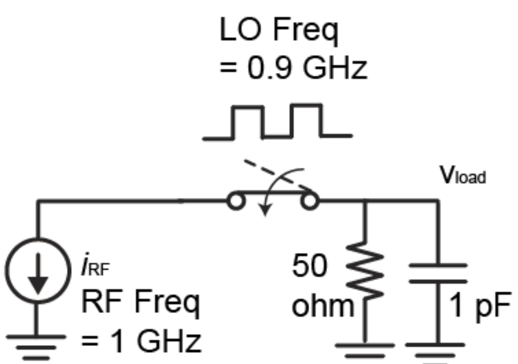
$$V_{load} = v_{RF}\cos(\omega_{RF}t)/2 \times \mathrm{LO}(t)$$

$$\mathrm{LO}(t) = 0.5 + (2/\pi)\cos(\omega_{LO}t) + (2/3\pi)\cos(3\omega_{LO}t)+\ldots$$

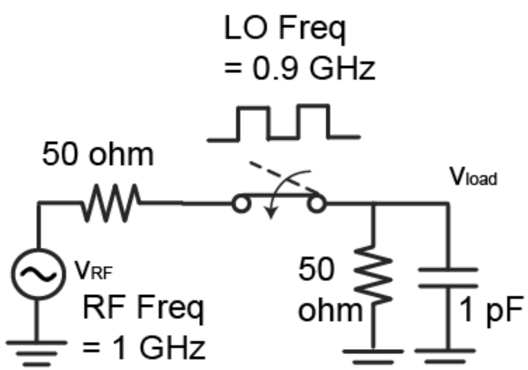
$$V_{load,IF} = v_{RF}\cos(\omega_{RF}t)/2 \times (2/\pi)\cos(\omega_{LO}t)$$

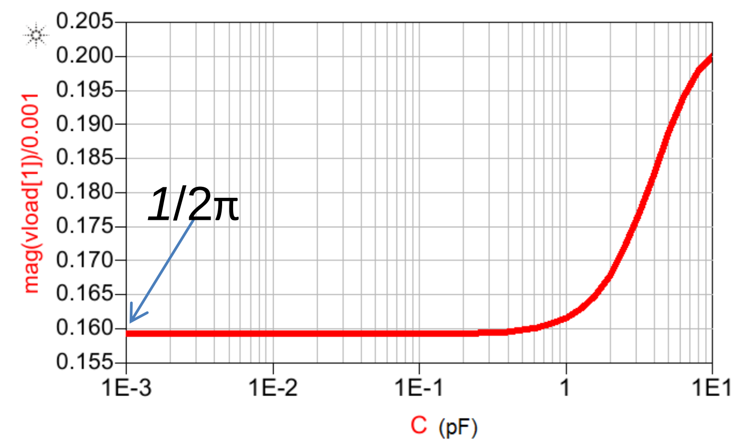
$$= (v_{RF}/2\pi) \times \cos(\omega_{IF}t)$$

Easy Example

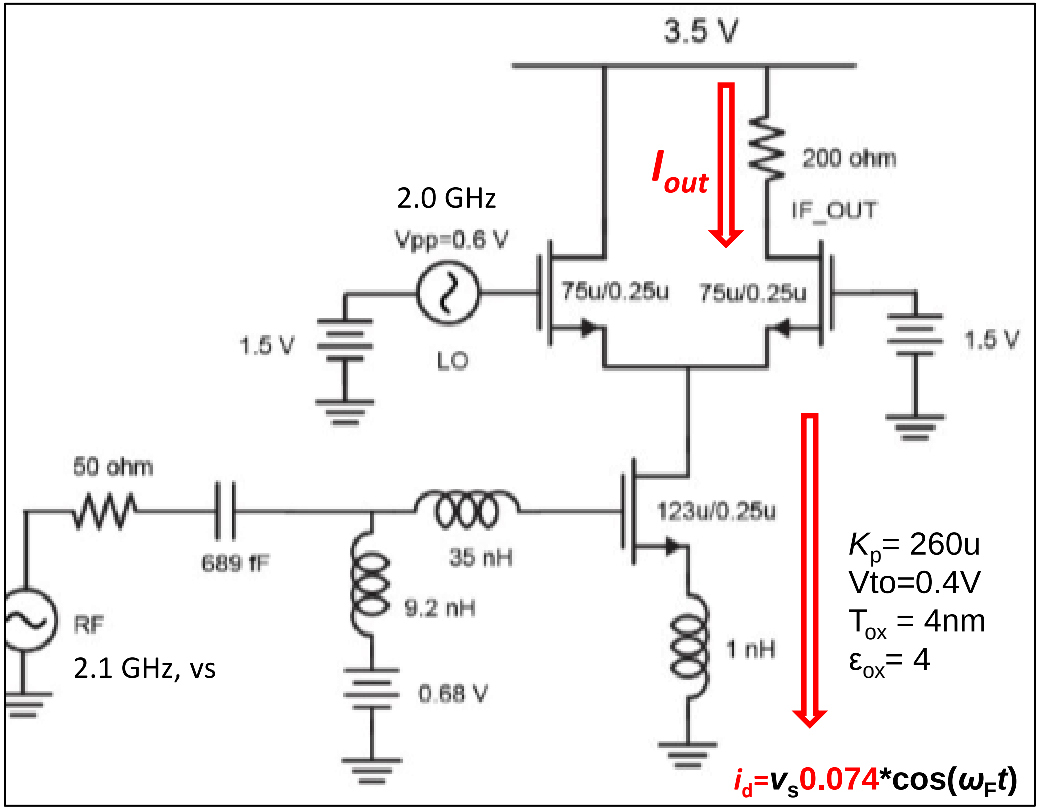


Difficult Example





Advanced Example: Analysis



K = 0.5*260u*75/0.25 = 0.039

$$i_D = K\left(v_{GS} - V_t\right)^2$$

$$i_{D1,2} = \frac{I}{2} \pm \sqrt{2KI}\left(\frac{v_{id}}{2}\right)\sqrt{1 - \frac{\left(v_{id}/2\right)^2}{I/2K}}$$

I = 5 mA + $\boldsymbol{v_s}$**0.074*cos($\boldsymbol{\omega_{RF} t}$)**

v_{id} =0.3cos(ω_{LO}t)

I_{out} ~ $I/2$ + sqrt(2KI)*v_{id}/2

~ $I/2$ + sqrt(2KI_{dc})*(1+I_{ac}/2I_{dc})*v_{id}/2

i_{IF} ~ sqrt(2KI_{dc}) $\boldsymbol{v_s}$**0.074**/2I_{dc}*0.3/2/2 = 0.011$\boldsymbol{v_s}$

v_{IF}~ i_{IF}*200 = **2.2**v_s

(conversion voltage gain = 2.2)

I_d = 0.5*K_p*W/L*(V_{gs}-V_T)^2 = 5 mA

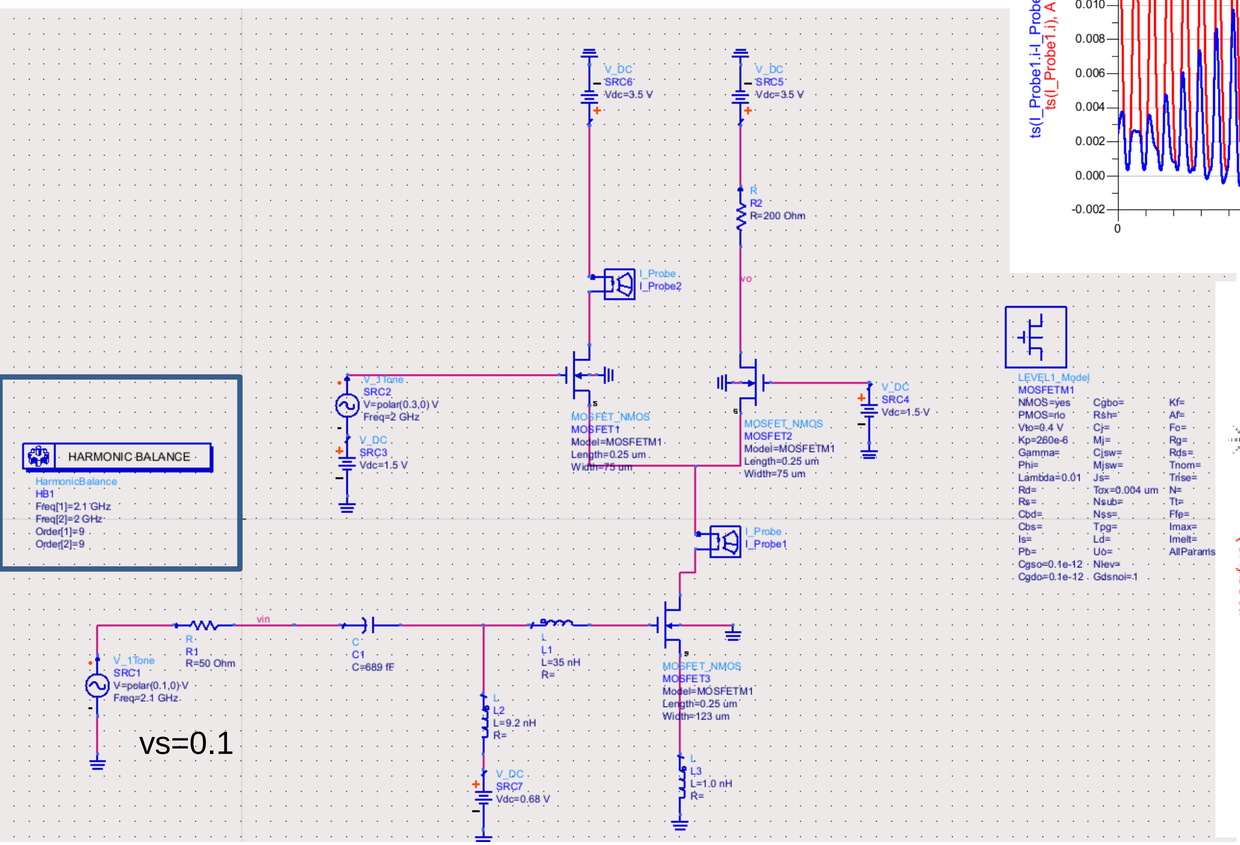
g_m = 2I_d/V_{ov} = 36 mS

Gm = 0.074

RF-to-IF leakage: $v_{out,RF}$ = $\boldsymbol{v_s}$**0.074/2** *200 = **7.4**v_s

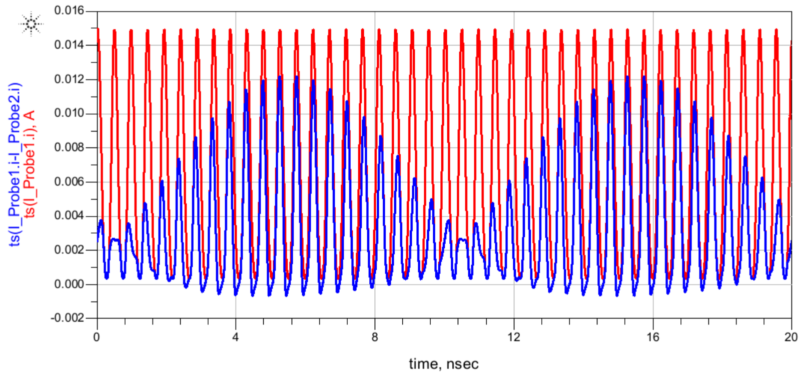
LO-to-IF leakage: $v_{out,LO}$= sqrt(2KI_{dc})*(1)*0.3/2*200 = **0.6V**

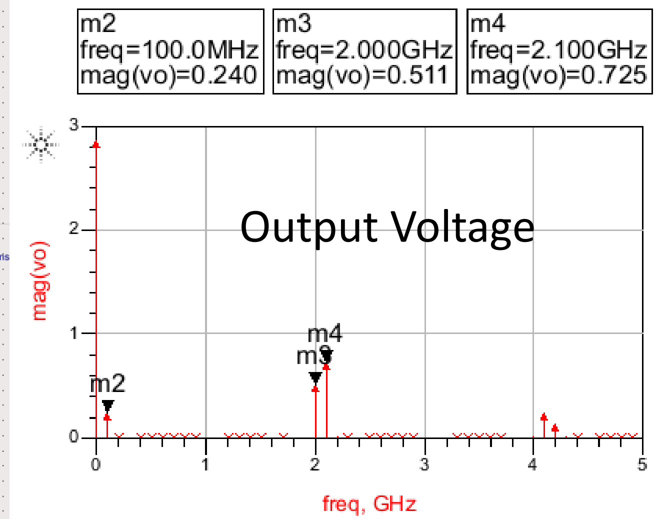
Advanced Example: Sim (1/4)



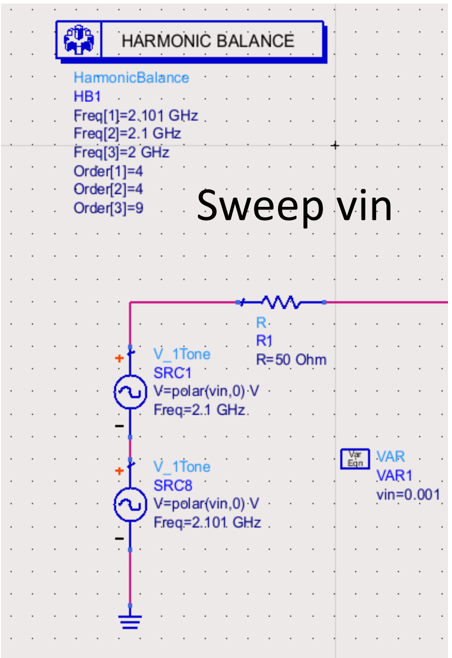
CS current

Load Current

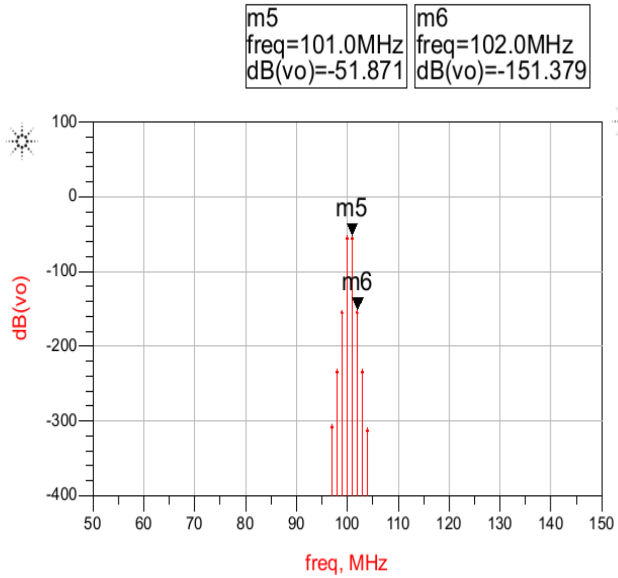




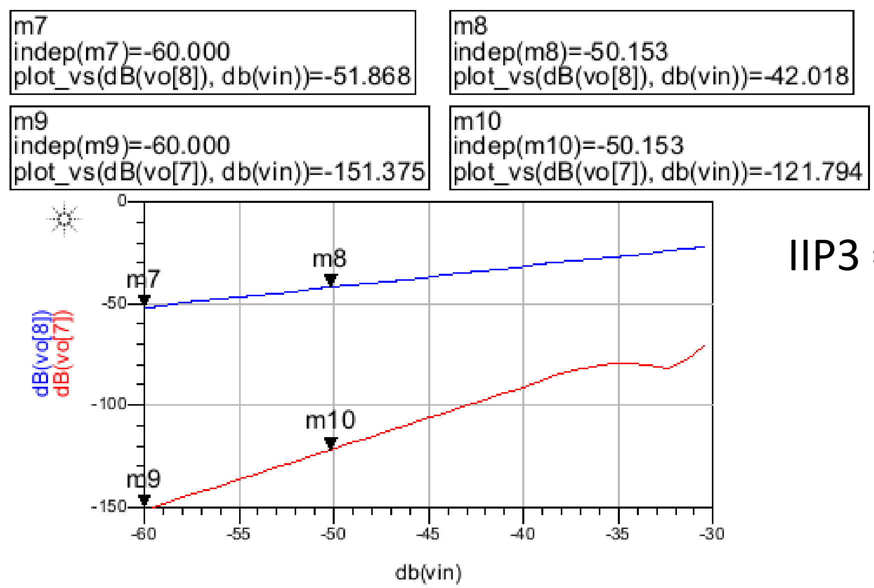
Advanced Example: Sim (2/4)



Sweep vin



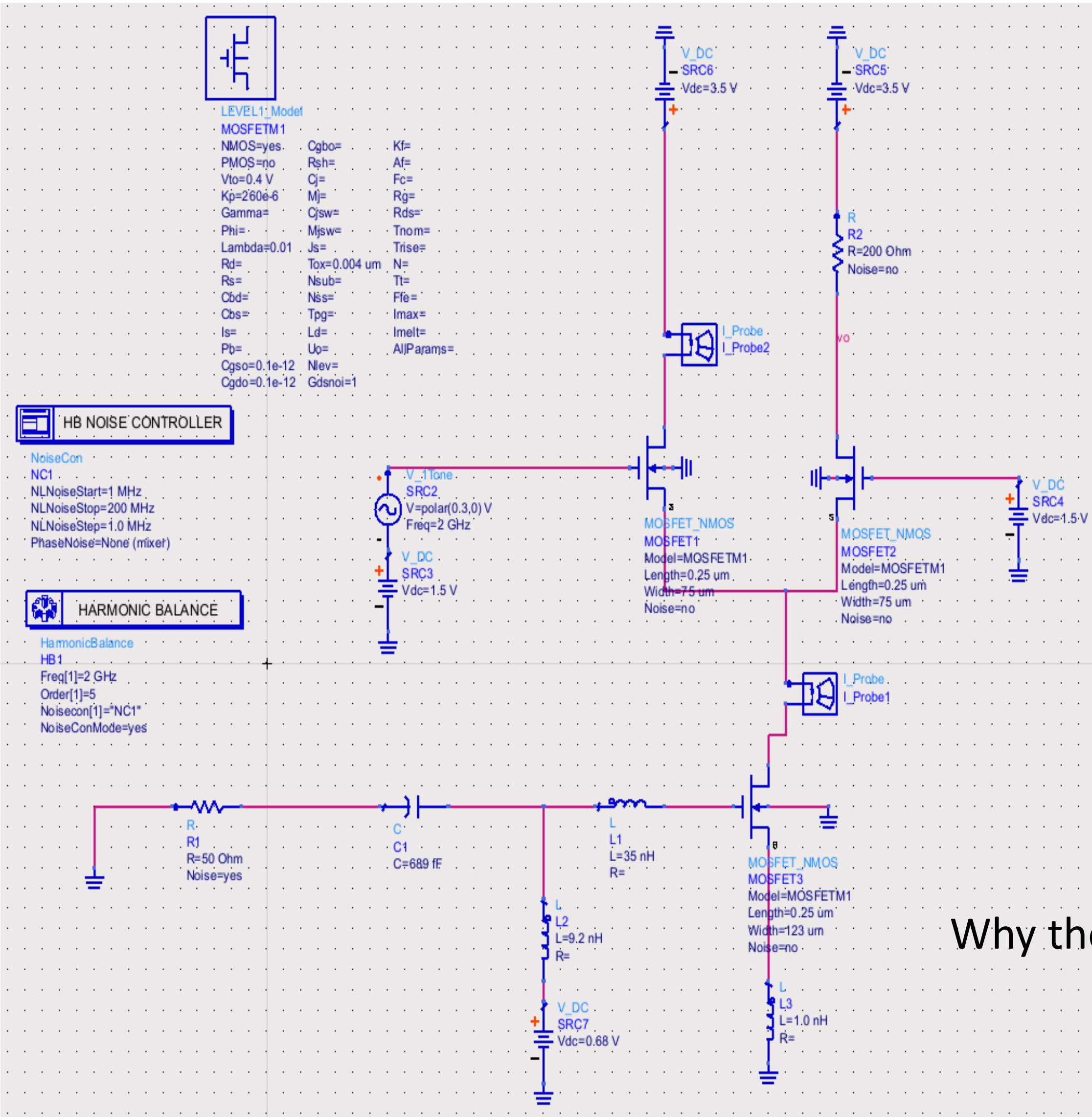
	freq	dB(vo)
	0.0000 Hz	9.529
	1000. kHz	-91.540
	2.000 MHz	-218.831
	3.000 MHz	-312.639
	4.000 MHz	-331.582
	97.00 MHz	-304.315
	98.00 MHz	-231.098
IM3	99.00 MHz	-151.375
Fund.	100.0 MHz	-51.868
	101.0 MHz	-51.871
IM3	102.0 MHz	-151.379
	103.0 MHz	-231.102
	104.0 MHz	-308.812
	198.0 MHz	-307.268
	199.0 MHz	-233.305
	200.0 MHz	-155.287

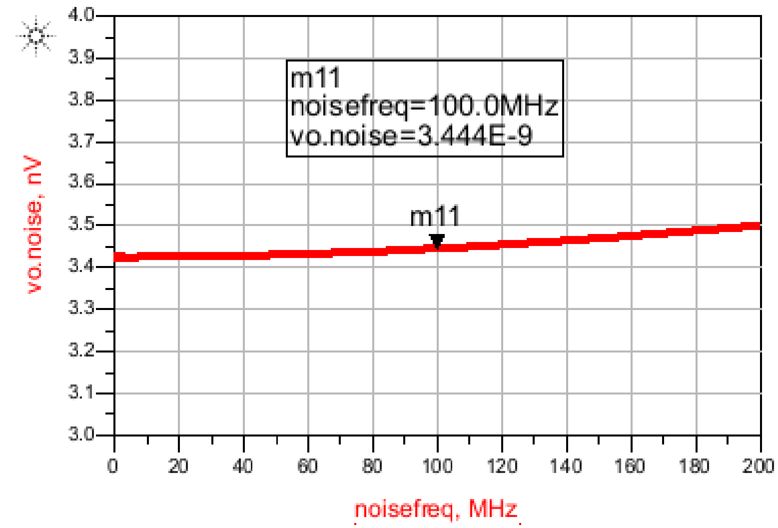


IIP3 = -2 dBV

The third-order nonlinearity is created by the FET source degeneration !

Advanced Example: Sim (3/4)



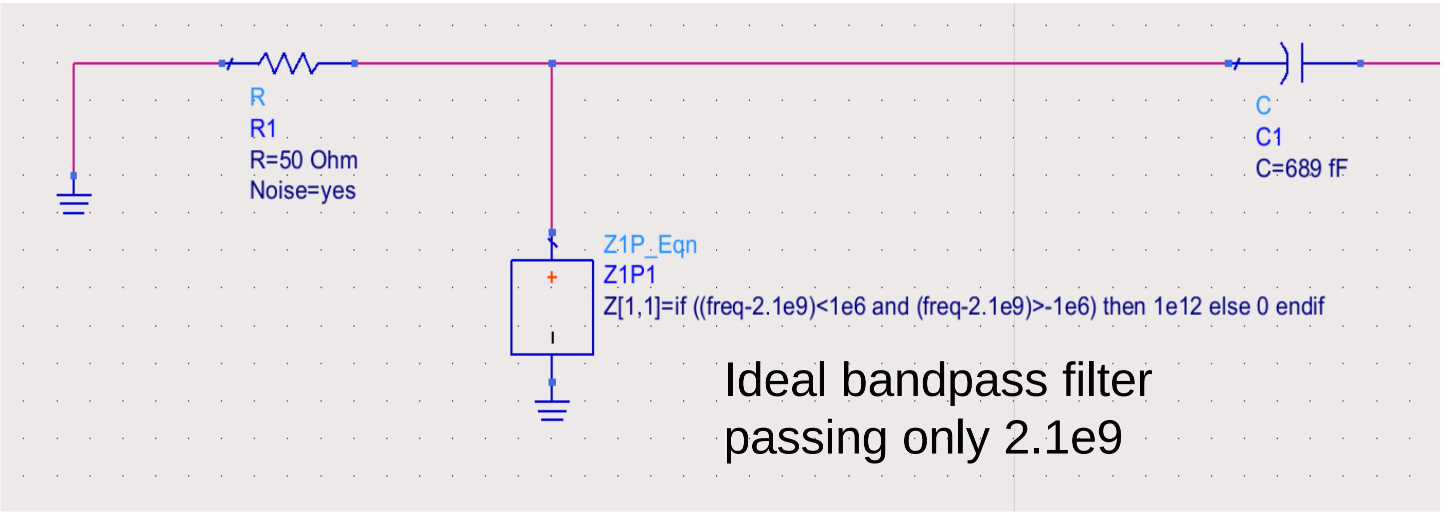


Noise contributed by Rs at 2.1 GHz:

$v_{n,out}$ = sqrt[(4kT*50)]*2.2 = 2.1 nV

Why the output noise is higher than 2.1 nV ?

Advanced Example: Sim (4/4)



- LO Freq = 2 GHz
- Output noise @ 100 MHz contributed by source noises at many frequencies
- High-frequency noise filtered by input matching network

Freq.	Noise Contribution (nV)	Accumulated Noise
1.9 GHz	**2.55e-9**	**2.55e-9**
2.1 GHz	**2.31e-9**	**3.44e-9**
3.9 GHz	2.6e-13	~3.44e-9
4.1 GHz	3.4e-13	~3.44e-9
5.9 GHz	8.9e-12	~3.44e-9
6.1 GHz	8.2e-12	~3.44e-9