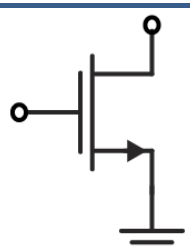
Today’s Agenda (Nov. 1)

- Important Distortion Matrices
- IIP2 and IIP3 For Cascade Circuits
- Hw8: Distortion Analysis
- ADS Harmonic Balance Setup

Important Distortion Matrices

i_{out} (or v_{out}) = $a_1 v_{in} + a_2 v_{in}^2 + a_3 v_{in}^3 + \ldots$

Very Important: v_{in} and i_{out} are small-signal !!!



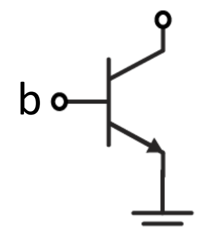
Long channel device

$I_d = 0.5\mu_n C_{ox} W/L*(V_{gs}-V_{th})^2$
$=0.5\mu_n C_{ox} W/L*V_{th}^2 - \mu_n C_{ox} W/L*V_{th} \boldsymbol{V_{gs}} + 0.5\mu_n C_{ox} W/L*\boldsymbol{V_{gs}^2}$

$I_d = 0.5\mu_n C_{ox} W/L*(V_{gs0}-V_{th} + v_{in})^2 =$

$0.5\mu_n C_{ox} W/L*(V_{gs0}-V_{th})^2 + \mu_n C_{ox} W/L*(V_{gs0}-V_{th})\, v_{in} + 0.5\mu_n C_{ox} W/L*v_{in}^{\boldsymbol{2}}$

=> $i_{out} = \mu_n C_{ox} W/L*(V_{gs0}-V_{th})\, v_{in} + 0.5\mu_n C_{ox} W/L*v_{in}^{\boldsymbol{2}}$ ☺



BJT

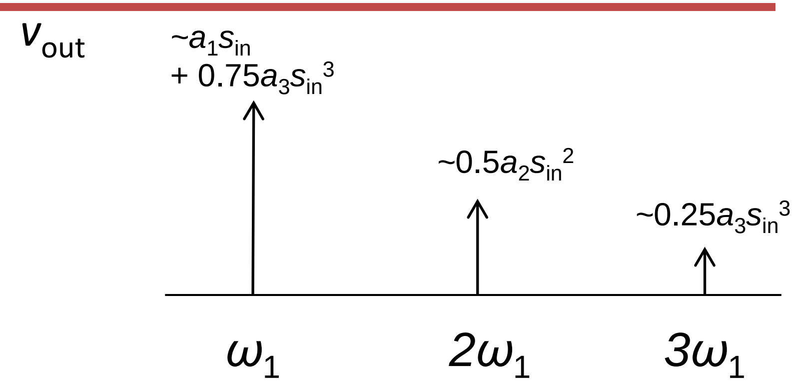
$I_c \approx I_{s0} exp(V_b/V_T)$
$= I_{s0} + I_{s0}/V_T*V_b + I_{s0}/2V_T*V_b^2 + I_{s0}/6V_T*V_b^3 + \ldots.$

$I_c \approx I_{s0} exp[(V_b + v_{in})/V_T] = \boldsymbol{I_{c0}} exp(v_{in}/V_T)$
$= I_{c0} + I_{c0}/V_T*v_{in} + I_{c0}/2V_T*v_{in}^2 + I_{c0}/6V_T* v_{in}^3 + \ldots.$ ☺

Important Distortion Matrices

i_{out} (or v_{out}) = $a_1 v_{in} + a_2 v_{in}^2 + a_3 v_{in}^3 + \ldots$

v_{in} and i_{out} are small-signal !!!

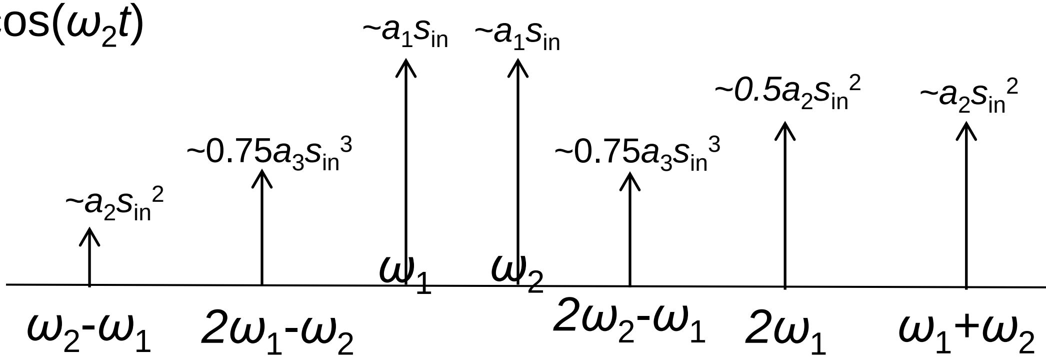


Single-Tone Excitation: $v_{in} = s_{in}\cos(\omega_1 t)$

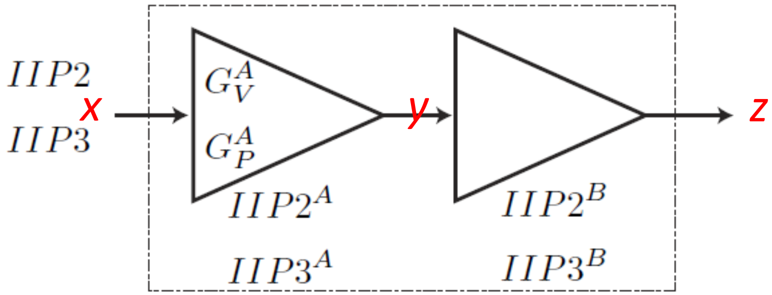
- HD2 = $a_2/(2a_1) \times s_{in}$
- HD3 = $a_3/(4a_1) \times s_{in}^2$
- IP_{1dB}: $s_{in} = \text{sqrt}(|4a_1|/|3a_3| \times 0.11)$

Two-Tone Excitation: $v_{in} = s_{in}\cos(\omega_1 t) + s_{in}\cos(\omega_2 t)$

- IM2 = $a_2/a_1 \times s_{in}$
- IIP2 $s_{in} = a_1/a_2$
- IM3 = $3a_3/(4a_1) \times s_{in}^2$
- IIP3 $s_{in} = \text{sqrt}(|4a_1|/|3a_3|)$



IIP2 and IIP3 For Cascade Circuits



$y = a_1 x + a_2 x^2 + a_3 x^3 + \cdots \quad z = b_1 y + b_2 y^2 + b_3 y^3 + \cdots$

$$z = c_1 x + c_2 x^2 + c_3 x^3 + \cdots$$

x, y, and z are voltage or current

$$\frac{1}{IIP2} = \frac{1}{IIP2^A} + \frac{a_1}{IIP2^B}$$

$$\frac{1}{IIP3^2} = \frac{1}{IIP3_A^2} + \frac{a_1^2}{IIP3_B^2}$$

IIP2 and IIP3 in the above formula are voltage or current

- Example 1: Suppose the input amplifiers of a cascade has $IIP2^A = +0\,\mathrm{dBm}$ and a voltage gain of $20\,\mathrm{dB}$. The second amplifier has $IIP2^B = +10\,\mathrm{dBm}$.

The formula has to be used in voltage domain!

case1

1. $IIP2^A$ = 1 mW which is 0.32V if the input is 50Ω
2. $IIP2^B$ = 10 mW which is 1V if the input is 50Ω
3. voltage gain of 20 dB => a_1 = 10
4. IIP2 = $(1/0.32 + 10/1)^{-1}$ = 0.076 V or -12.4 dBm

case2

1. $IIP2^A$ = 1 mW which is 0.45V if the input is 100Ω
2. $IIP2^B$ = 10 mW which is 0.45V if the input is 10Ω
3. voltage gain of 20 dB => a_1 = 10
4. IIP2 = $(1/0.45 + 10/0.45)^{-1}$ = 0.041 V or -20.7 dBm

IIP2 and IIP3 For Cascade Circuits

$$\frac{1}{IIP3^2} = \frac{1}{IIP3_A^2} + \frac{a_1^2}{IIP3_B^2}$$

IIP3 in the above formula are voltage or current

- LNA has an $IIP3^A = -10\,\mathrm{dBm}$ and a power gain of $20\,\mathrm{dB}$. The mixer has an $IIP3^B = -20\,\mathrm{dBm}$.

case1

1. $IIP3^A$ = 0.1 mW which is 0.1V if the input is 50Ω
2. $IIP3^B$ = 0.01 mW which is 32mV if the input is 50Ω
3. power gain of 20 dB => a_1 = 10
4. $IIP3^2 = (1/0.1^2 + 10^2/0.032^2)^{-1}$

=> IIP3 = 3.2 mV or -40 dBm

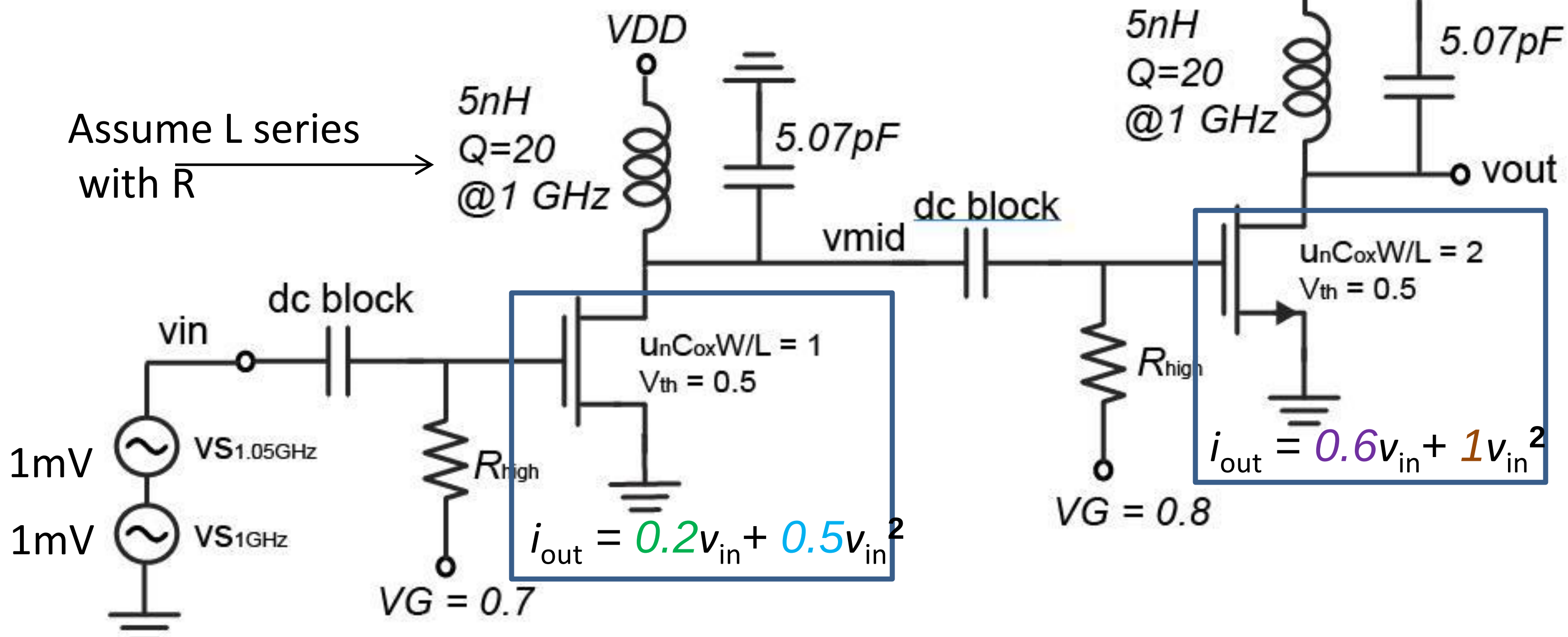
case2

1. $IIP3^A$ = 0.1 mW which is 0.14V if the input is 100Ω
2. $IIP3^B$ = 0.01 mW which is 14mV if the input is 10Ω
3. power gain of 20 dB => a_1 = 32
4. $IIP3^2 = (1/0.14^2 + 32^2/0.014^2)^{-1}$

=> IIP3 = 0.44 mV or -60 dBm

HW Example

$i_{out} = \mu_n C_{ox} W/L*(V_{gs0}-V_{th})\, v_{in} + 0.5\mu_n C_{ox} W/L*v_{in}^2$



1. $V_{mid\_1.0GHz} \sim -0.2*1m*628 = -0.125$
2. $V_{mid\_1.05GHz} \sim -0.2*1m*(135-270j) = -0.027-0.054j$
3. $V_{mid\_2.05GHz} \sim -0.5*1m*1m*-20j = 1e-5j$
4. $V_{mid\_2.1GHz} \sim -0.5*0.5*1m*1m**-20j = 5e-6j$
5. $V_{mid\_0.05GHz} \sim -0.5*1m*1m*(1.6+1.6j) = -0.8u-0.8uj$

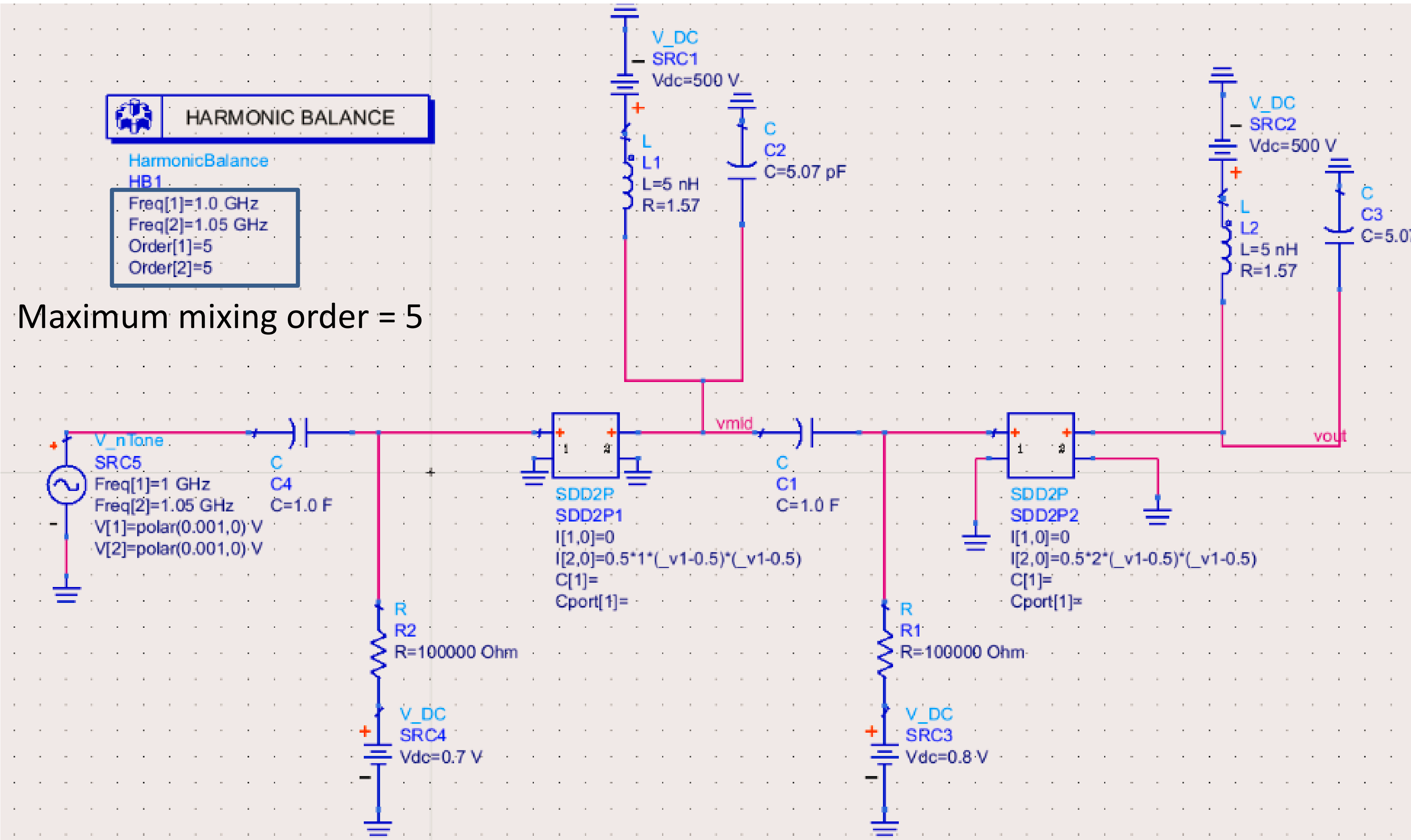
$V_{o\_1.0G} \sim -0.6*-0.125*628 = 47$ V (?!)

$V_{o\_1.1GHz}$ from 4 and 1 $\sim -1*-0.125*5e-6j*(35-160j)$
$= 1e-4 + 2.2e-5j$

$V_{o\_1.1GHz}$ from 2 and 5 $\sim$
$-1*(-0.027-0.054j)(-0.8u-0.8uj)*(35-160j)$
$= -9.6e-6 - 5.7e-6j$

$V_{o\_1.1GHz} \sim 1e-4 + 2.2e-5j$

ADS Harmonic Balance Setup



Maximum mixing order = 5

Assume solution space: m*1.05 + n*1 |m|+|n | < 6

ADS Harmonic Balance Setup

	freq	(vmid)
m=1, n =-1	0.0000 Hz	499.969 + j0.000
m=2, n=-2	50.00 MHz	-7.889E-7 - j7.854E-7
m=1, n =-1	100.0 MHz	4.033E-19 - j9.720E-21
m=-2, n=3	900.0 MHz	-3.181E-17 - j4.531E-17
m=-1, n =2	950.0 MHz	1.316E-16 + j2.155E-16
m=0, n=1	1.000 GHz	-0.125 + j0.008
m=1, n =0	1.050 GHz	-0.023 + j0.052
m=2, n=-1	1.100 GHz	-2.026E-49 + j2.337E-48
m=3, n =-2	1.150 GHz	-6.539E-17 + j1.890E-16
m=-1, n=3	1.950 GHz	-1.031E-17 - j3.303E-18
m=0, n =2	2.000 GHz	-4.457E-8 + j5.229E-6
m=1, n=1	2.050 GHz	-7.832E-8 + j1.004E-5
m=2, n =0	2.100 GHz	-3.459E-8 + j4.831E-6
m=3, n=-1	2.150 GHz	1.854E-18 + j1.183E-18
m=-1, n =4	2.950 GHz	-8.433E-18 + j2.624E-17
m=0, n=3	3.000 GHz	-1.184E-18 + j2.102E-17
	3.050 GHz	-3.487E-18 + j4.037E-18
	3.100 GHz	4.690E-19 + j4.651E-18
	3.150 GHz	5.769E-18 + j3.468E-18
	3.200 GHz	1.106E-18 + j2.423E-17
	4.000 GHz	0.000 + j0.000
	4.050 GHz	1.340E-18 - j4.749E-18
	4.100 GHz	7.339E-19 + j1.269E-17
	4.150 GHz	5.686E-18 - j2.858E-17
	4.200 GHz	1.431E-18 - j2.962E-18
	5.000 GHz	2.019E-19 - j1.082E-17
	5.050 GHz	3.661E-18 + j1.075E-17
	5.100 GHz	0.000 + j0.000
	5.150 GHz	3.593E-18 + j1.969E-18
	5.200 GHz	1.641E-19 + j3.036E-17
	5.250 GHz	-1.480E-18 - j7.660E-18

freq	(vout)
0.0000 Hz	499.844 + j0.000
50.00 MHz	-0.015 + j0.005
100.0 MHz	-3.862E-11 - j8.091E-11
900.0 MHz	-3.431E-15 + j3.261E-15
950.0 MHz	-1.036E-4 - j5.779E-5
1.000 GHz	46.758 - j6.139
1.050 GHz	-6.436 - j7.291
1.100 GHz	9.356E-5 + j3.659E-5
1.150 GHz	-1.264E-14 - j5.860E-15
1.950 GHz	9.163E-11 - j8.805E-11
2.000 GHz	0.020 + j0.162
2.050 GHz	0.133 + j0.051
2.100 GHz	0.024 - j0.020
2.150 GHz	7.002E-11 + j7.162E-11
2.950 GHz	-2.199E-16 - j4.119E-17
3.000 GHz	7.682E-6 - j4.189E-7
3.050 GHz	1.590E-5 - j3.911E-6
3.100 GHz	9.533E-6 - j6.240E-6
3.150 GHz	1.281E-6 - j2.764E-6
3.200 GHz	-6.728E-17 - j9.321E-18
4.000 GHz	2.046E-12 - j1.144E-10
4.050 GHz	7.421E-12 - j4.334E-10
4.100 GHz	1.010E-11 - j6.161E-10
4.150 GHz	6.117E-12 - j3.895E-10
4.200 GHz	1.390E-12 - j9.244E-11
5.000 GHz	1.038E-16 - j3.888E-17
5.050 GHz	-3.087E-17 + j2.804E-17
5.100 GHz	-4.442E-17 - j1.739E-20
5.150 GHz	-2.747E-18 - j1.043E-21
5.200 GHz	-1.078E-16 - j3.004E-17
5.250 GHz	3.022E-17 + j7.226E-18