How to Simulate IIP3 using SpectreRF?

Anuranjan Jha, Columbia Integrated Systems Lab

Revised: November 14, 2005

Low frequency case: Where you do not need 50 ohm source and input matching.

Let's begin with the simplest example — a common-source amplifier with resistive load with no degeneration and no input matching. We will deal in units of dBV.

Fig. 1(a) presents a test setup for measuring the IIP3 of my amplifier. First I set the two-tones needed for the test as 10 MHz and 12 MHz (see fig. 2(a) and 2(b)). The input is specified in terms of peak amplitude. Even though I am using a port in the simulation, it is not required *here*. In the results you will note that I have taken the V_{GS} voltage as my input reference. With ports, unless there is a perfect matching with its input resistance, the voltage you get from it is dependent on the load. For example, since the port is driving a capacitive load here, the voltage at the gate will be 40 mVpp for Vpk set to 20 mVpp in the port properties. I can now run *pss* to find the steady state response and then proceed to find the 3^{rd} -order amplitude in units of dBV. The *pss* results are shown in fig. 3. I tabulated the results for different V_{GS} cases and plotted them using MATLAB. The intercept point is shown in fig. 6(a). The *IIP*₃ for this Common-Source amplifier is about -7.5 dBV.

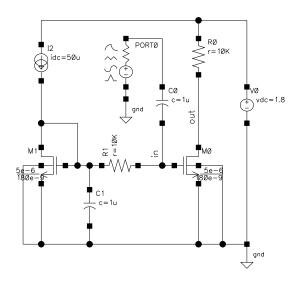
Next I simulated an amplifier with same nFET but with a source degeneration resistance of 500 Ω and load of 5 k Ω . Figs. 1(b), 4, 5 shows the test setup, the properties of the *vsin* source used in the setup and the SpectreRF results when two-tone signals of amplitude 350 mV are applied, respectively. The *IIP*3 result is shown in fig. 6(b). It has improved to about -2.5 dBV.

The data and MATLAB code for Common-Source amplifier is attached below.

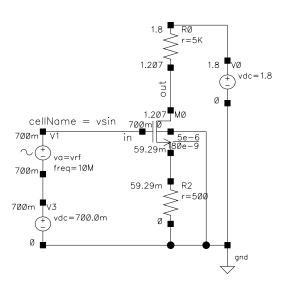
```
% Results of two-tone test of Common-Source Amplifier
% Circuit: /home/anu/cadence/ee6314_F05/CSampl
```

```
vrf = [1 2 5 10 20 30 40 50 75 100 150]*1e-3;
in = [-54.02 -48 -40.04 -34.02 -28 -24.48 -21.98 ...
-20.04 -16.52 -14.02 -10.5];
out10M = [-36.54 -30.52 -22.57 -16.6 -10.79 -7.663 ...
-5.99 -5.09 -4.064 -3.63 -3.262];
out8M = [-127.8 -109.74 -85.9 -67.98 -50.28 -38.52 ...
-28.71 -23.59 -18.3 -16.09 -14.35];
im3 = out10M - out8M;
inp = [-54.02 -48 -40.04 -34.02 -28 -24.48 -21.98 ...
-20.04 -16.52 -14.02 -10.5 -7.5];
int1 = out10M(1) + (inp-inp(1));
int3 = out8M(1) + 3*(inp-inp(1));
```

```
figure;
plot(in,out10M,'k-x','linewidth',2,'markersize',12); hold on;
plot(in,out8M,'k-o','linewidth',2,'markersize',12);
plot(inp,int1,'r-x','linewidth',2,'markersize',8);
```







(b)

Fig. 1. Test setup for IIP3 measurement of (a) Common-Source Amplifier (b) Source-degenerated amplifier.

```
plot(inp,int3,'g-o','linewidth',2,'markersize',8); hold off;
set(gca,'ylim',[-175 15],'ytick',[-175:25:0],'fontsize',16);
L = legend('\omega_1','2\omega_1 - \omega_2');
set(L,'box','off','fontsize',16,'location','northwest');
xlabel('V_{gs}, dBV','fontsize',16);
ylabel('V_{out}, dBV','fontsize',16);
% Results in an IIP3 of -7.5 dBV
print -depsc CSamplIIP3.eps
```

RF CASE: WHERE YOU DO NEED 50 OHM SOURCE AND INPUT MATCHING. Think about it... Coming up...

ок	Cancel	Apply	Defaulte	Previous	Novt			Help	ок	Cance	Defaults	Apply		
UK			port	Previous	Next		off 😑	neih	~	Care	v qpsp	1 debu 3		
View Name			symboli					0						
								Periodic Steady State Analysis						
	Instance Name		PORTO	PORTŮ			off =		Fundamental Tones					
			Ac	td 🛛	Delete	Modify	1		# 1	lame	Expr	Value	Signal	SrcId
	User Property		Ма	Master Value Local Value			Display		req1	10M	10M	Large	PORTO	
	lvsign	nore	TRUE				off 🤤		2 1	req2	12M	12M	Large	PORTO
	CDF P	Paramete	r		Value		Display		Ī		<u> </u>	Ĩ	Large 💷	
esist	tance		50	0 Ohms <u>í</u>			off 🖃			Clear/Ad	d Delei	te Up	date From Sch	hematic
ort n	umber						off 🖃							
IC voltage		ľ	I			off =		200	Beat Fri Beat Pe	13 2512	2M	Auto	o Calculate 🔳	
ource type		sir	sine 🖃			off 🖃			Detterre					
Frequency name 1		f	freqL					Output harmonics						
			0.0						Uuu	put nam	nonics			
	equency		10	OM Hz			off 🖃		a second	and the second	nonics narmonics -	20		
Fre		1		OM Hz cf V			off		a second	and the second		20		
Fre An	equency oplitude 1	1		and a second second					Nun	nber of h				
Fre An An	equency oplitude 1 oplitude 1	1 1 (Vpk)	V	and a second second			off 💷		Nun	nber of h uracy De	narmonics efaults (err		liberal	
Fra An An Ph	equency oplitude 1 oplitude 1	1 1 (Vpk) 1 (dBm) Sinusoid	V	and a second second			off 💷		Acc	nber of h uracy De I conser	armonics efaults (err vative i	preset)		
Fre An An Ph Sir	equency oplitude 1 oplitude 1 ase for 5	1 1 (Vpk) 1 (dBm) Sinusoid vel	V	and a second second			off		Nun Acci Add	nber of h uracy De I conser itional Ti	efaults (err vative r me for Sta	preset) noderate _ bilization (ts		yes
Fra An An Ph Sir De	equency oplitude 1 oplitude 1 ase for 1 ne DC lev lay time	1 1 (Vpk) 1 (dBm) Sinusoid vel	1	and a second second			off = off = off =		Nun Accu Addi Sav	nber of h uracy De I conser itional Ti e Initial	efaults (err vative _ r me for Sta Transient F	preset) noderate _ bilization (ts	stab) 📗	yes
Fra An An Ph Sir De spla	equency oplitude 1 oplitude 1 ase for 1 ne DC lev lay time	1 1 (Vpk) 1 ((IBm) Sinusoid vel d sinusoi	1 <u>v</u>	and a second second			off = off = off = off =		Nun Accu Addi Sav	nber of h uracy De I conser itional Ti	efaults (err vative _ r me for Sta Transient F	preset) noderate _ bilization (ts	stab) 📗	yes
Fre An Ar Ph Sir De ispla	equency uplitude 1 uplitude 1 ase for 4 ne DC lev lay time y second	1 1 (Vpk) 1 (IIGm) Sinusoid vel d sinusoi name 2	1 1 4 f	cf V			off = off = off = off = off =	Ţ	Nun Accu Addi Sav	nber of h uracy De I conser itional Ti e Initial	efaults (err vative _ r me for Sta Transient F	preset) noderate _ bilization (ts	stab) 📗	yes
Fre An Ar Ph Sir De ispla Fre Fre	equency oplitude 1 oplifude 1 ase for 5 ne DC lev lay time y second equency	1 1 (Vpk) 1 (dBm) Sinusoid vel d sinusoi name 2 2	1 d 1 1	cf ¥			off off off off off off off	-	Num Acc: Addi Sav Osc	nber of h uracy De I conser itional Ti e Initial illator	efaults (err vative _ r me for Sta Transient F	preset) noderate _ bilization (ts	stab) 📗	yes
Fre An Arr Ph Sir De ispla Fre An	equency aplitude 1 aplitude 1 ase for : ase for : a DC lev lay time y second equency equency aplitude 2	1 1 (Vpk) 1 (dBm) Sinusoid vel d sinusoi name 2 2	1 d 1 1	cf पूँ ceq2 2M Hzूँ			off "	Ţ	Num Acc: Addi Sav Osc	nber of h uracy De I conser itional Ti e Initial	efaults (err vative _ r me for Sta Transient F	preset) noderate _ bilization (ts	stab) 📗	yes

(a)

(b)

Fig. 2. (a) Properties of the port used in the test setup of fig. 1(a) (b) PSS analysis form.

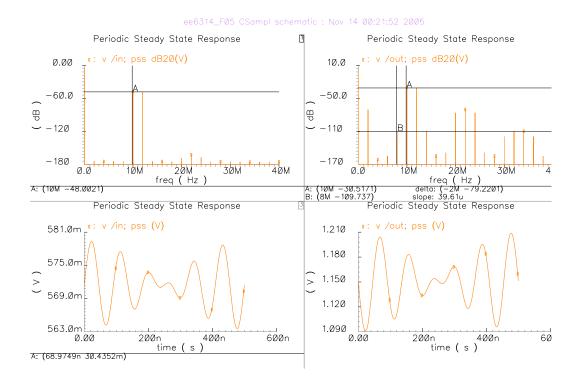


Fig. 3. SpectreRF results for smallest applied V_{GS} .

ок	Cancel	Apply	Defaults	Previous	Next		He
lvsignore T			TRUE		off 🖃		
	CDF P	aramete	r)	Value	Display	
AC ma	agnitude		Ĩ			off 🖃	
AC ph	ase		Ĭ.			off 🖃	
DC vo	Itage		Ĩ			off 🚽	
Offse	t voltage		Ľ			off 🖃	
Amplitude				cf V		off =	
Frequ	ency		10	DM Hz		off 🖃	
Delay time					off 🖃		
Damping factor					off 🖃		
First 1	requency	[,] name	fr	reqlį		off 🖃	
Secor	nd freque	ncy nan	ne fr	reqŽ		off 🖃	
Noise	file name		Ĩ			off 🛶	
Number of noise/freq pairs			oairs 🦉			off 🚘	
XF magnitude			Ĭ.		off =		
PAC magnitude			Ĭ.		off =		
PAC phase			Ĭ.		off 💷		
Initia <mark>l</mark> phase for Sinusoid			oid Ĭ.		off 🖃		
Amplit	tude 2		VI	rf V		off 💷	
Initial phase for Sinusoid 2			oid 2		off 🖃		
Frequ	ency 2		12	2M Hz		off	

Fig. 4. Properties of the *vsin* source used in the test setup.

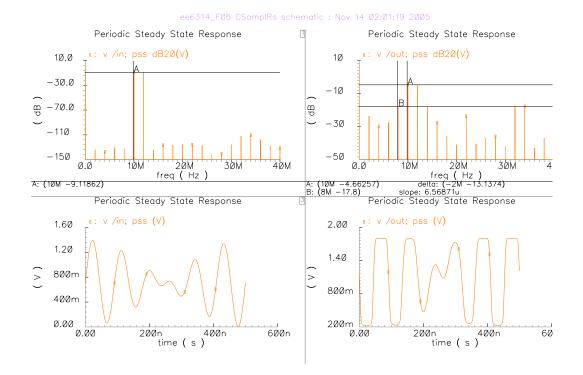


Fig. 5. SpectreRF results for largest applied V_{GS} for fig. 1(b)

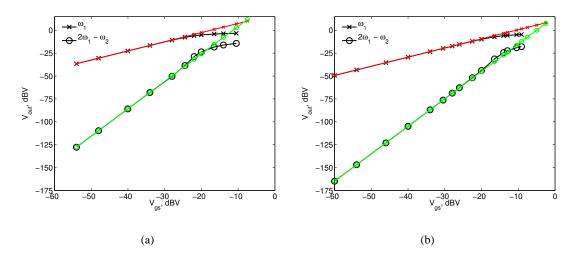


Fig. 6. IIP_3 comparison for (a) Common-Source amplifier and (b) Source degenerated amplifier.