Johns Hopkins University
MMIC Class Fall 2010
Measured Results (Spring 2011)

John E. Penn & Dr. Willie Thompson

5x10mm Tile

9-60x60mil

3-60x90mil

3-60x120mil

Test Circuits:

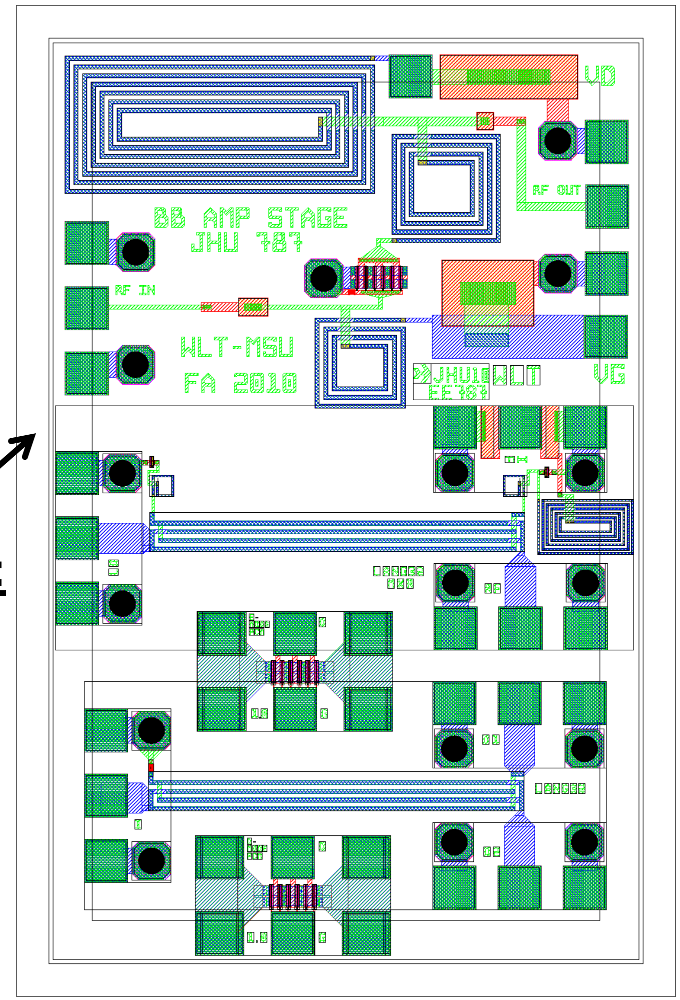
JHU10WLT

2-6GHz Amp

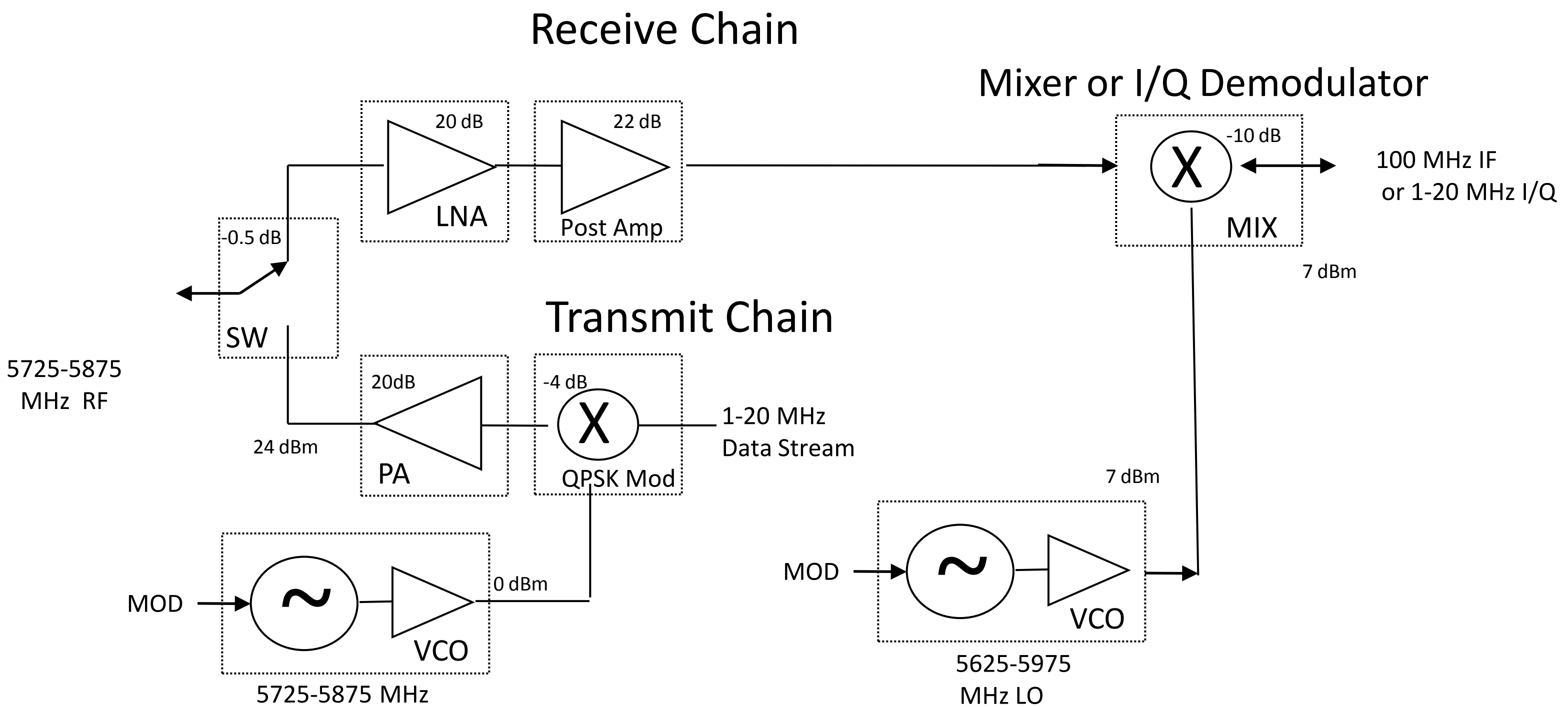
Diode Mixer

Test PHEMTs

Lang Coupler



Typical RF Sub-System Block Diagram
Students Design Low DC Power Circuits



Chip Set for the 5725-5875 MHz ISM Bands

<u>Design Goals:</u>

Battery Power (What Voltage?)

Low Power (i.e Power Efficient)

Output Power 10 or 100 mW?

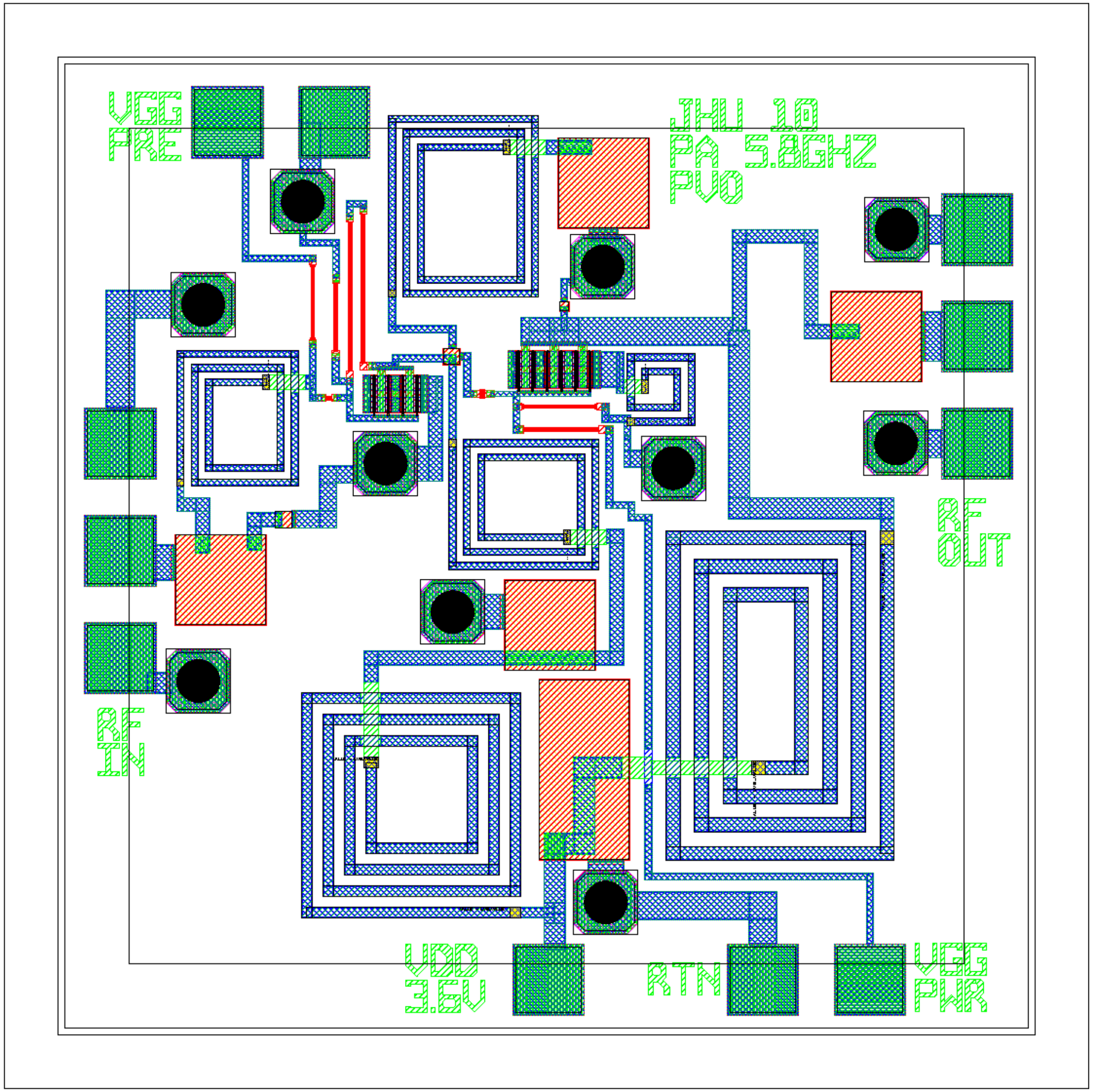
Data Rate? Filters?

PROJECTS F10 (Checklist)

C-band Power Amplifier –Paul Van Opens jhu10pvo
C-band Power Amplifier –Mitch Flowers jhu10mf
C-band Low Noise Amplifier –Wade Freeman jhu10wf
C-band Power Amplifier –James Pociluyko jhu10jnp
C-band Voltage Controlled Osc–Chris Hinton jhu10crh
C-band Voltage Controlled Osc–Ben Woodworth jhu10bw
C-band Transmit/Receive Switch–Nick Garneski jhu10ng
C-band Mixer–James McKnight jhu10jwm

Name	DRC	LVS	Current/Bias	Text	Visual
jhu10bw	**X**	**X**	**(22mA) X**	**X**	**X**
jhu10mf	**X**	**X**	**(?) X**	**X**	**X**
jhu10ng	**X**	**X**	**X**	**X**	**X**
jhu10crh	**X**	**X**	**(10mA) X**	**X**	**X**
jhu10jwm	**X**	**X**	**X**	**X**	**X**
jhu10jnp	**X**	**X**	**(20/36mA) X**	**X**	**X**
jhu10pvo	**X**	**X**	**(20/65mA) X**	**X**	**X**
jhu10wf	**X**	**X**	**(10/10mA) X**	**X**	**X**
jhu10pr1	**X**	**X**		**X**	
jhu10pr2	**X**	**X**		**X**	
jhu10prj	**X**			**X**	
jhu09prj	**X**			**X**	
jhu10wlt	**X**	**X**		**X**	**X**
jhu10p24	**X**	**X**		**X**	
jhu10jep	**X**			**X**	

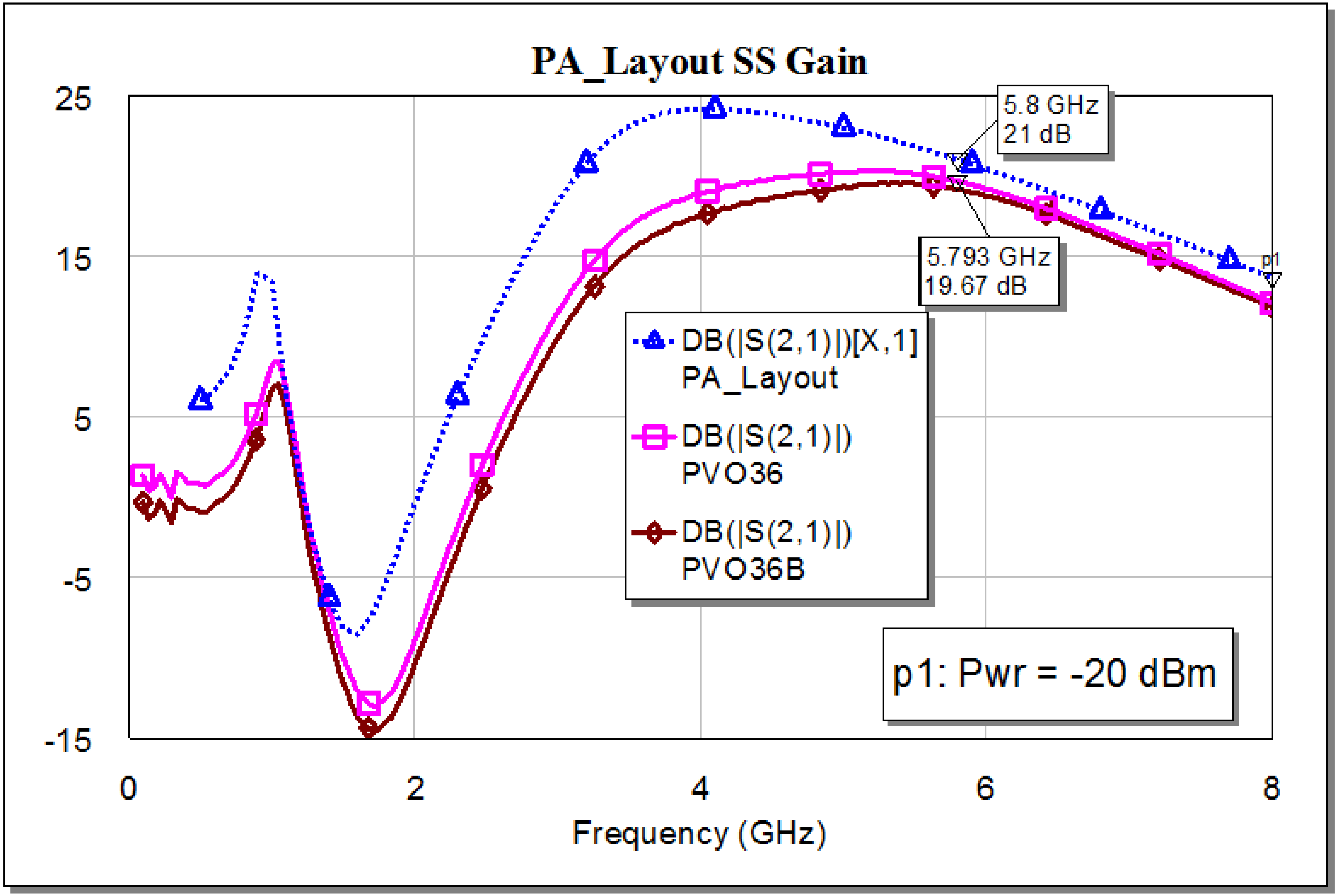
Test PHEMTs: E/D 4x15, 6x50, 6x80E; 4x50E, 6x40D, 6x44D, 6x86D, 6x55D, 10x96E



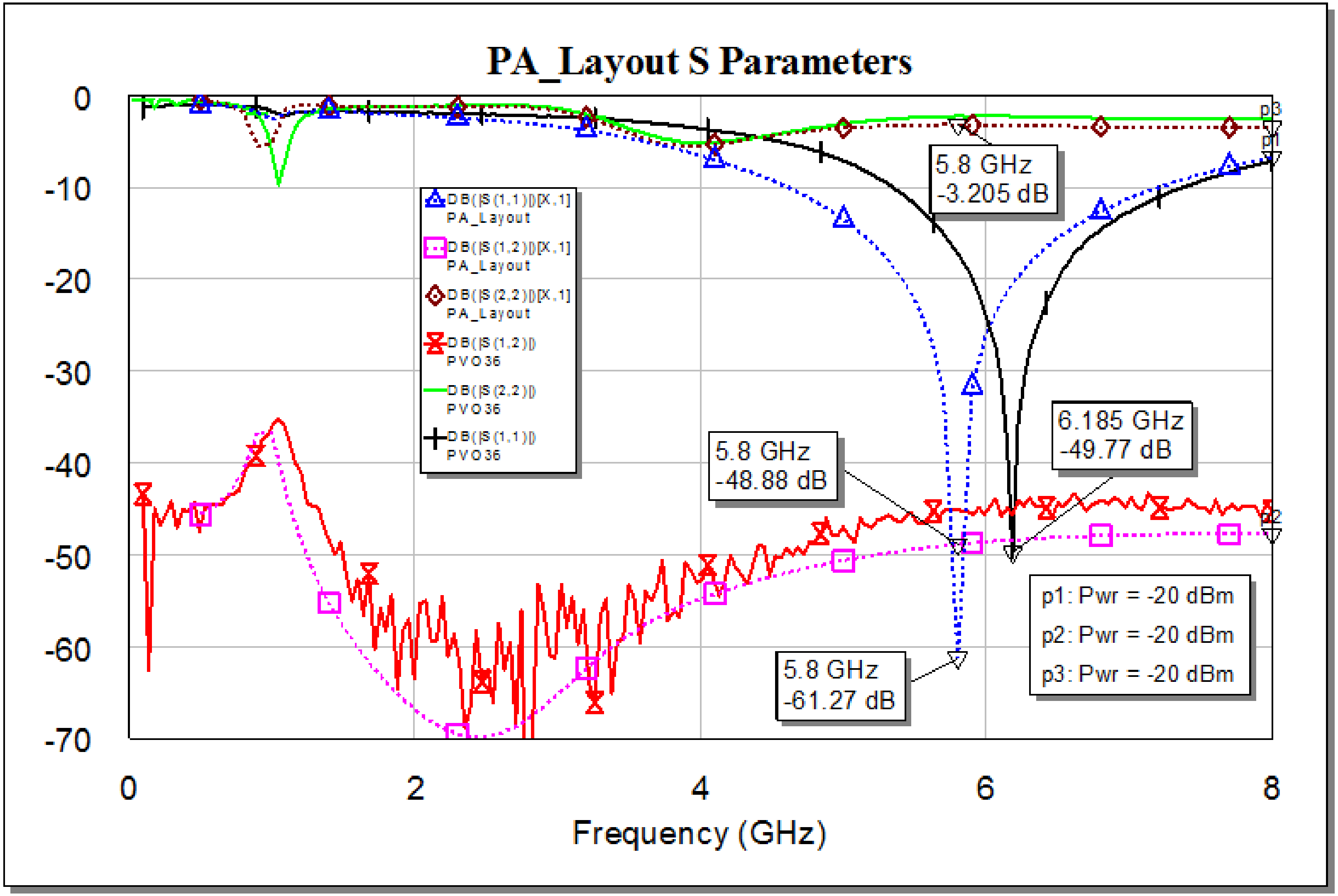
1) Paul Van Opens
JHU10PVO
Power Amp

Power Amplifier for 5.8 GHz band with about 20 dB SS gain targeted for 100 mW Pout.
DC Bias measured was about as predicted: VD 3.6V at 70-75 mA
S-parameters are shown following with good agreement between simulations and measurements and a slight shift in frequency of the input match.
Measured output power was about 2 dB below the 20 dBm goal , which was pretty typical for the designs from the fall 2010 JHU MMIC Class.
Fabrication was provided by TriQuint's using their TQPED GaAs process.

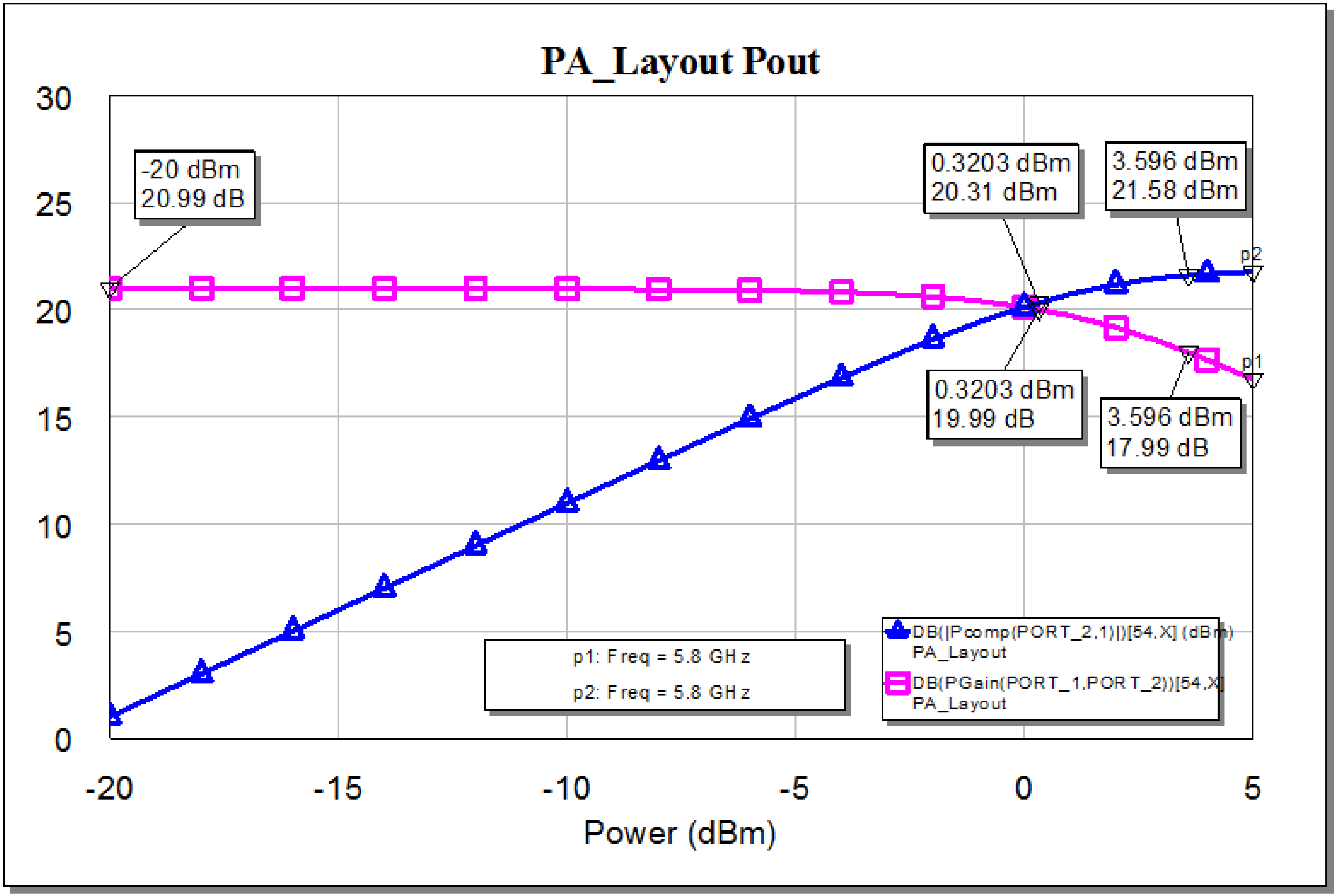
PVO 5.8 GHz Power Amp (Meas/Sim)



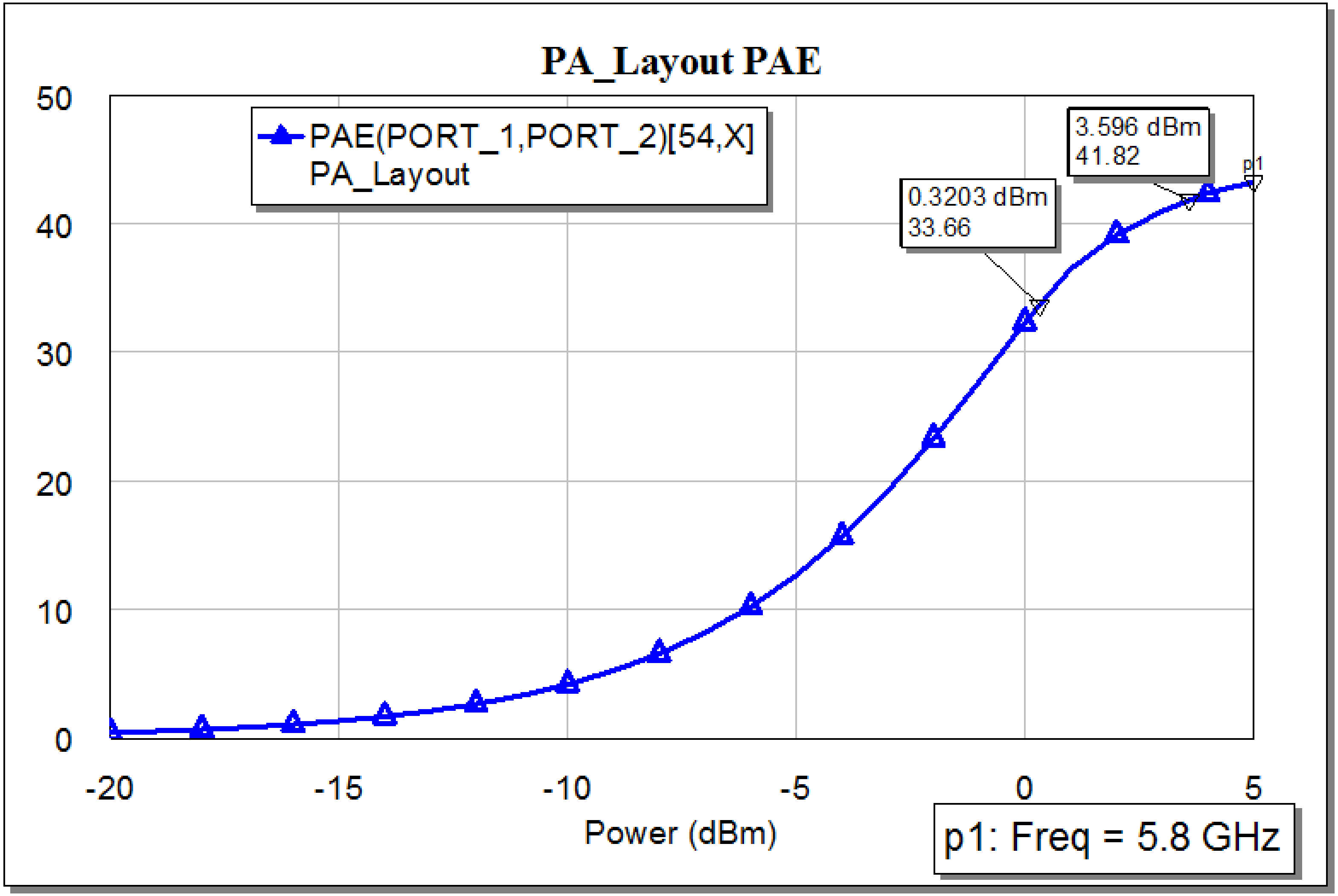
PVO 5.8 GHz Power Amp (Meas/Sim)



PVO 5.8 GHz Power Amp (Sim)



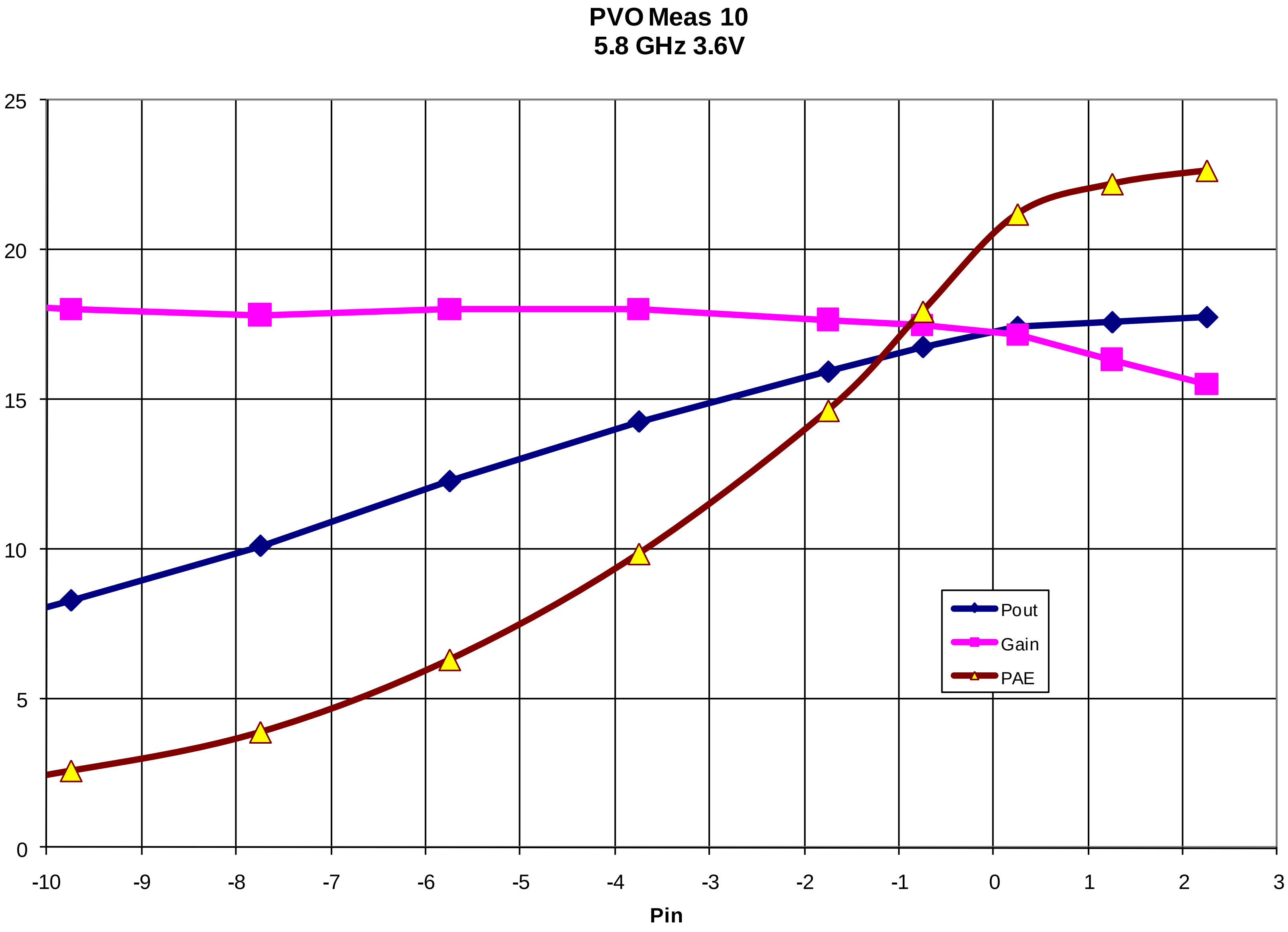
PVO 5.8 GHz Power Amp (Sim)

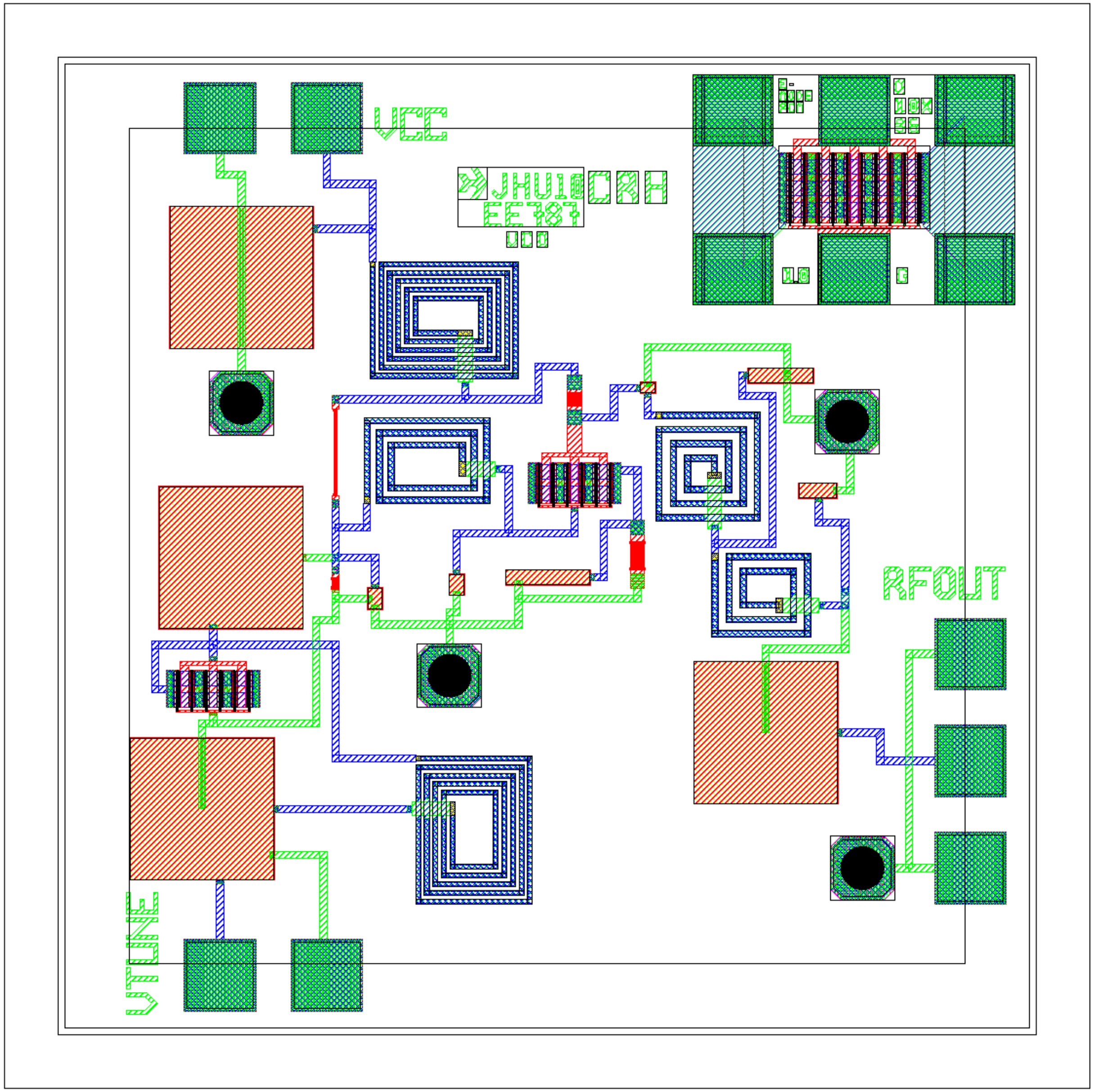


PVO 5.8 GHz Power Amp (Meas)

Paul Van Opens Power Amp--5.8 GHz 3.6 V									
				Loss 3.5 dB for thru					
5.8 GHz	Die#2	**PVO 5.8 GHz E/Dmode Fall10 TQPED**				3.6V ; 70 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.6V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-20.0	-5.67	-21.75	-3.92	17.83	70	252.0	0.41	0.2	0.2
-10.0	4.83	-11.75	6.58	18.33	71	255.6	4.55	1.8	1.8
-8.0	6.50	-9.75	8.25	18.00	71	255.6	6.68	2.6	2.6
-6.0	8.33	-7.75	10.08	17.83	72	259.2	10.19	3.9	3.9
-4.0	10.50	-5.75	12.25	18.00	73	262.8	16.79	6.4	6.3
-2.0	12.50	-3.75	14.25	18.00	74	266.4	26.61	10.0	9.8
0.0	14.17	-1.75	15.92	17.67	73	262.8	39.08	14.9	14.6
1.0	15.00	-0.75	16.75	17.50	72	259.2	47.32	18.3	17.9
2.0	15.67	0.25	17.42	17.17	71	255.6	55.21	21.6	21.2
3.0	15.83	1.25	17.58	16.33	70	252.0	57.28	22.7	22.2
4.0	16.00	2.25	17.75	15.50	71	255.6	59.57	23.3	22.6

PVO 5.8 GHz Power Amp (Meas)



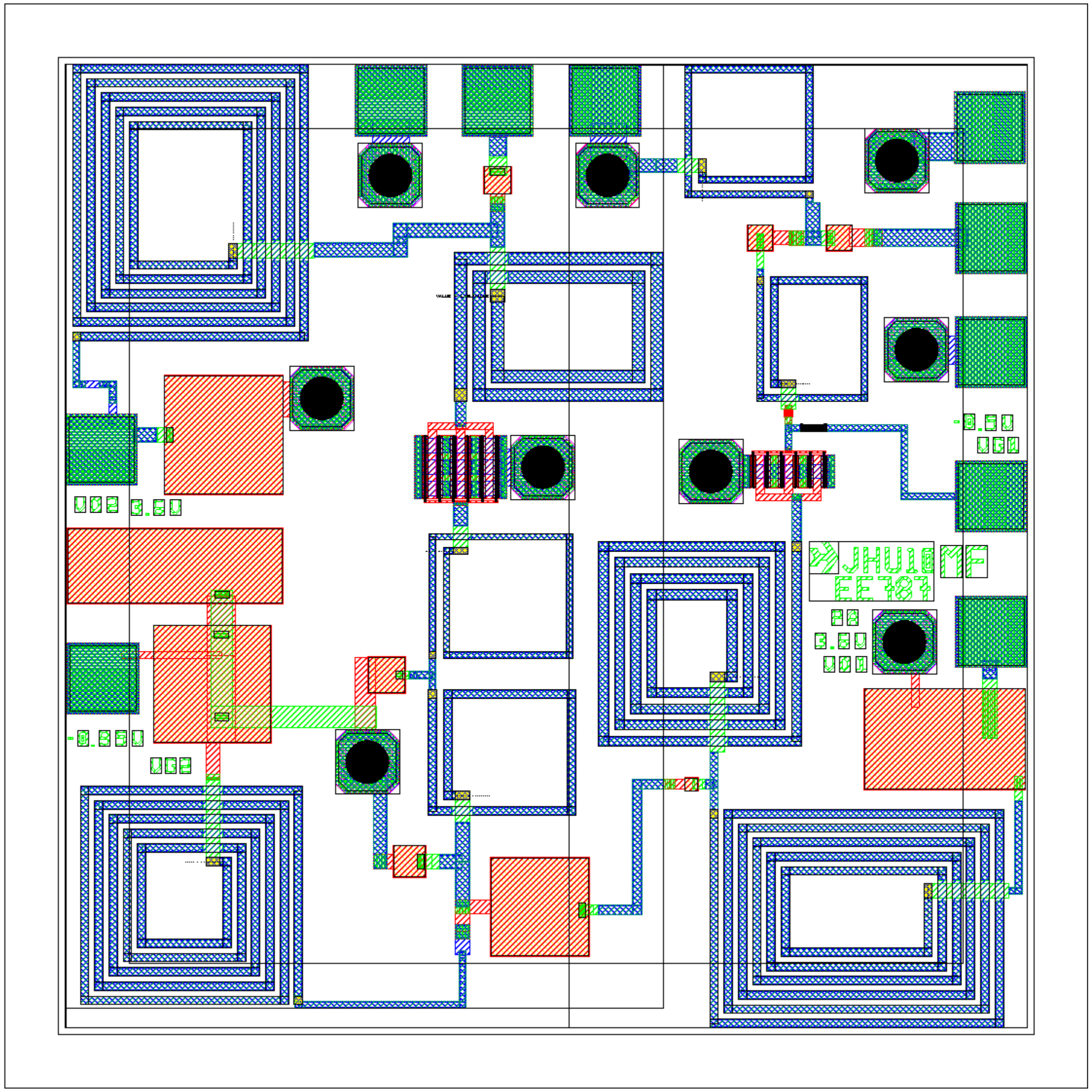


2) Chris Hinton JHU10CRH VCO

Voltage Controlled Oscillator (VCO) for 5.8 GHz band.
DC Bias was as predicted: 3V at 10-11 mA
Did not appear to oscillate, however the spectrum analyzer showed periodic bursts around 7GHz which seemed to be the oscillation attempting to build up but did not have sufficient margin. Hope to re-simulate EM of layout to look for unsimulated parasitic coupling and to try an output load (other than 50 ohms) to see if it will oscillate. Tried manual Load Pull Tuner to try and get it to oscillate.

Test PHEMT 10x96E
3V 27, 76 mA Bias
E960327 Vg=+0.53V
E960376 Vg=+0.64V

3) Mitch Flowers
JHU10MF PA



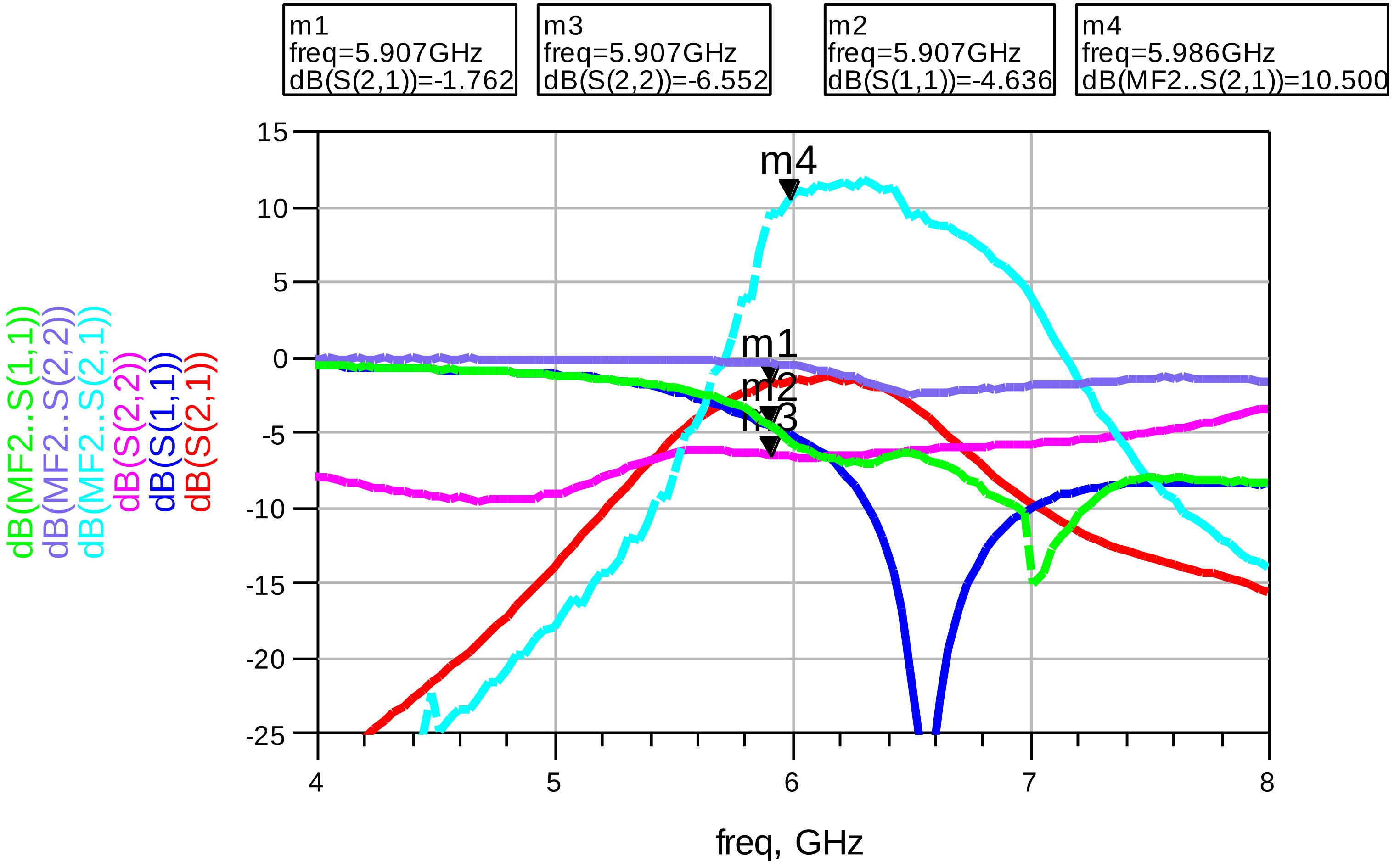
Power Amplifier for 5.8 GHz band. Often it is hard to eliminate low frequency oscillation problems with the probe station at the JHU Dorsey campus, and this design presented some of those issues when the DC bias was increased to about 10 dB gain. Measurements were made of just the first stage (-0.5V VGS, 6-7 mA at 3.6V) to see if the input match looked reasonable. Then the 2nd stage was biased at its class B (near pinchoff) bias and the input power level increased. During power measurements, the input signal was increased until it saturated and eliminated the low frequency oscillations. Output power was then close to its 20 dbm goal. Wire bonding 100 pf caps next to the MMIC and retesting should provide better results.

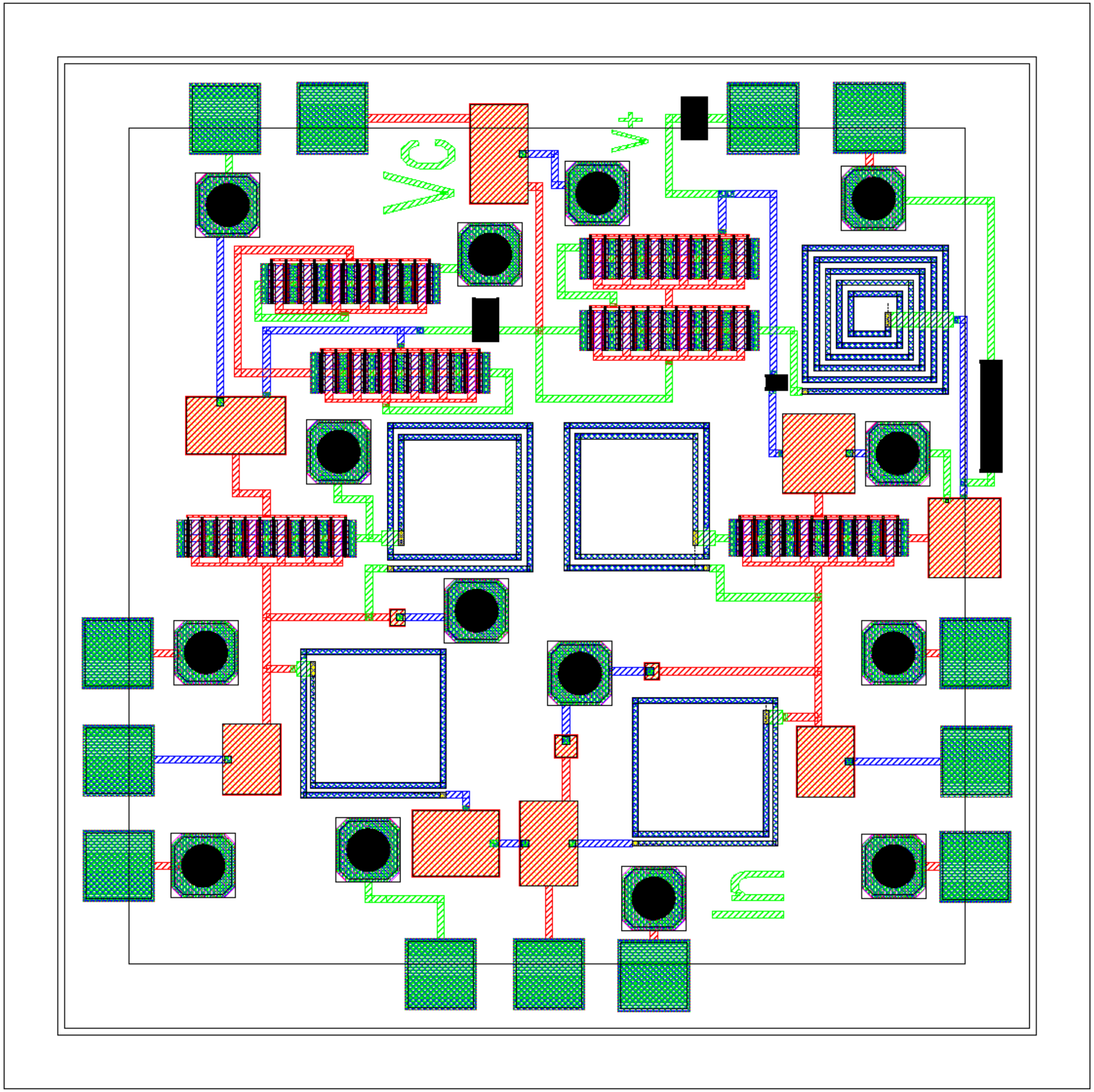
MF 5.8 GHz Power Amp
Low Frequency Stability Test Problems

Mitch Flowers Power Amp--5.8 GHz Low Freq. Stability Test Problems									
				Loss 3.5 dB for thru		Stg1 3.6V at 16 mA			
5.8 GHz	Die#1	**MF 5.8 GHz Dmode Fall10 TQPED**				3.6V ; 70 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**IStg2(V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
9.0	16.50	7.25	18.25	11.00	(3.0/46)	195.6	66.83	34.2	31.5
10.0	16.67	8.25	18.42	10.17	(3.0/48)	201.6	69.50	34.5	31.2
10.0	17.00	8.25	18.75	10.50	(3.2/50)	217.6	74.99	34.5	31.4
11.0	17.50	9.25	19.25	10.00	(3.4/52)	234.4	84.14	35.9	32.3
12.0	17.83	10.25	19.58	9.33	(3.5/54)	246.6	90.78	36.8	32.5
13.0	18.17	11.25	19.92	8.67	(3.6/54)	252.0	98.17	39.0	33.7

Note: Adjusted 2nd stage bias and input drive level until low frequency (~20 MHz) oscillations disappeared. Note, output power of about 20 dBm which meets the design goal. Gain above 10 dB seemed to be the edge of the oscillation/stability region. Might be able to retest with decoupling caps closer to the MMIC die. Performance shown with 1st stage at 3.6V 16 mA bias.

MF 5.8 GHz Power Amp (1st Stage Only-solid, both-dash) Low Frequency Stability Test Problems



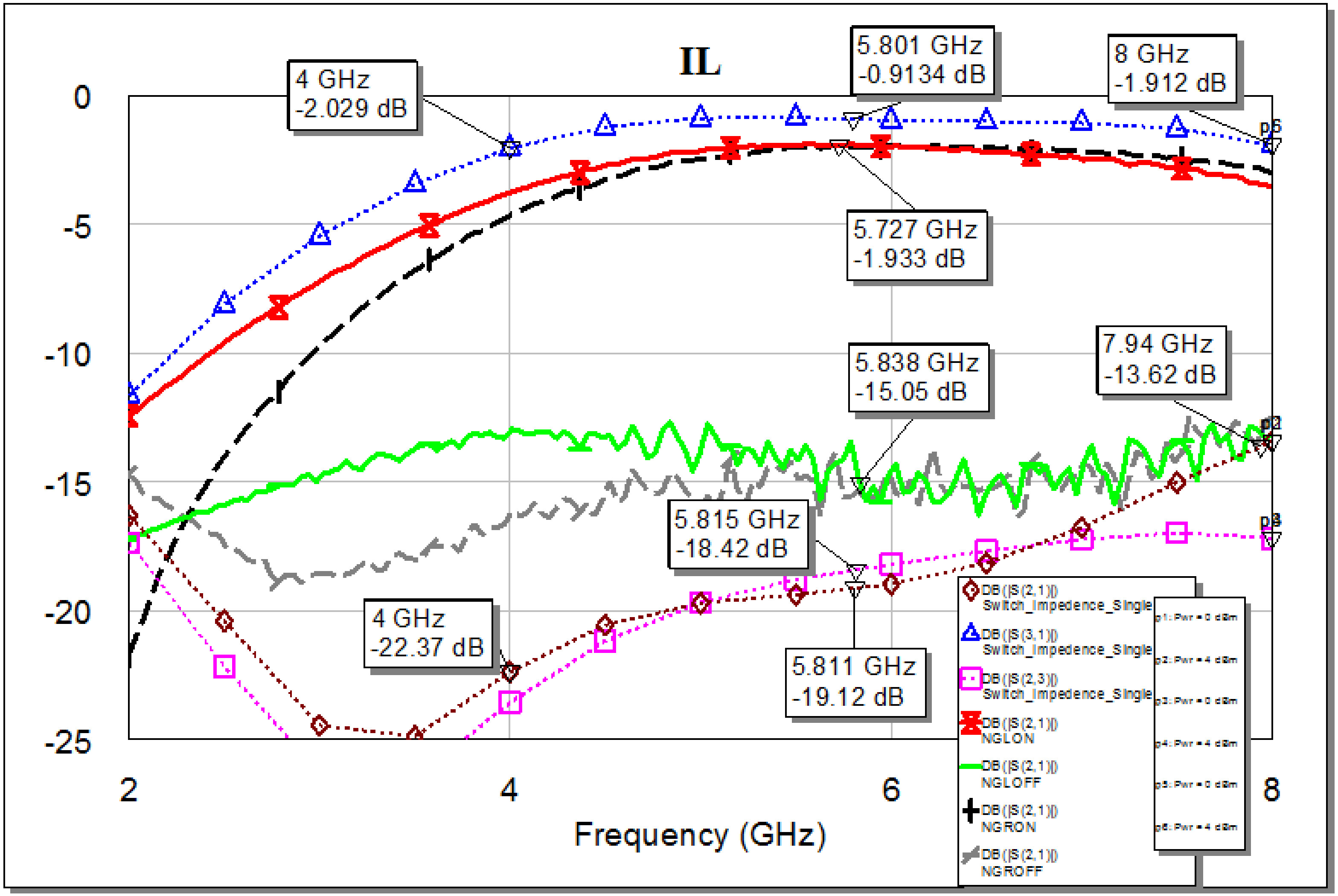


4) Nick Garneski
JHU10NG TRS

Transmit/Receive Switch (TRS) for 5.8 GHz band. This design includes a circuit to create the complementary switch control inputs from a nominal 3V supply and an control input of 0, or 3V. The design worked well including the driver. Plots of simulation versus measurements follow.

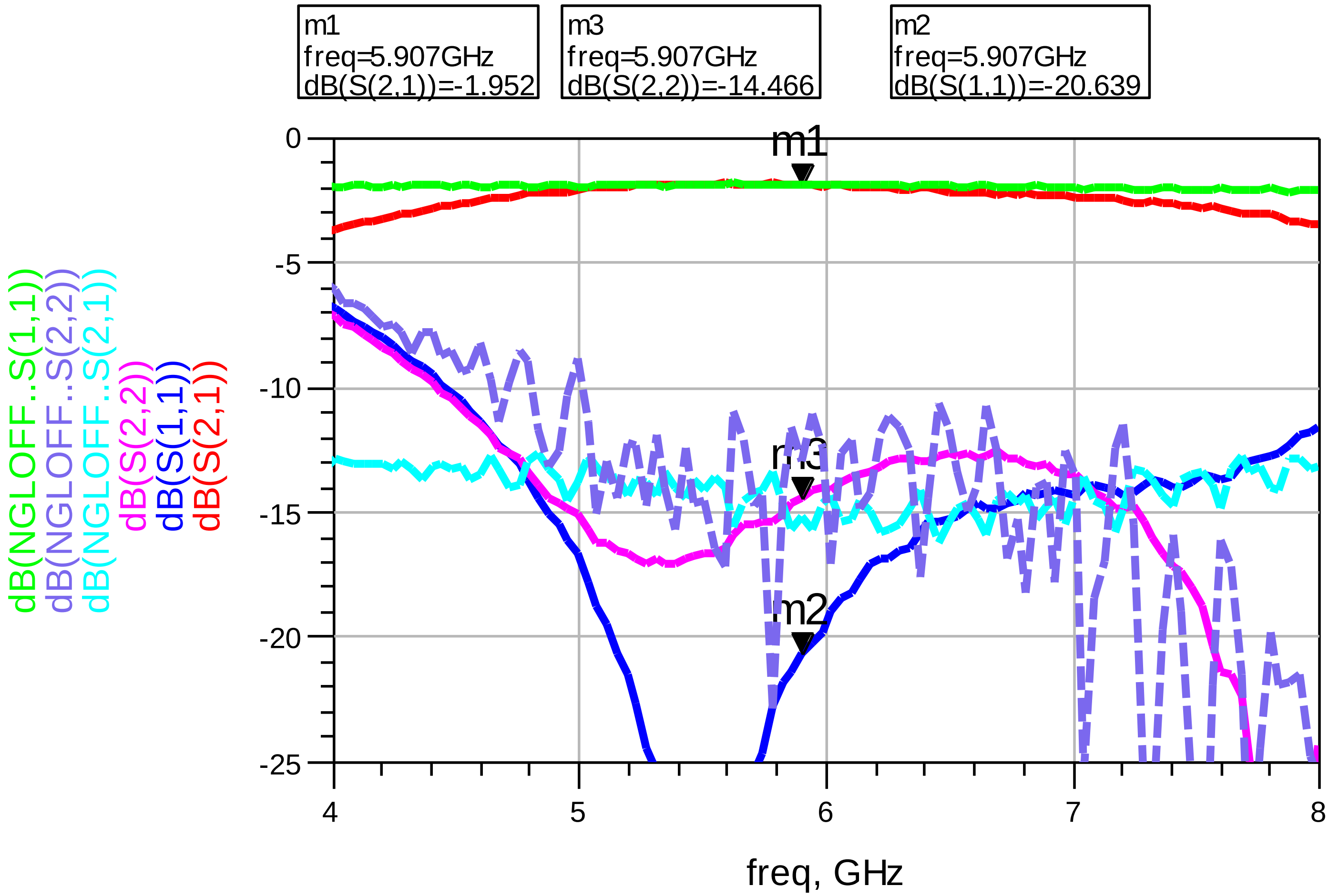
S-Parameter Files (on, off)
Left = L , Right + R
NGLON V+ 3V, Vc 0V
NGLOFF V+ 3V, Vc 3V
NGRON V+ 3V, Vc 3V
NGROFF V+ 3V, Vc 0V

NG 5.8 GHz TR Switch (Meas vs. Sim-dotted)

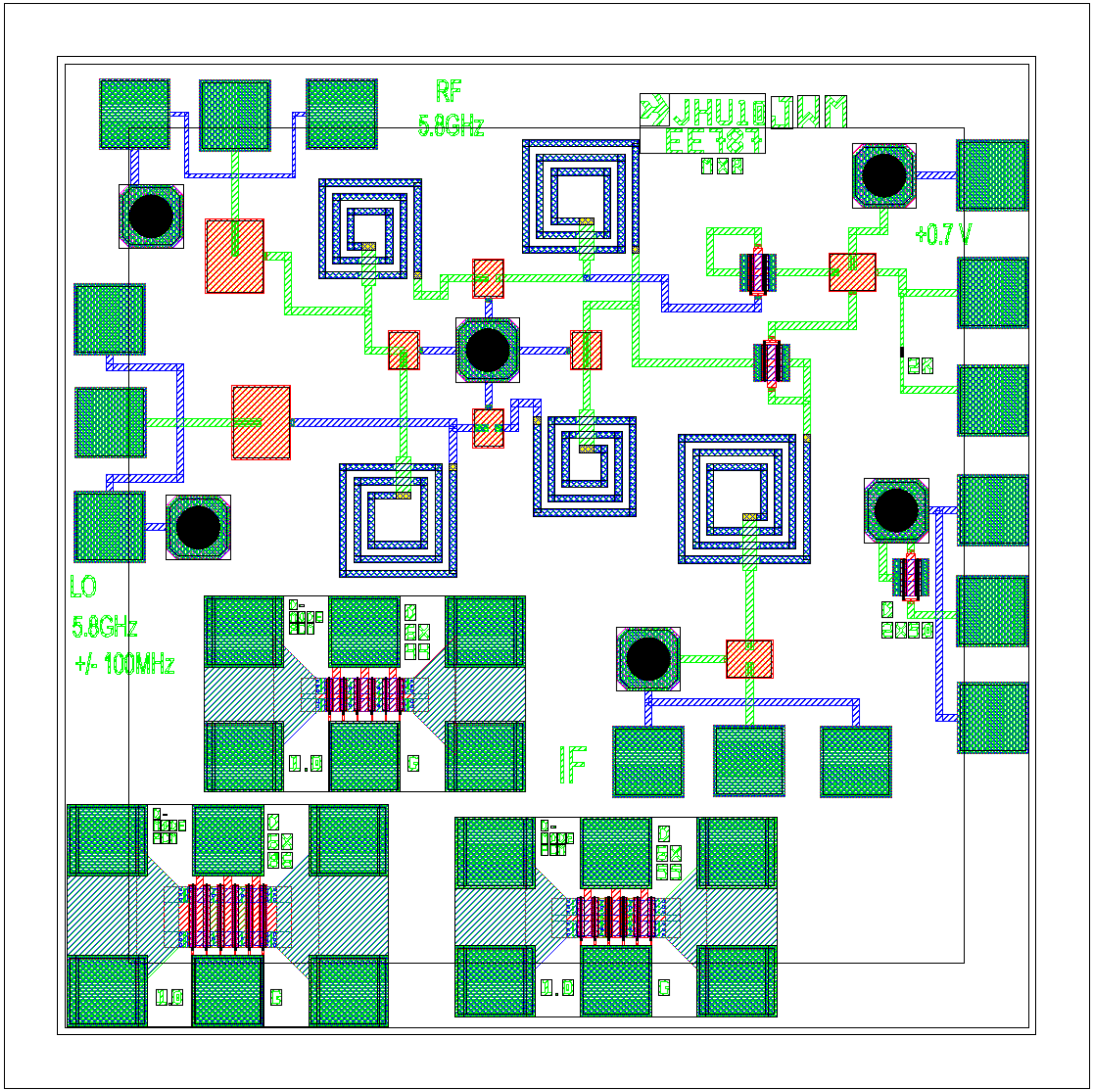


Note: 3rd RF port is terminated in 50 ohms and is not calibrated (noisy meas.).

NG 5.8 GHz TR Switch (Meas ON/OFF)



Note: 3rd RF port is terminated in 50 ohms and is not calibrated (noisy meas.).



5) James McKnight JHU10JWM MXR

Diode Mixer for 5.8 GHz band. This design includes a lumped element hybrid and a DC offset to provide good conversion loss with low Local Oscillator (LO) drive levels. Following are the results which were very good when +0.7V at 1-2 mA of DC bias is provided. This mixer was combined with Ben Woodworth's VCO design and worked very well (see JHU10PR1).

Test PHEMT 6x44D
D264313 Vg = -0.51V 3V 13 mA
D264327 Vg = -0.35V 3V 27 mA
Test PHEMT 6x86D
D516326 Vg = -0.51V 3V 26 mA
D516353 Vg = -0.35V 3V 53 mA
Test PHEMT 6x55D
D330317 Vg = -0.51V 3V 17 mA
D330334 Vg = -0.35V 3V 34 mA

JM 5.8 GHz Mixer

Measured Mixer										**Freq (GHz**
James McKnight Mixer 5.8 GHz LO										5.80
				RF 5.81/5.825 GHz and IF 10/25 MHz -10 dBm setting						
	LO = 5.8 GHz									
1) RF 5.81/5.825 GHz										
Down Conversion			**IF=10 MH**	No Bias			**IF=25 MHz**			
LO 5.8G	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	**LO 5.8G**	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	
6	4.25	-57.2	-11.8	**-45.5**	6	4.25	-56.0	-11.8	**-44.3**	
8	6.25	-33.2	-11.8	**-21.4**	8	6.25	-34.2	-11.8	**-22.4**	
10	8.25	-27.2	-11.8	**-15.5**	10	8.25	-31.2	-11.8	**-19.4**	
12	10.25	-26.0	-11.8	**-14.3**	11	9.25	-32.3	-11.8	**-20.6**	
14	12.25	-25.3	-11.8	**-13.6**	12	10.25	-36.5	-11.8	**-24.8**	
Down Conversion			**IF=10 MH**	"+0.7V Bias w/ 2K Resistor"			**IF=25 MHz**			
LO 5.8G	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	**LO 5.8G**	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	
0	-1.75	-47.8	-11.8	**-36.1**	0	-1.75	-46.7	-11.8	**-34.9**	
2	0.25	-47.0	-11.8	**-35.3**	2	0.25	-46.0	-11.8	**-34.3**	
4	2.25	-46.3	-11.8	**-34.6**	4	2.25	-45.7	-11.8	**-33.9**	
6	4.25	-44.0	-11.8	**-32.3**	6	4.25	-43.3	-11.8	**-31.6**	
8	6.25	-31.2	-11.8	**-19.4**	8	6.25	-32.7	-11.8	**-20.9**	
10	8.25	-26.7	-11.8	**-14.9**	10	8.25	-30.2	-11.8	**-18.4**	
12	10.25	-26.0	-11.8	**-14.3**	12	10.25	-35.3	-11.8	**-23.6**	
14	12.25	-25.5	-11.8	**-13.8**						
Down Conversion			**IF=10 MH**	"+0.7V Bias w/o Resistor 2mA"			**IF=25 MHz**			
LO 5.8G	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	**LO 5.8G**	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	
0	-1.75	-27.8	-11.8	**-16.1**	0	-1.75	-28.0	-11.8	**-16.3**	
2	0.25	-26.8	-11.8	**-15.1**	2	0.25	-27.0	-11.8	**-15.3**	
4	2.25	-25.8	-11.8	**-14.1**	4	2.25	-26.3	-11.8	**-14.6**	
6	4.25	-24.7	-11.8	**-12.9**	6	4.25	-25.5	-11.8	**-13.8**	
8	6.25	-22.7	-11.8	**-10.9**	8	6.25	-24.3	-11.8	**-12.6**	
10	8.25	-21.8	-11.8	**-10.1**	10	8.25	-23.7	-11.8	**-11.9**	
12	10.25	-21.3	-11.8	**-9.6**	12	10.25	-23.5	-11.8	**-11.8**	
14	12.25	-21.5	-11.8	**-9.8**	14	12.25	-24.8	-11.8	**-13.1**	

Note: Mixer works better with forward biased diodes.

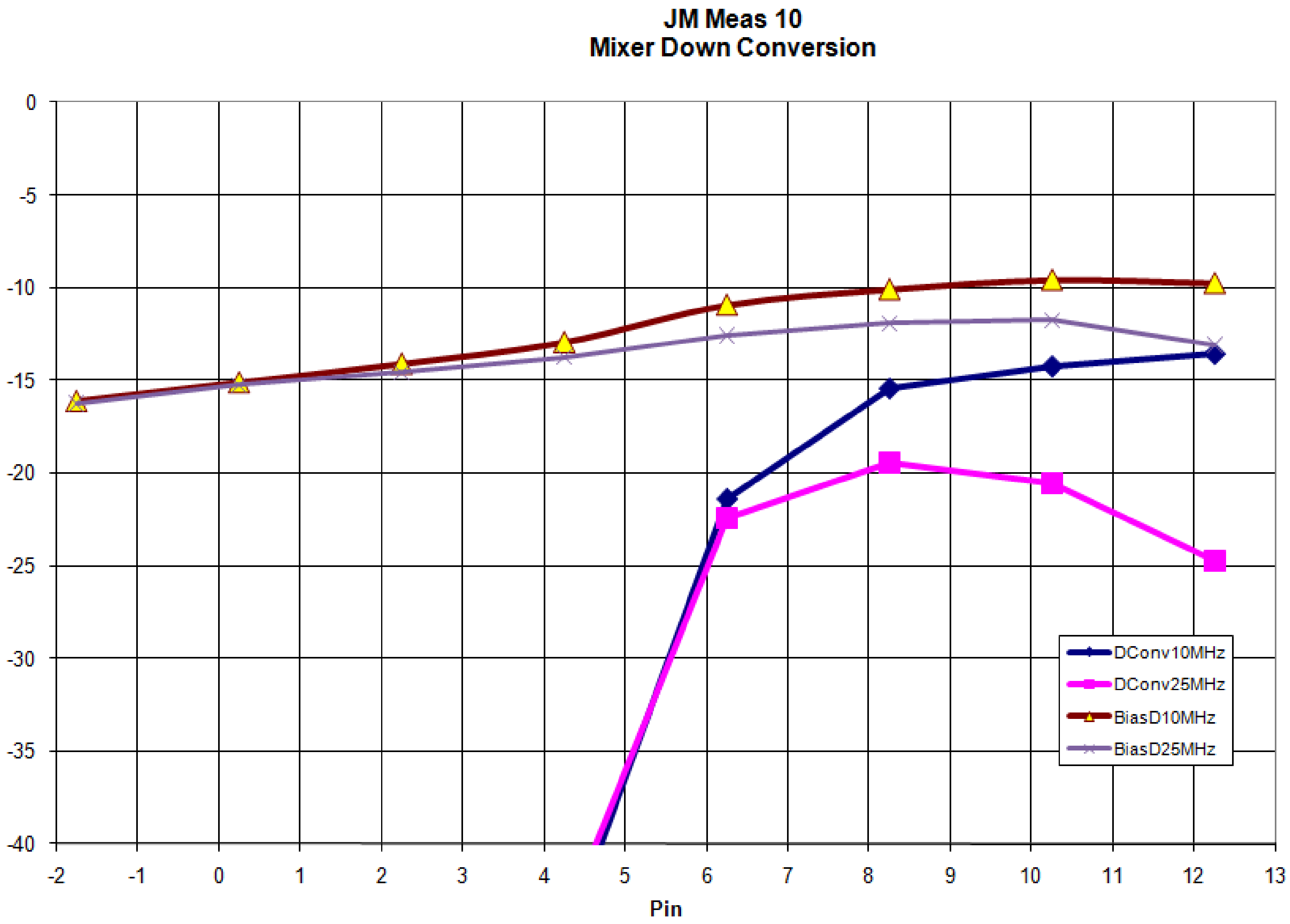
JM 5.8 GHz Mixer

Up Conversion			RF=5.79 M	"+0.7V Bias w/o Resistor 2mA"			RF=5.775 MHz		
LO 5.8G	**LO (corr)**	**RF (meas)**	**RF (corr)**	**Loss (gain)**	**LO 5.8G**	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain**
2	0.25	-46.3	-44.6	**-34.6**	2	0.25	-43.5	-41.8	**-31.8**
4	2.25	-40.5	-38.8	**-28.8**	4	2.25	-37.8	-36.1	**-26.1**
6	4.25	-34.5	-32.8	**-22.8**	6	4.25	-32.5	-30.8	**-20.8**
8	6.25	-31.0	-29.3	**-19.3**	8	6.25	-29.7	-27.9	**-17.9**
10	8.25	-29.2	-27.4	**-17.4**	10	8.25	-28.2	-26.4	**-16.4**
12	10.25	-27.8	-26.1	**-16.1**	12	10.25	-27.2	-25.4	**-15.4**
14	12.25	-27.3	-25.6	**-15.6**	14	12.25	-26.7	-24.9	**-14.9**

Up Conversion			RF=5.79 M	No Bias			RF=5.775 MHz		
LO 5.8G	**LO (corr)**	**RF (meas)**	**RF (corr)**	**Loss (gain)**	**LO 5.8G**	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain**
2	0.25	-48.0	-46.3	**-36.3**	2	0.25	-45.3	-43.6	**-33.6**
4	2.25	-43.7	-42.0	**-32.0**	4	2.25	-40.3	-38.6	**-28.6**
6	4.25	-37.7	-36.0	**-26.0**	6	4.25	-34.7	-33.0	**-23.0**
8	6.25	-35.3	-33.6	**-23.6**	8	6.25	-32.7	-31.0	**-21.0**
10	8.25	-35.0	-33.3	**-23.3**	10	8.25	-33.0	-31.3	**-21.3**
12	10.25	-35.2	-33.5	**-23.5**	12	10.25	-33.7	-32.0	**-22.0**
14	12.25	-35.3	-33.6	**-23.6**	14	12.25	-34.3	-32.6	**-22.6**

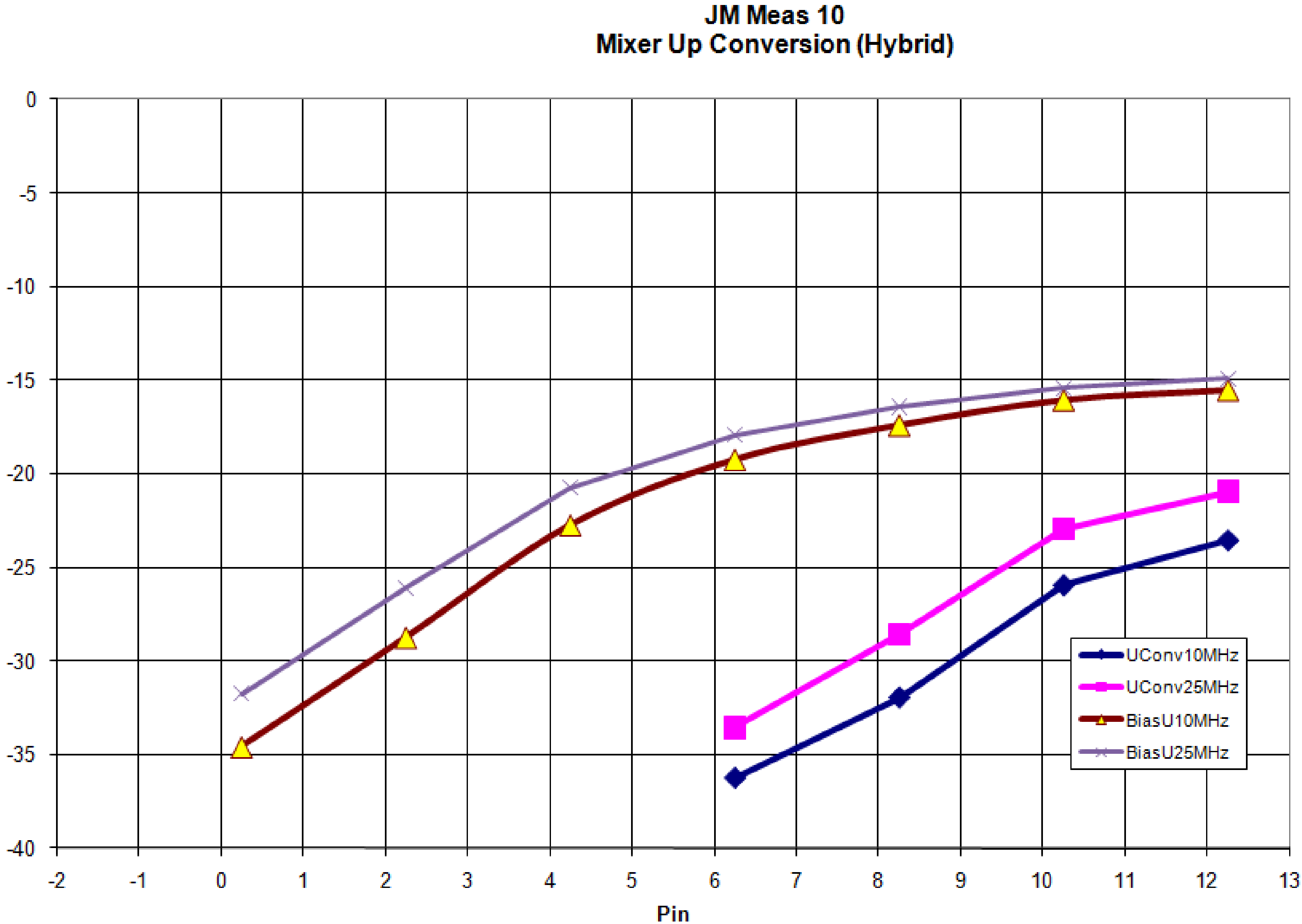
Note: Hybrid LE Design should work best as a down converting mixer, but was tested in the up configuration for completeness.

JM 5.8 GHz Mixer



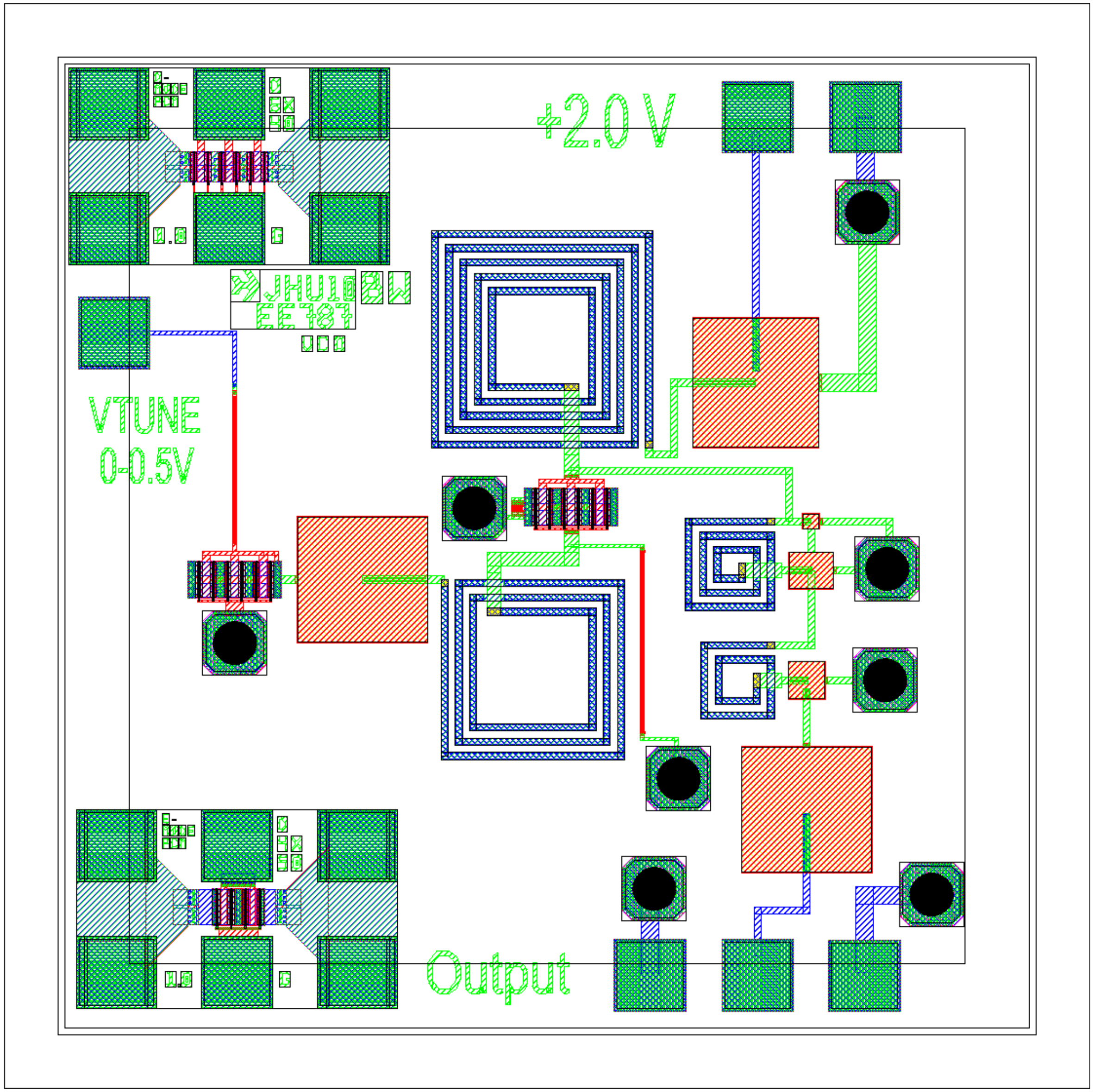
Note: Mixer works better with forward biased diodes (+0.7V).

JM 5.8 GHz Mixer



Note: Hybrid LE Design should work best as a down converting mixer, but was tested in the up configuration for completeness.

6) Ben Woodworth JHU10BW VCO



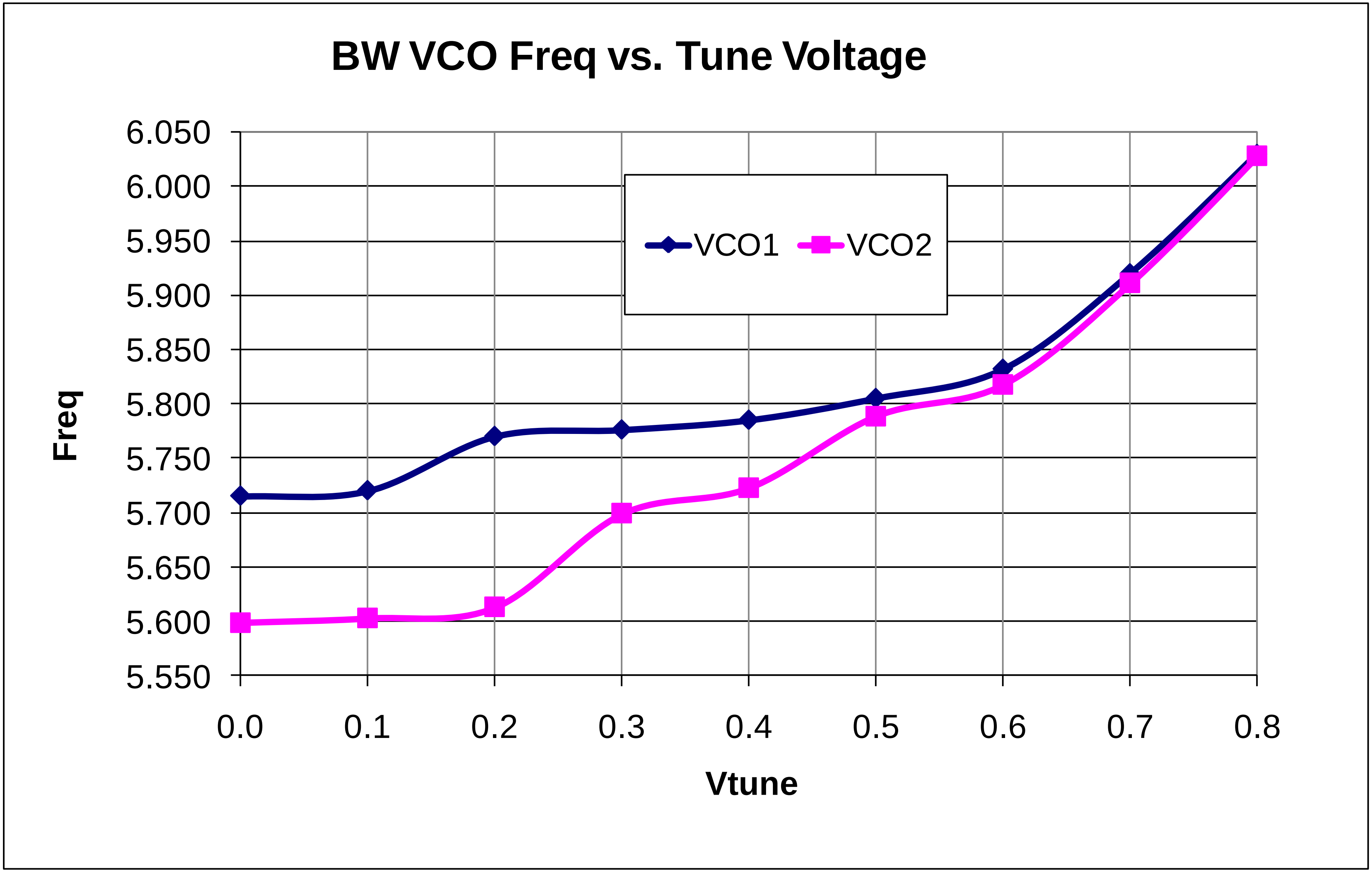
Voltage Controlled Oscillator (VCO) for 5.8 GHz band.
DC Bias was as predicted: 2V at 22-23 mA.
Oscillated at the desired frequency band with about 2.5 mW of output power. Two die were measured for a tuning voltage of 0 to 0.8V with similar results. This VCO was combined with James McKnight's mixer design and worked very well (see JHU10PR1).

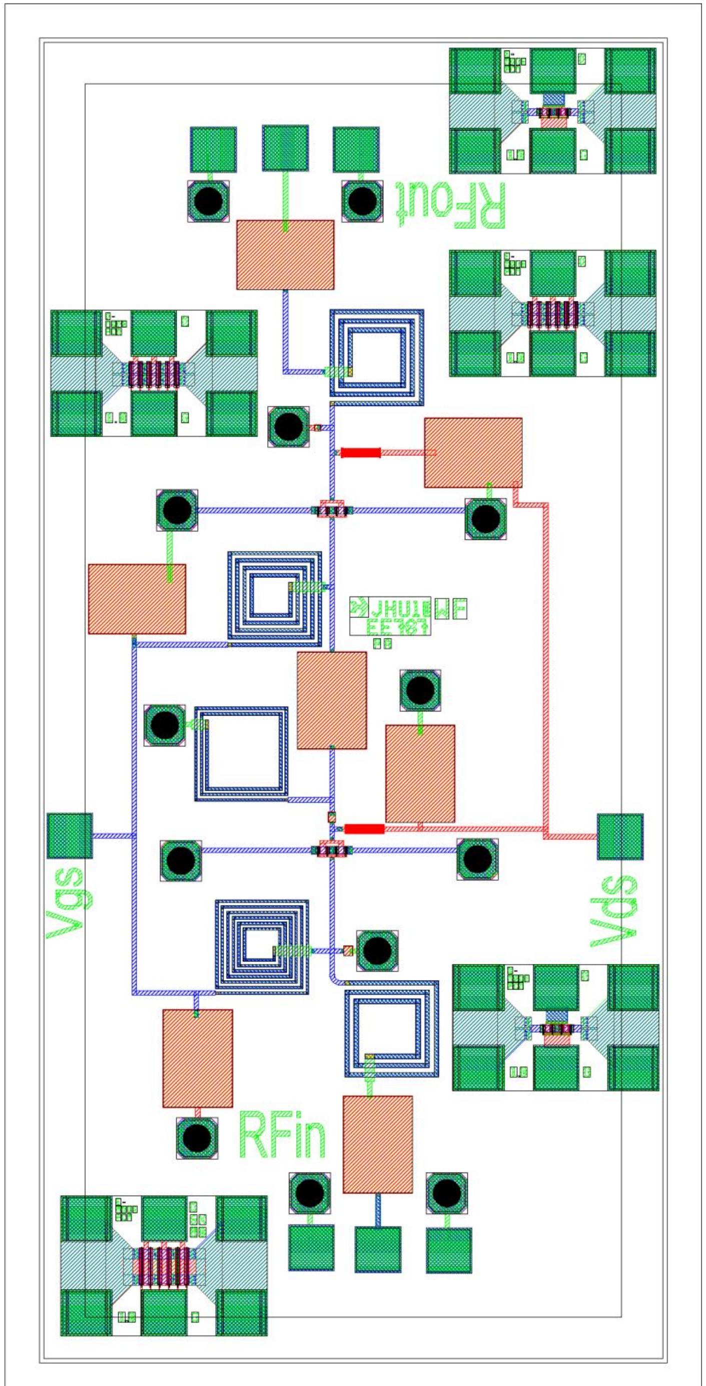
Test PHEMT 6x40D at 3V
D240312 VG=-0.51V
D240324 VG=-0.35V
D240344 VG=-0.12V
Test PHEMT 4x50E at 3V
E200306 VG=+0.53V
E200316 VG=-+0.64V
E200326 VG=+0.73V

BW 5.8 GHz VCO (Meas)

Measured MWO VCO											
Ben Woodworth											
Good tuning range, Dead on in Frequency											
				Pout measured 3.4 to 4.4, or ~ 4 dbm							
MWO VC(	**2V at 22-23mA**		**Die #1**					**MWO VC(**	**2V at 22-23mA**		**Die #2**
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**					**VBias (V)**	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**
0.0	5.715	2.7	**4.4**					0.0	5.599	2.7	**4.4**
0.1	5.720	2.7	**4.4**					0.1	5.603	2.7	**4.4**
0.2	5.770	2.7	**4.4**					0.2	5.613	2.7	**4.4**
0.3	5.776	2.5	**4.3**					0.3	5.699	2.5	**4.3**
0.4	5.785	2.3	**4.1**					0.4	5.723	2.3	**4.1**
0.5	5.805	1.7	**3.4**					0.5	5.789	1.7	**3.4**
0.6	5.832	1.7	**3.4**					0.6	5.818	1.7	**3.4**
0.7	5.920	2.7	**4.4**					0.7	5.911	2.7	**4.4**
0.8	6.030	2.2	**3.9**					0.8	6.028	2.2	**3.9**

BW 5.8 GHz VCO (Meas)



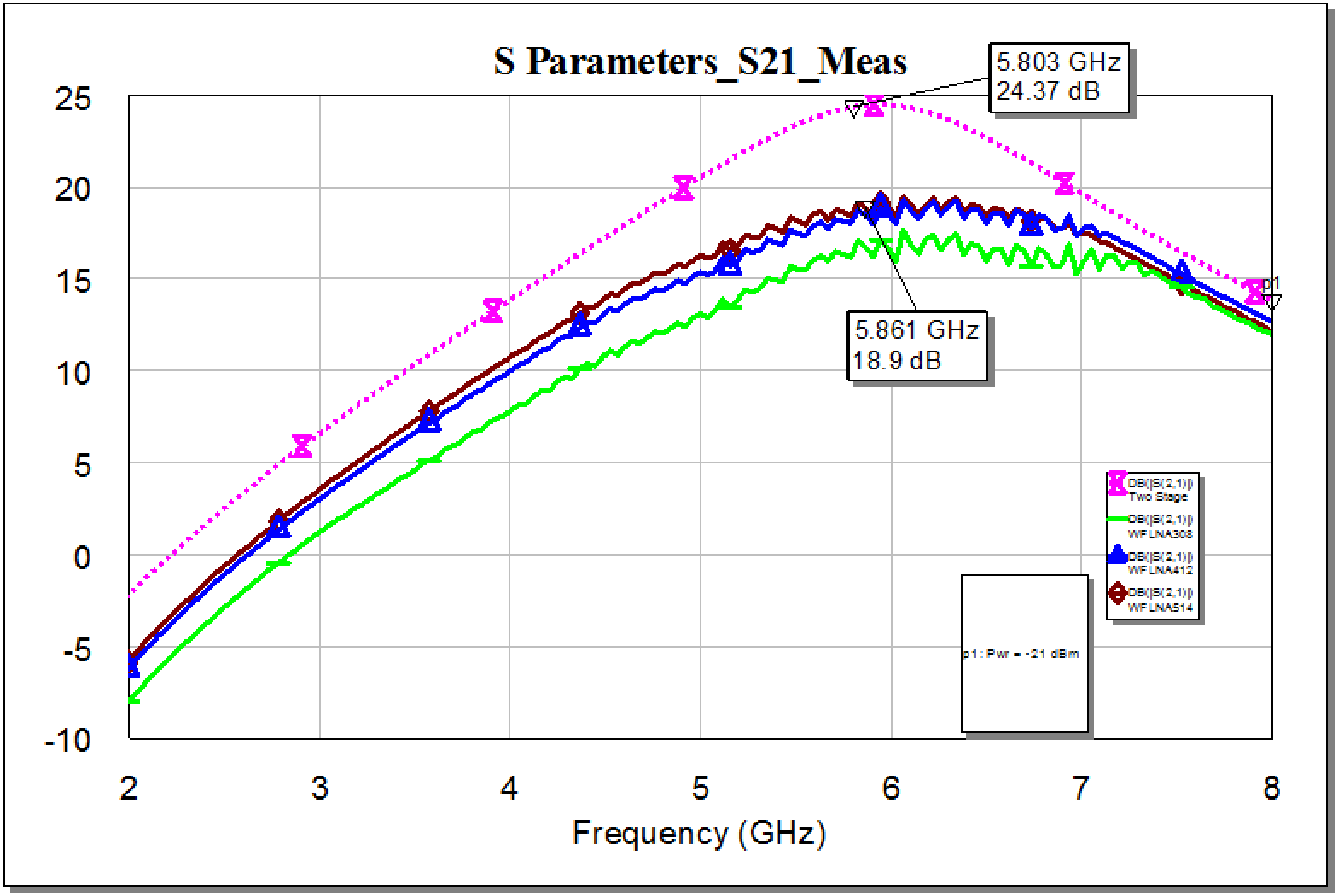


7) Wade Freeman
JHU10WF LNA?

Low Noise Amplifier for 5.8 GHz band. Since this is a low DC powered LNA, the 8510 NWA tends to lose lock if you lower the input power level below about -10 dBm, however this level is too high and compresses the gain of the LNA. The gain measurement with the Noise Figure meter is higher and matches the simulations. Noise figure was just above 1 dB. S-parameters were taken for biases of 3V at 8 mA, 4V at 12 mA, and 5V at 14 mA.

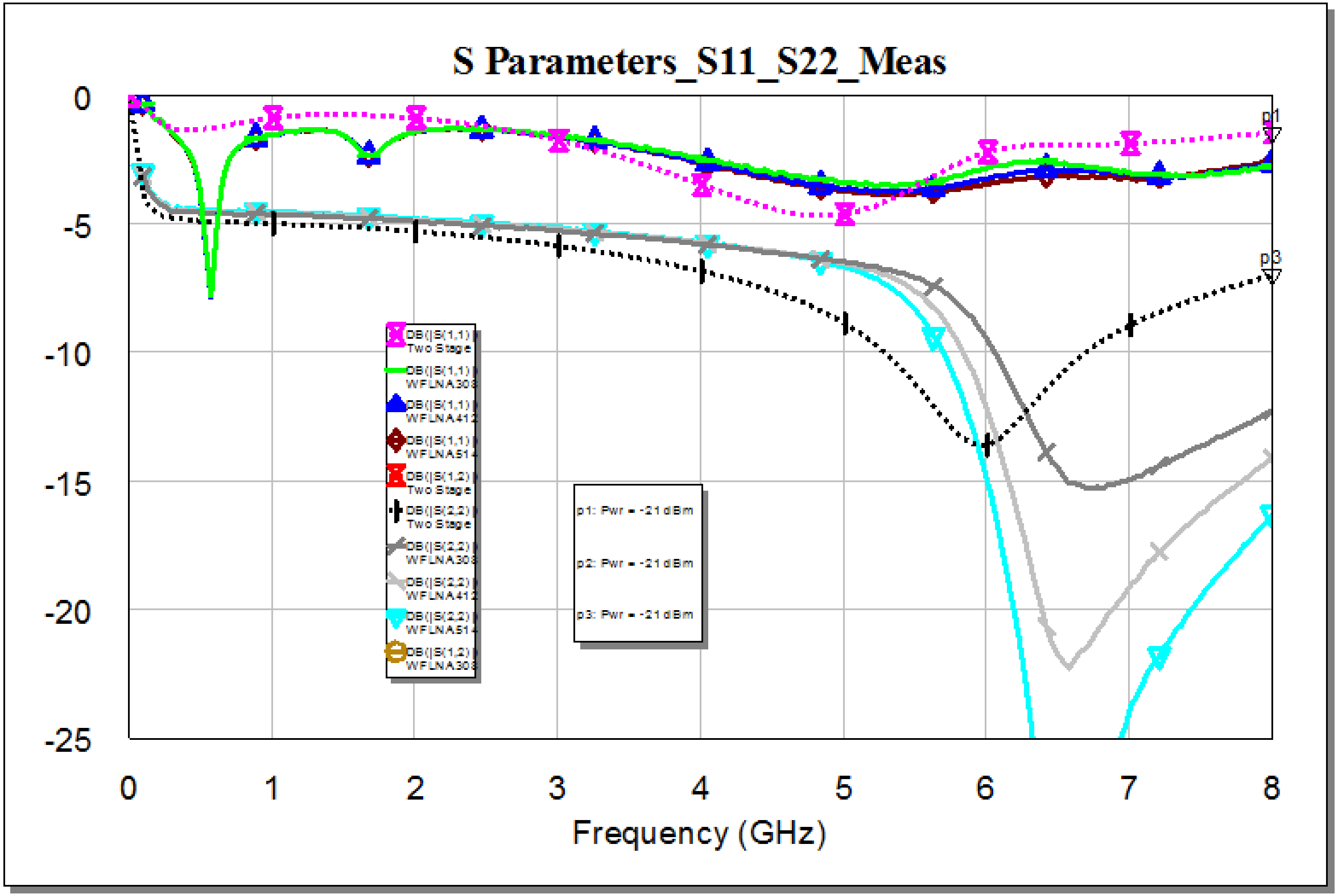
Test PHEMT 4x15D 3V
D60306 VG=-0.35V
D60311 VG=-0.12V
Test PHEMT 4x15E 3V
E60305 VG=-+0.64V
E60308 VG=+0.73V
Test PHEMT 6x80E 3V
E480320 VG=-+0.53V
E480347 VG=+ 0.64V

WF 5.8 LNA (Meas/Sim)

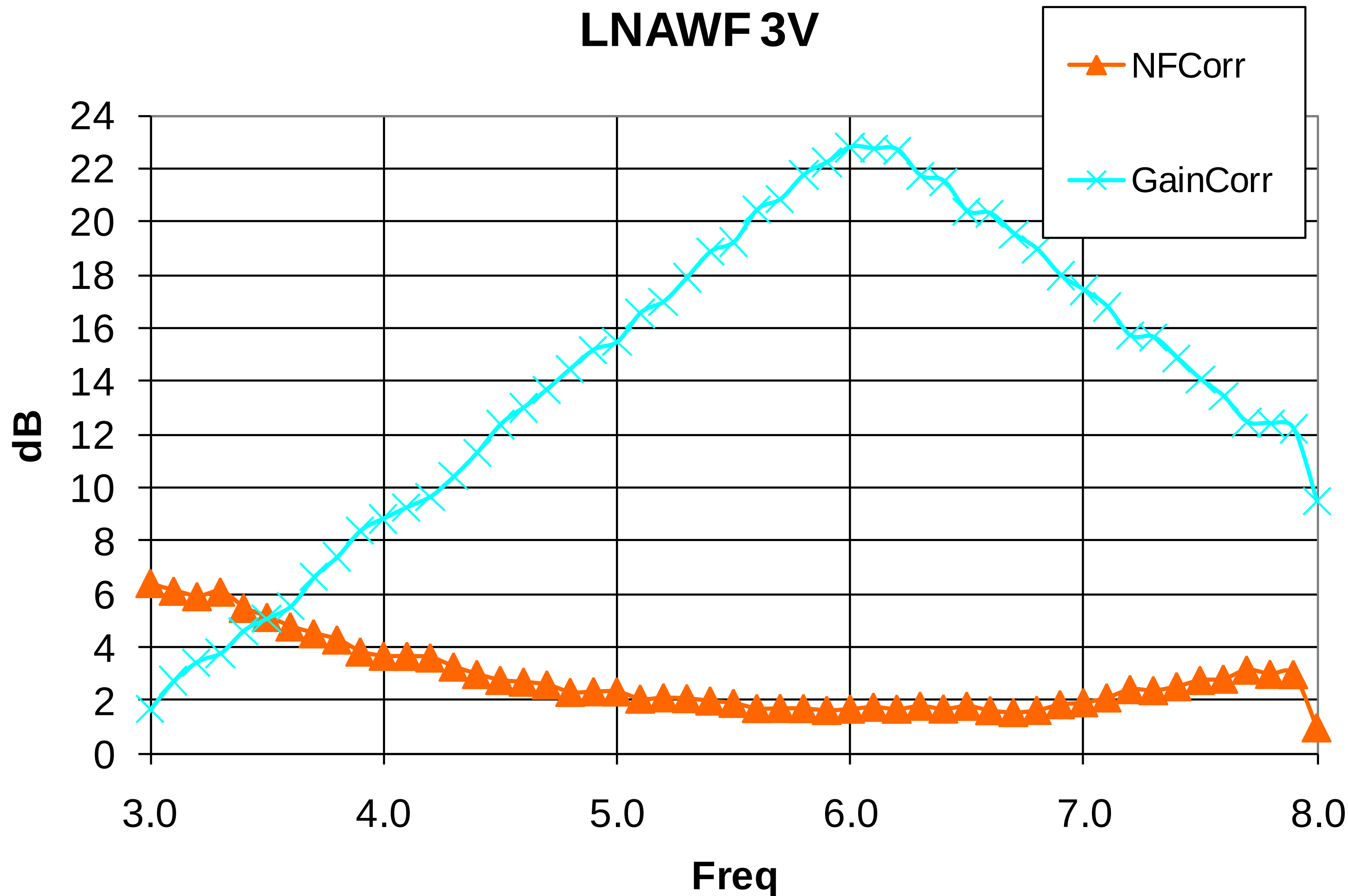


Measured Gain in Compression on 8510 NWA (Low DC Power MMIC)

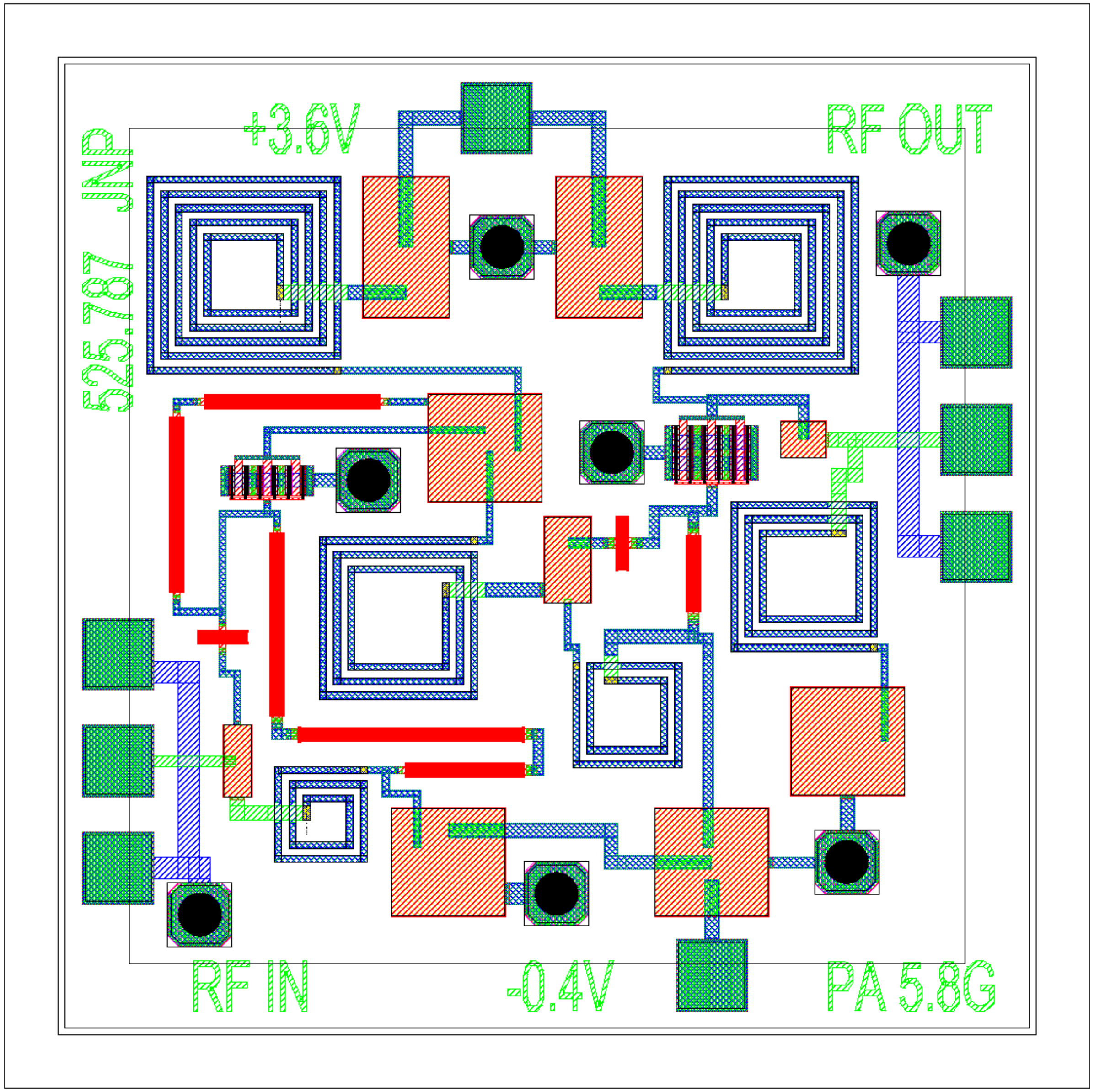
WF 5.8 LNA (Meas/Sim)



WF 5.8 LNA (Meas NF/Gain)



Better Gain Measurement using NF meter (Low DC Power MMIC)

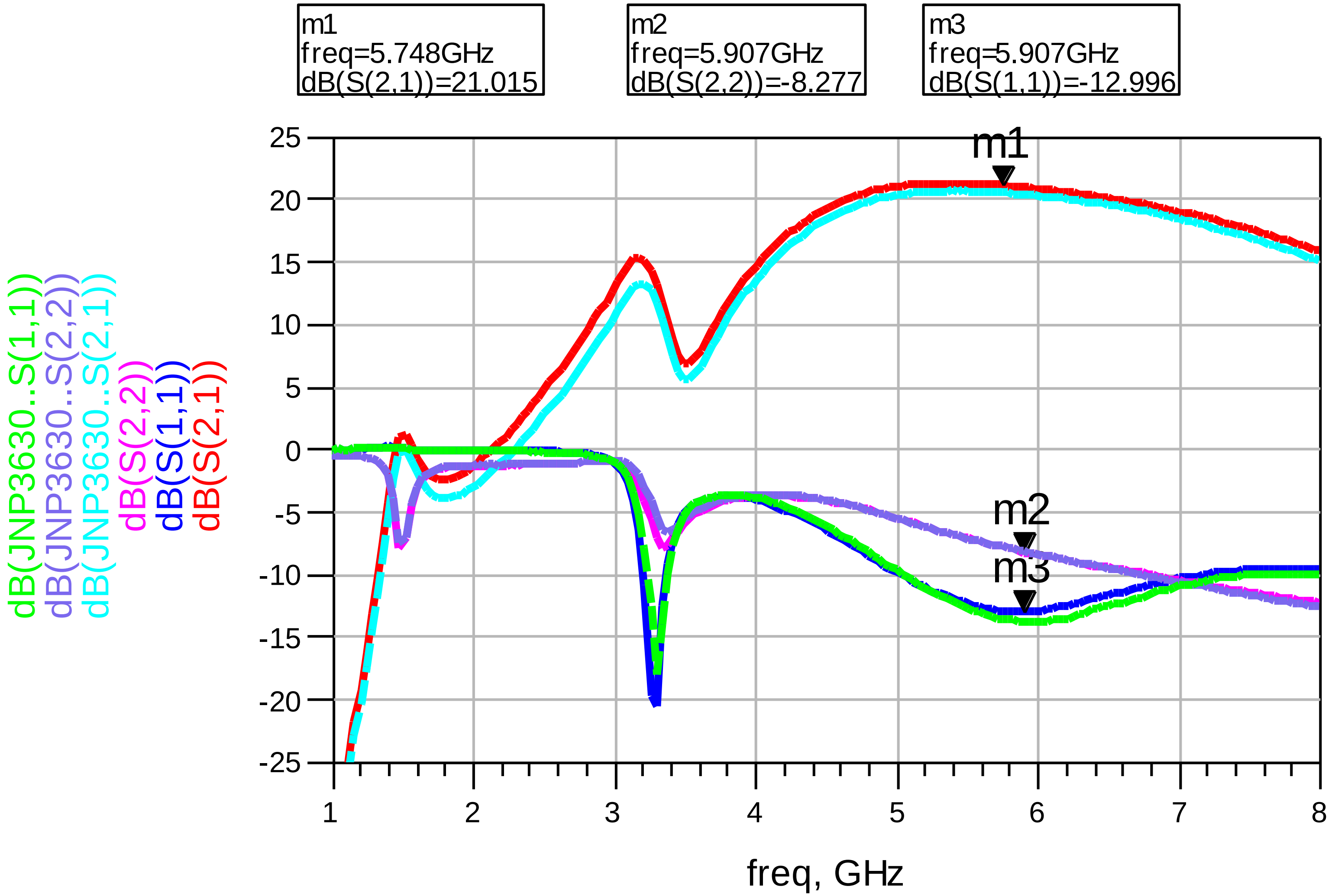


8) James Pociluyko
JHU10JNP PA

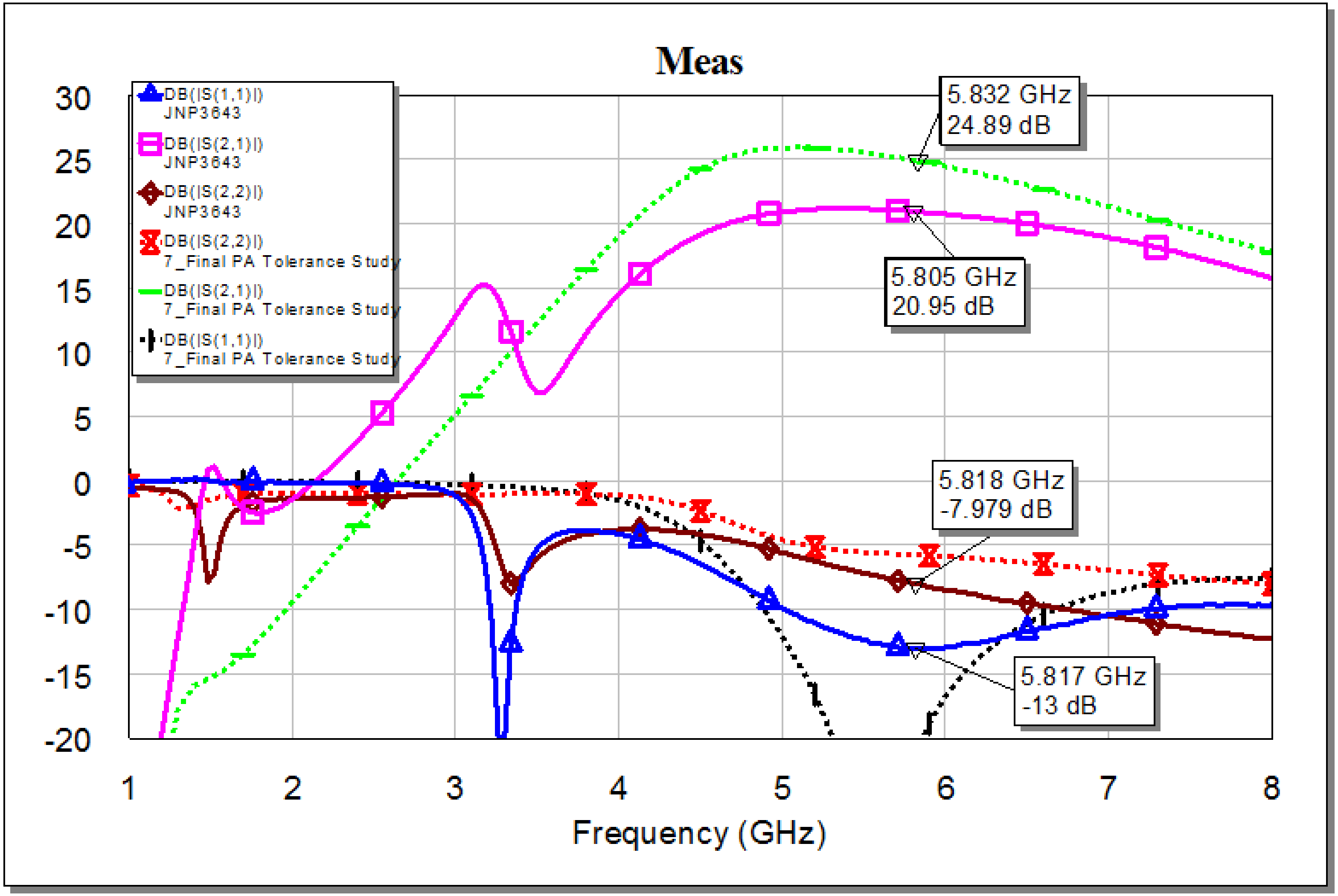
Another Power Amplifier for 5.8 GHz band with about 20 dB SS gain and 100 mW Pout. There were some initial small signal oscillation problems with the measurements but small tweaks in the setup produced good stable results.
DC Bias was measured at several biases. S-parameters are shown versus simulations. Power measurements show good efficiency and the design achieved 100 mW of output power.

JNP227 2V at 27 mA -0.5V
18-19 dB gain
JNP3630 3.6V at 30 mA -0.5V
18-19 dB gain
JNP3643 3.6V at 43 mA -0.4V
18-19 dB gain

JNP 5.8 PA (Meas 3.6V 30 mA-dash, 43 mA-solid)



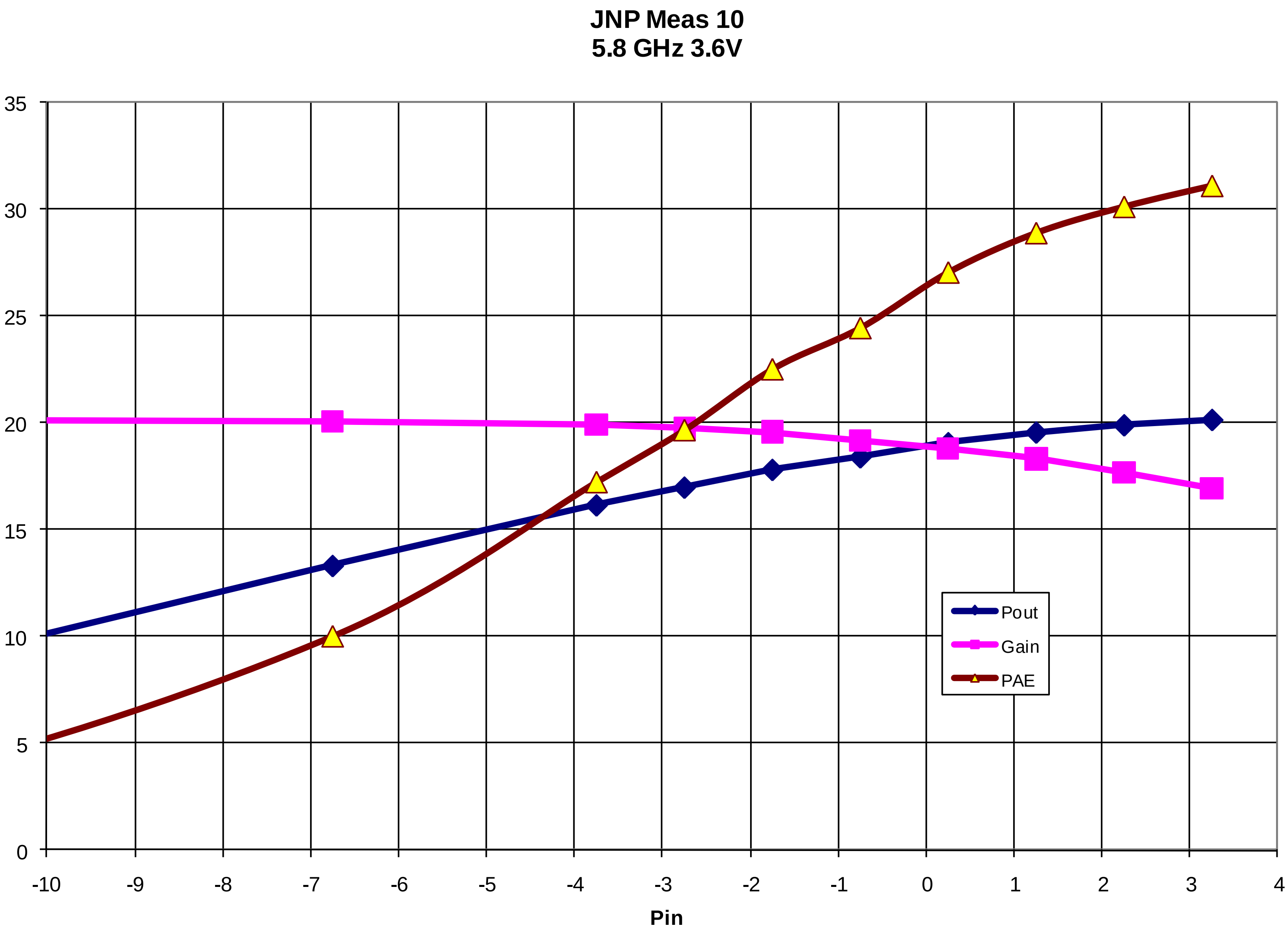
JNP 5.8 PA (Meas 43 mA-solid vs. Sim-dash)

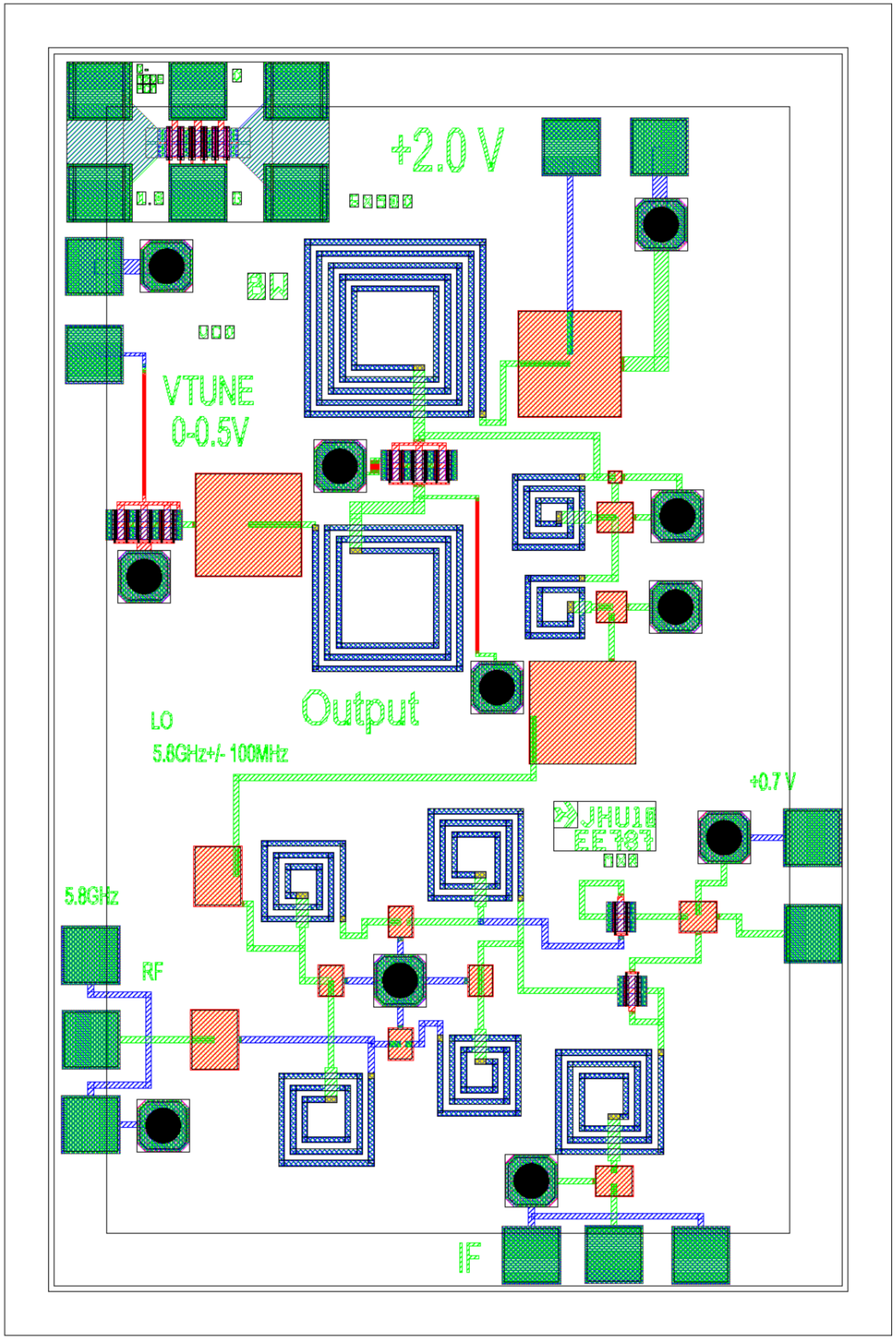


JNP 5.8 GHz Power Amp (Meas)

James Pociluyko Power Amp--5.8 GHz 3.6 V									
				Loss 3.5 dB for thru					
5.8 GHz	Die#1	**PVO 5.8 GHz E/Dmode Fall10 TQPED**				3.6V ; 66 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.6V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-15.0	1.67	-16.75	3.42	20.17	57	205.2	2.20	1.1	1.1
-10.0	6.67	-11.75	8.42	20.17	57	205.2	6.95	3.4	3.4
-5.0	11.58	-6.75	13.33	20.08	59	212.4	21.53	10.1	10.0
-2.0	14.42	-3.75	16.17	19.92	66	237.6	41.40	17.4	17.2
-1.0	15.25	-2.75	17.00	19.75	70	252.0	50.12	19.9	19.7
0.0	16.08	-1.75	17.83	19.58	74	266.4	60.67	22.8	22.5
1.0	16.67	-0.75	18.42	19.17	78	280.8	69.50	24.8	24.5
2.0	17.33	0.25	19.08	18.83	82	295.2	80.91	27.4	27.0
3.0	17.83	1.25	19.58	18.33	86	309.6	90.78	29.3	28.9
4.0	18.17	2.25	19.92	17.67	89	320.4	98.17	30.6	30.1
5.0	18.42	3.25	20.17	16.92	91	327.6	103.99	31.7	31.1

JNP 5.8 GHz Power Amp (Meas)





9) James McKnight & Ben Woodworth JHU10PR1 VCO + MXR

Students consider the impact of their design on other blocks in the system for integration into a larger MMIC. While they do not have sufficient time in their six week design cycle to integrate the blocks together, some of the designs are incorporated into larger die sites within the tile as space allows. The instructor combines and compacts the layouts into a larger die site. In this example, Ben Woodworth's VCO was combined with James McKnight's mixer design in a 60x90 mil die site. The combination worked very well. The diode DC offset bias of the mixer allowed a low LO drive from the VCO to provide good conversion loss. Conversion loss is shown following for the combined circuit. The VCO output frequency was tuned slightly by the mixer diode DC bias (RF match shift), and was measured with the 0.7V diode bias.

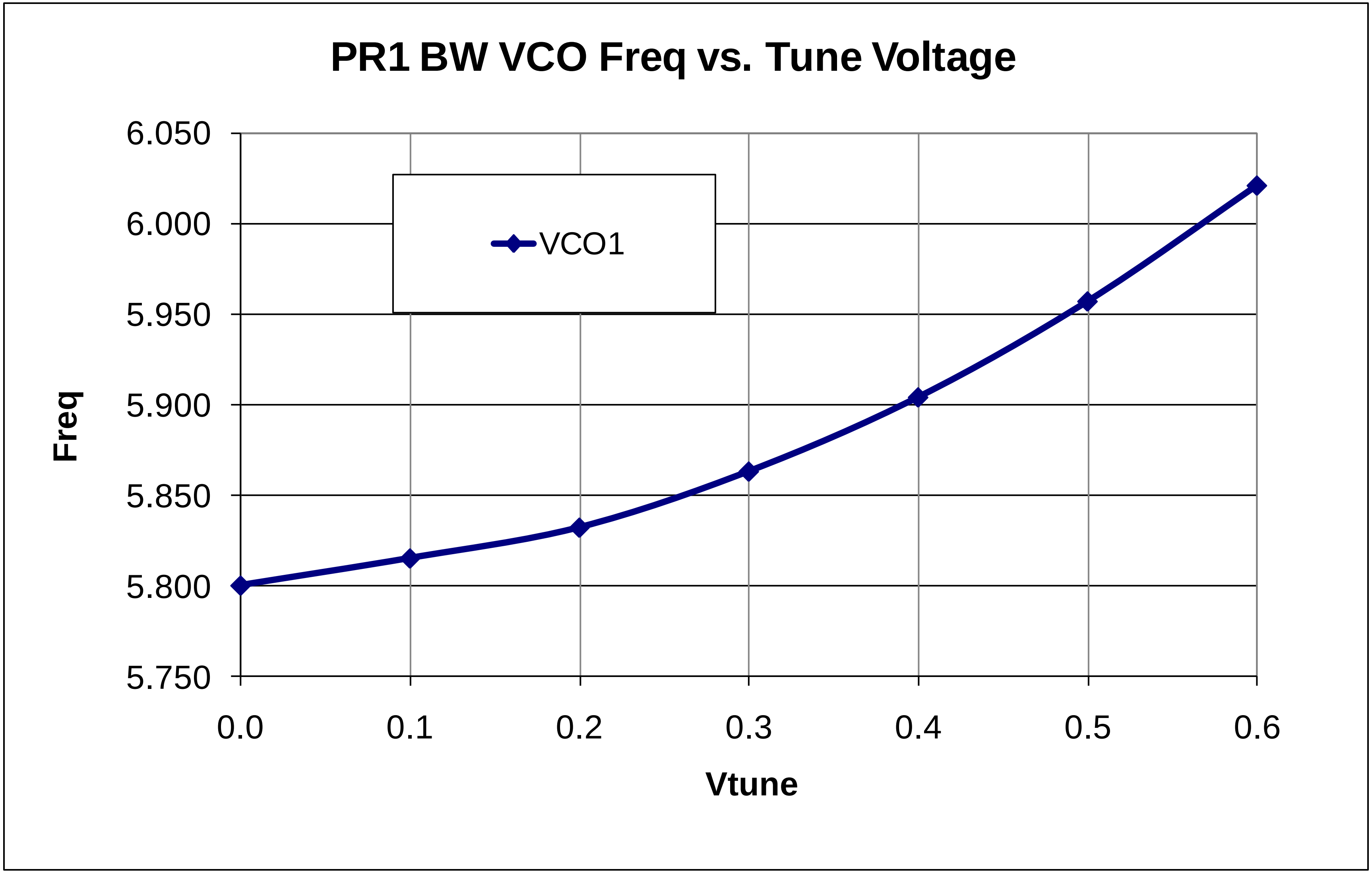
JHU10PR1: JM and BW 5.8 GHz VCO+MIX (Meas)

Measured MWO PR2 VCO+MIX				**4/3/2011**				
Ben Woodworth								
James McKnight								
			3.5 dB thru at 5.8 GHz					
Good tuning range, Dead on in Frequency								
2V at 24mA			**Best IF around 30 MHz**			**Vbias=+0.7V**		
MWO VCO+MIX			**Note: VCO frequency varies a bit with Vbias tuning**					
VTune (V)	**Freq (GHz)**		**Changes RF load to VCO**					
0.0	5.800		**RF = 5.8 GHz at -10 dBm**			**Vtune = 0.2V ~30MHz IF**		
0.1	5.815		**VBias(V)**	**Ibias(mA)**	**IF (dBm)**	**IF (MHz)**	**Conv Loss (dB)**	
0.2	5.832		0.0	0	27.7	-53.5	-41.55	
0.3	5.863		0.6	1	29.4	-30.7	-18.72	
0.4	5.904		0.7	2	31.9	-28.3	**-16.38**	
0.5	5.957		0.8	2	35.2	-28.3	**-16.38**	
0.6	6.021							
LO Leakage; RF = 5.8 at - 10 dBm, measured 5.8G at IF = -29.33								
LO/IF Isolation = 15.83 dB								

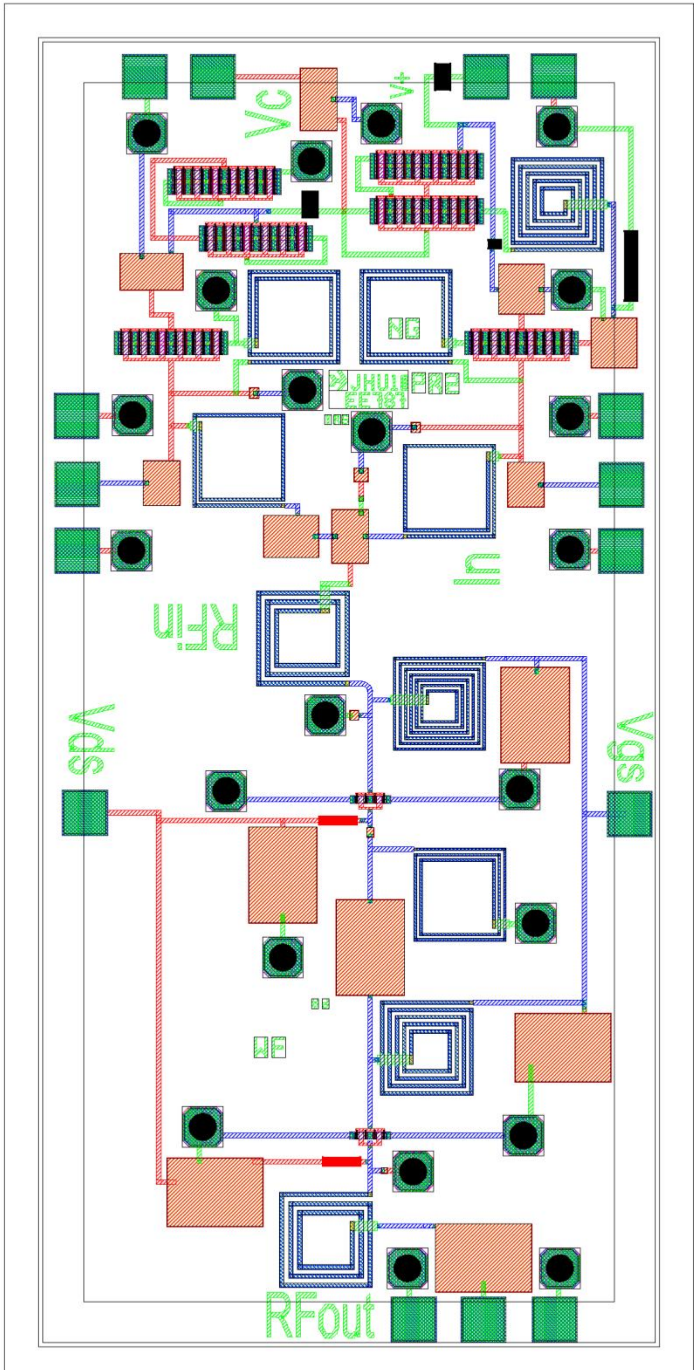
Worked Very Well! Diode Bias on Mixer of about +0.7V at 2 mA dramatically Lowers the LO power needed for decent conversion loss. VCO was measured to produce about 4 dBm of output power which is sufficient to drive the Mixer with the Bias offset. The Diode Bias did slightly affect the VCO output frequency since it changes the RF load somewhat. LO/IF Isolation was measured: 16 dB.

Conversion Loss: 16 dB VDD: 2V @ 24 mA; Vtune=0.2V; Vbias=0.7V @ 2 mA

JHU10PR1: JM and BW 5.8 GHz VCO+MIX (Meas)



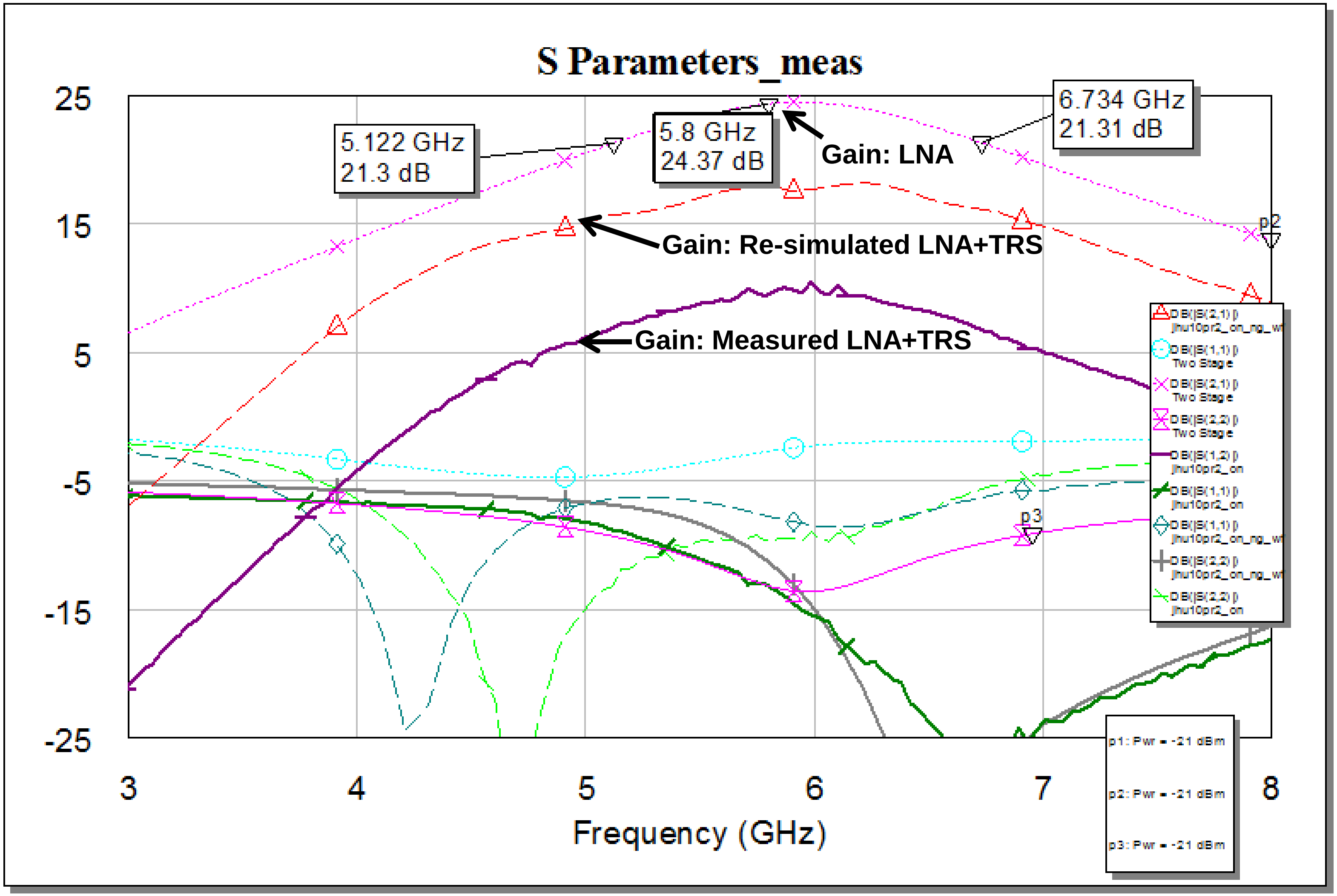
VCO Tuning Range with Vbias=0.7V @ 2 mA; VDD=2V @ 24 mA



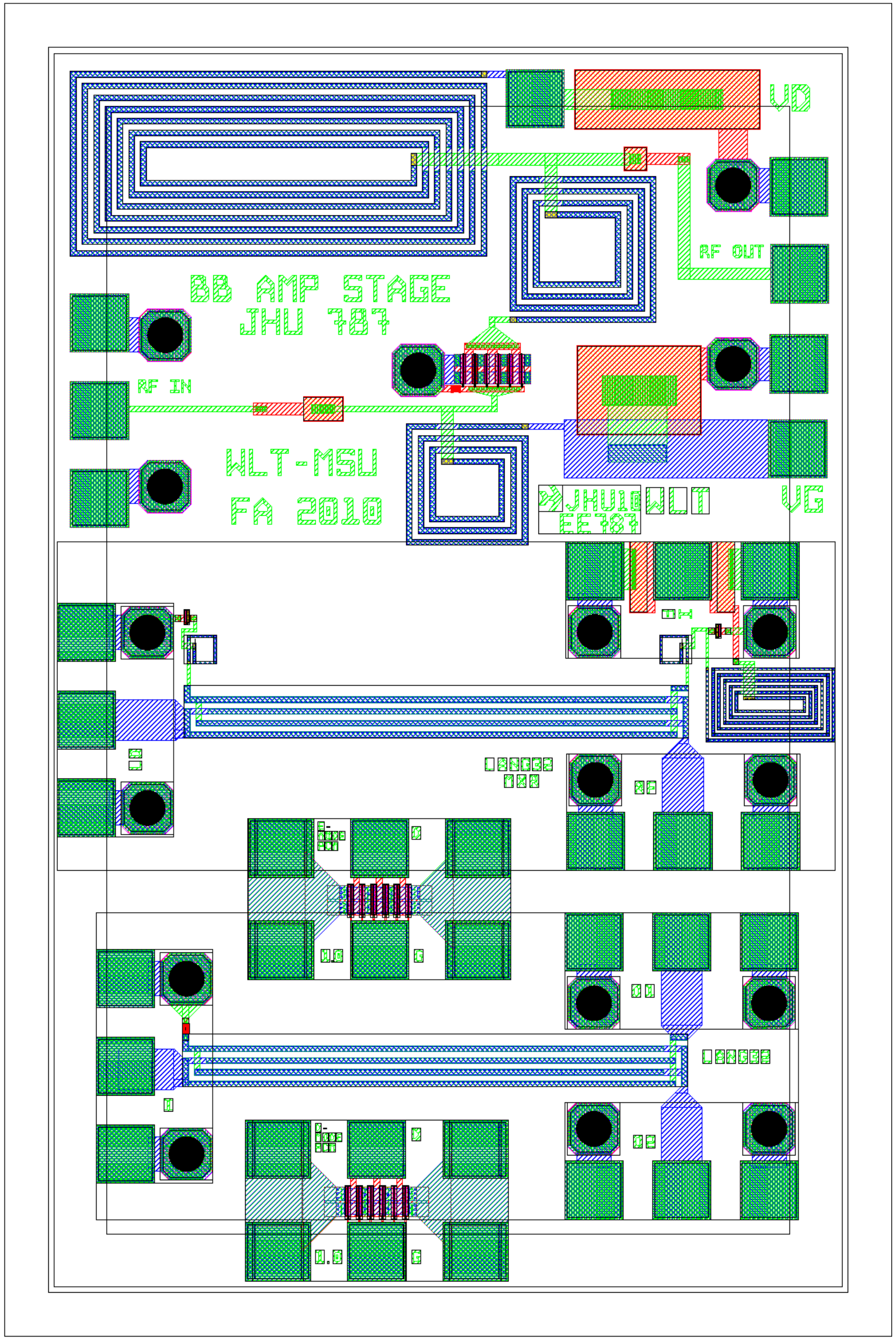
10) Nick Garneski & Wade Freeman
JHU10PR2 TRS + LNA

Students consider the impact of their design on other blocks in the system for integration into a larger MMIC. While they do not have sufficient time in their six week design cycle to integrate the blocks together, some of the designs are incorporated into larger die sites within the tile as space allows. The instructor combines and compacts the layouts into a larger die site. In this example, Nick Garneski's TR Switch was combined with Wade Freeman's LNA design in a 60x120 mil die site. This combination illustrates some of the impact of subsystem design when you combine at the system level. Both designs worked well individually, but the combined TR Switch and LNA had significantly lower gain than would be expected from individual measurements. Following is a re-simulation of the TR Switch measurements combined with the LNA measurements showing a significant drop in gain. If you look at the return loss of the LNA, it was optimized for 50 ohm loads but has high VSWR and may explain the low gain of the combination. Also, there may be some subtle variation due to compacting the layouts in order to squeeze them into the single die site.

JHU10PR2: WF and NG 5.8 GHz TRS+LNA (Meas ON/OFF)



Simulation vs. Measured—Low Gain due to High VSWR (LNA)?

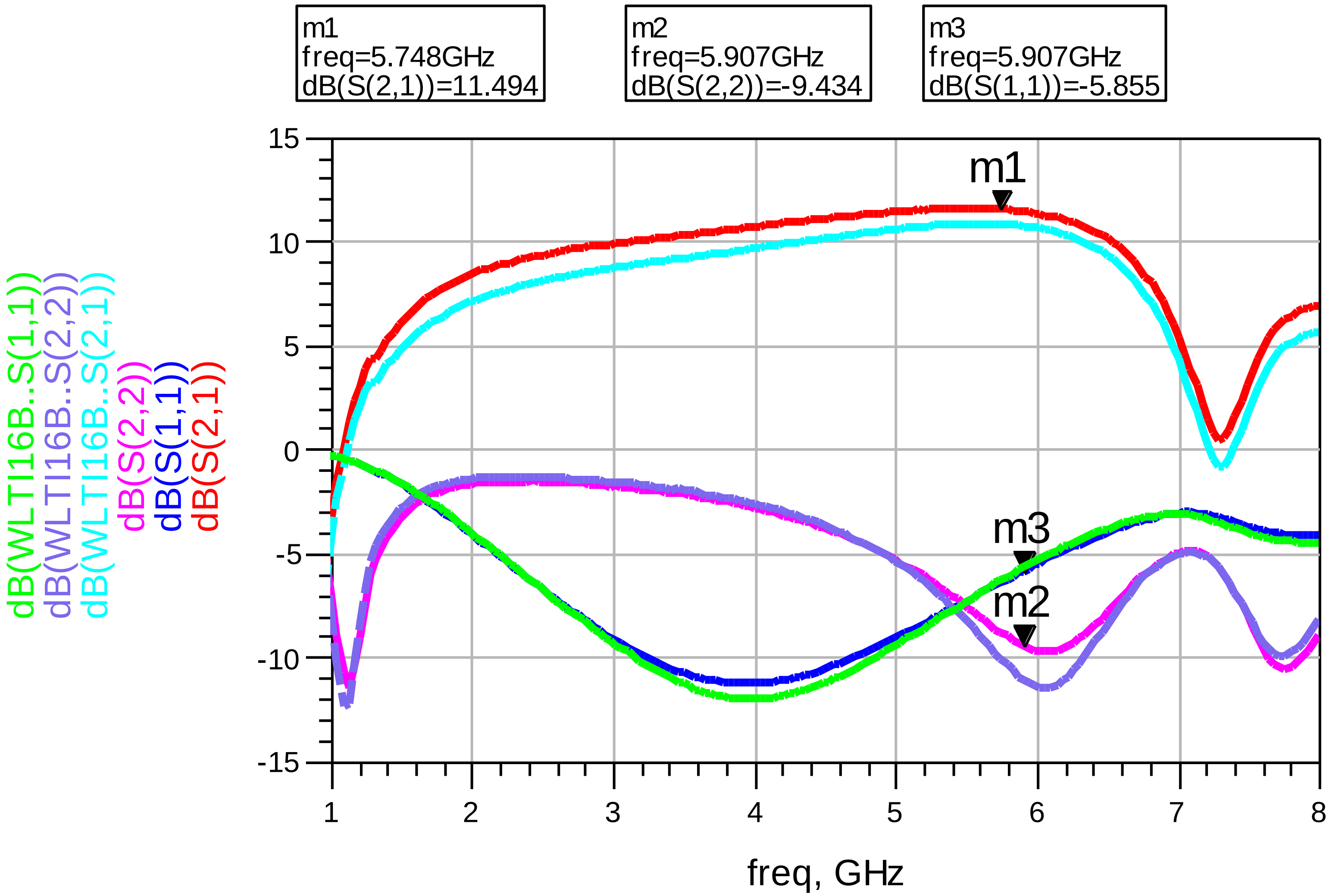


11) Dr. Willie Thompson
JHU10WLT PA
32 GHz Lang Coupler
32 GHz Diode Mixer
E/D Mode 6x50 um PHEMTs

BroadBand Amplifier for 2-6 GHz. The other test circuits, a 32 GHz Lang Coupler Circuit and a 32 GHz Lang Diode Mixer, could not be measured with the current equipment at Dorsey.

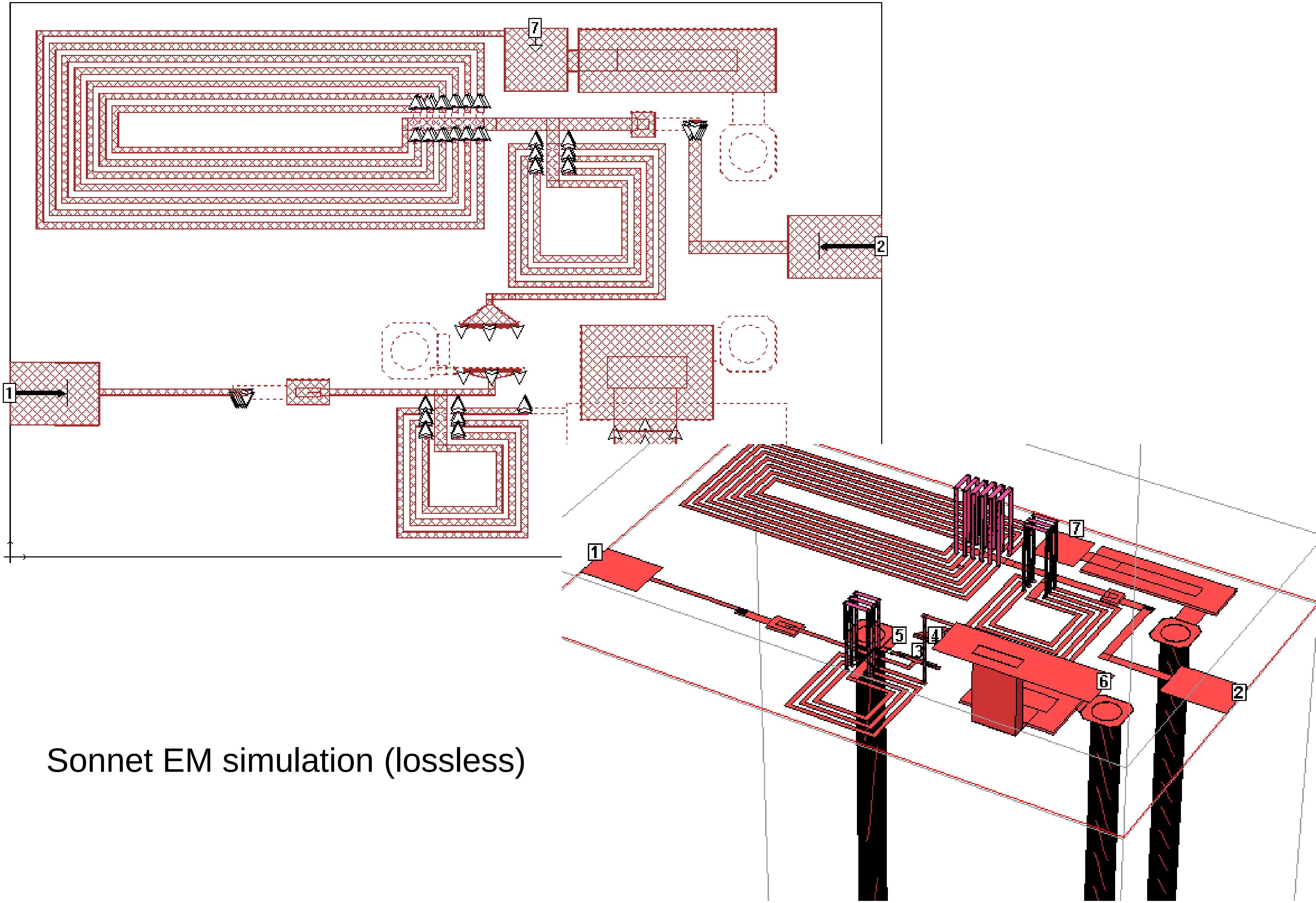
Test PHEMT 6x50D 3V
D300315 VG=-0.51V
D300330 VG=-0.35V
D300355 VG=-0.12V
Test PHEMT 6x50E 3V
E300310 VG=+0.53V
E300325 VG=+0.64V
E300340 VG=+0.73V

JHU10WLT: Amp 2-6 GHz (Meas 16 mA, 32 mA IDS)



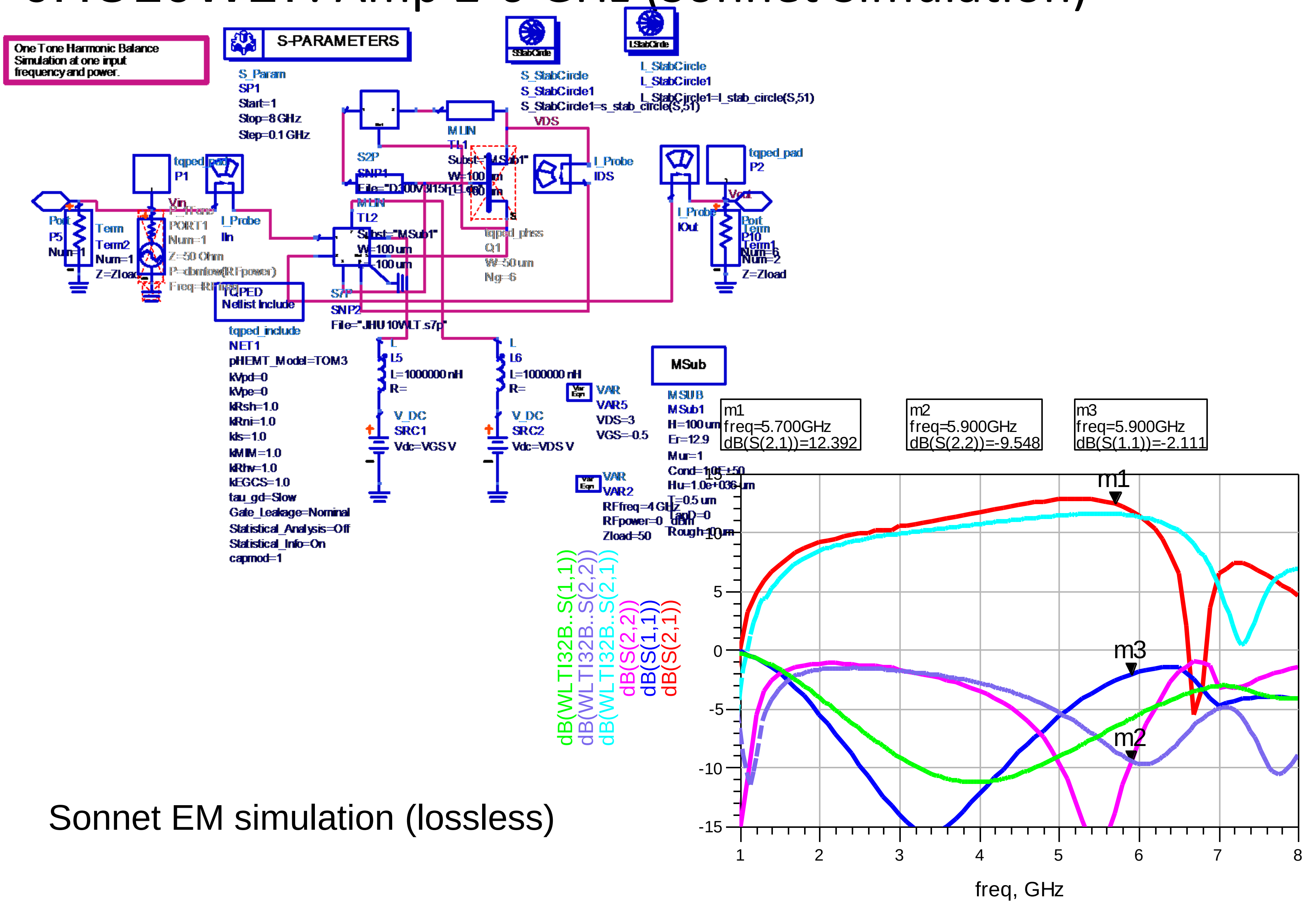
Measured Power Amp at 3.1V 16 mA, 32 mA bias

JHU10WLT: Amp 2-6 GHz (Sonnet Simulation)



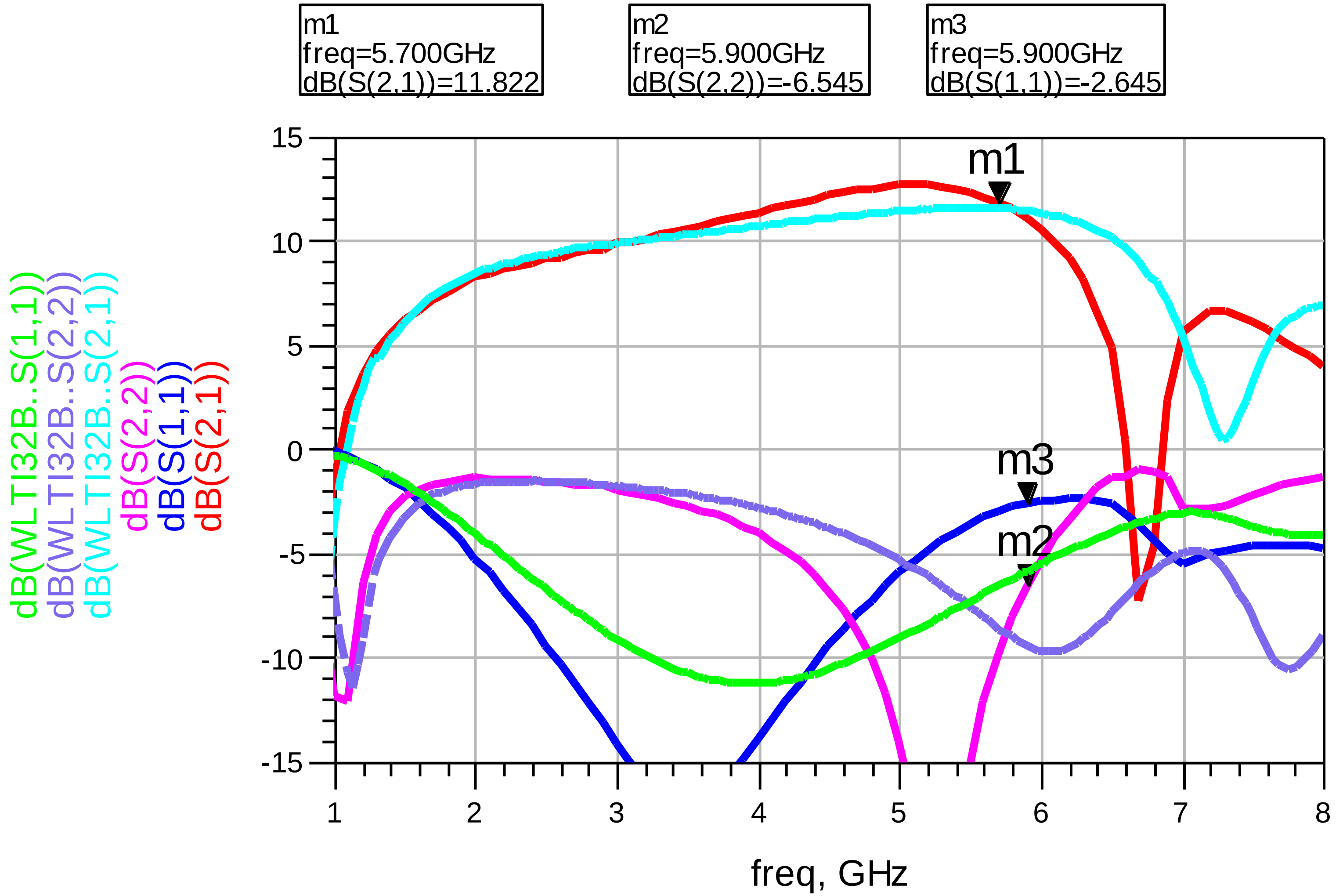
Sonnet EM simulation (lossless)

JHU10WLT: Amp 2-6 GHz (Sonnet Simulation)



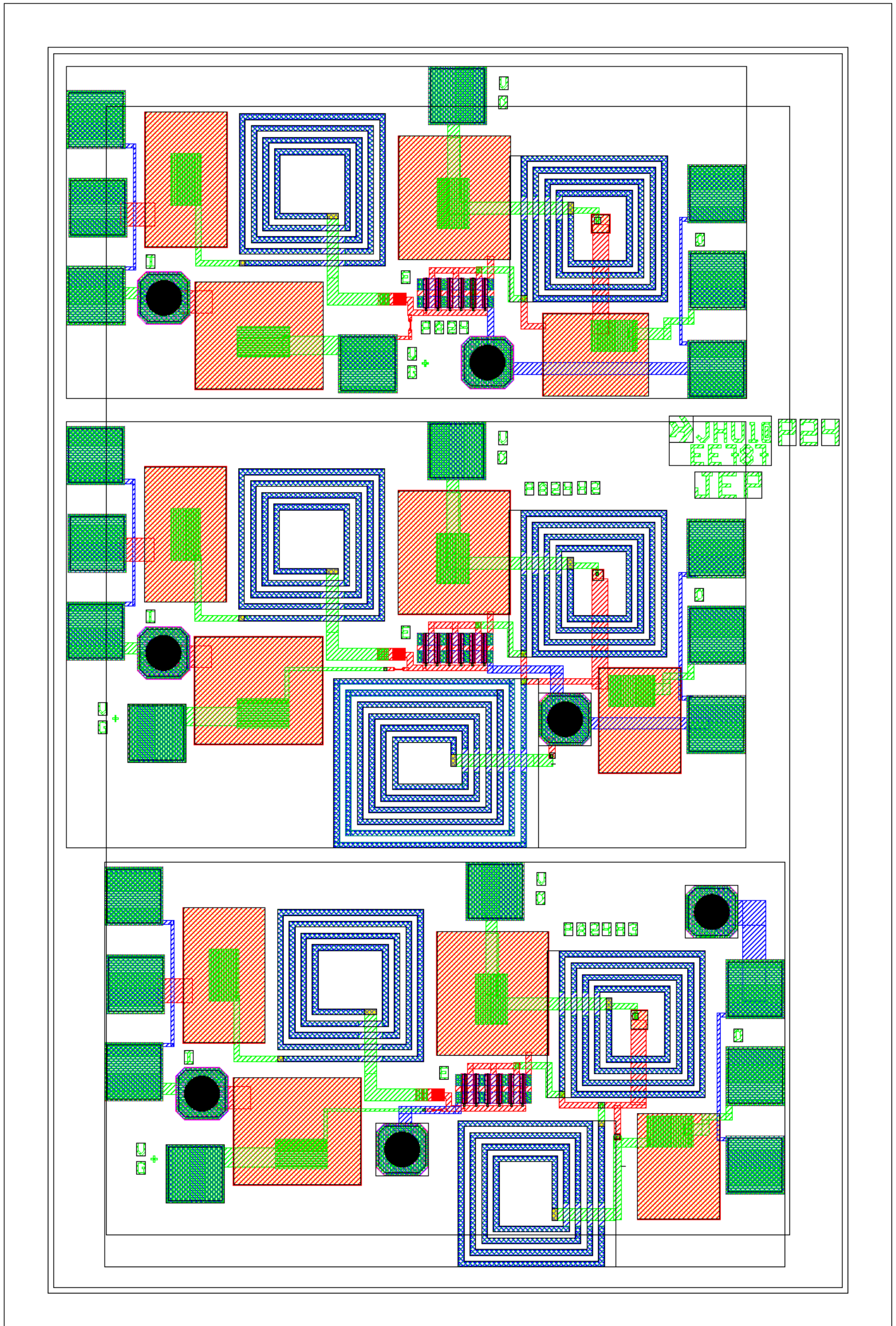
Sonnet EM simulation (lossless)

JHU10WLT: Amp 2-6 GHz (Sonnet Simulation)



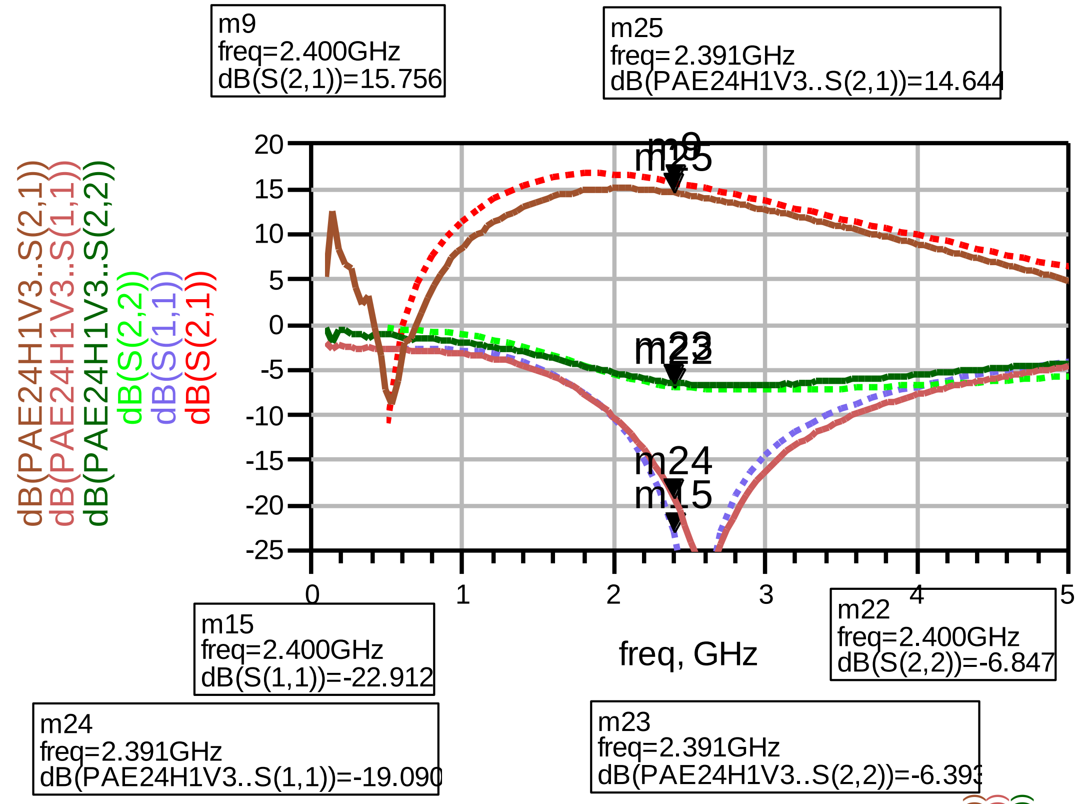
Sonnet EM simulation (lossless vs. Measured)

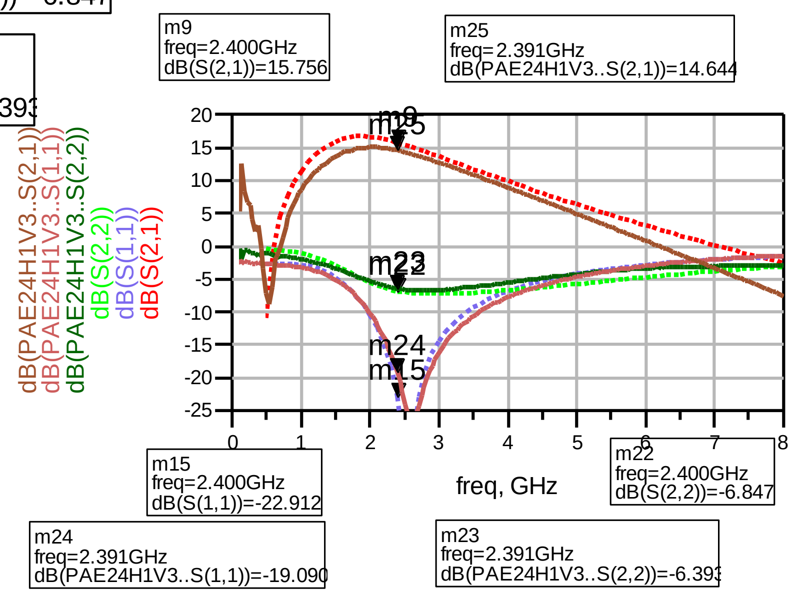
12) John Penn
JHU10P24 2.4 GHz PA Test Circuits



Power Amplifiers for 2.4 GHz.
These test circuits include a design matched to the fundamental (H1), another with a 2nd harmonic short circuit (H2), and a third with an open circuit 3rd harmonic (H3) for efficiency comparisons. The H1 and H3 designs compare well to s-parameter measurements but the H2 design did not have much gain initially. It appeared to be marginally unstable under probe measurements. Later, it was remeasured with better results but had to be overdriven to get a measurement with the NWA. Power measurements were initially taken of the H1 and H3 designs, and later the H2 design was able to be re-measured and had the best efficiency. The H3 design was the worst efficiency.

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)

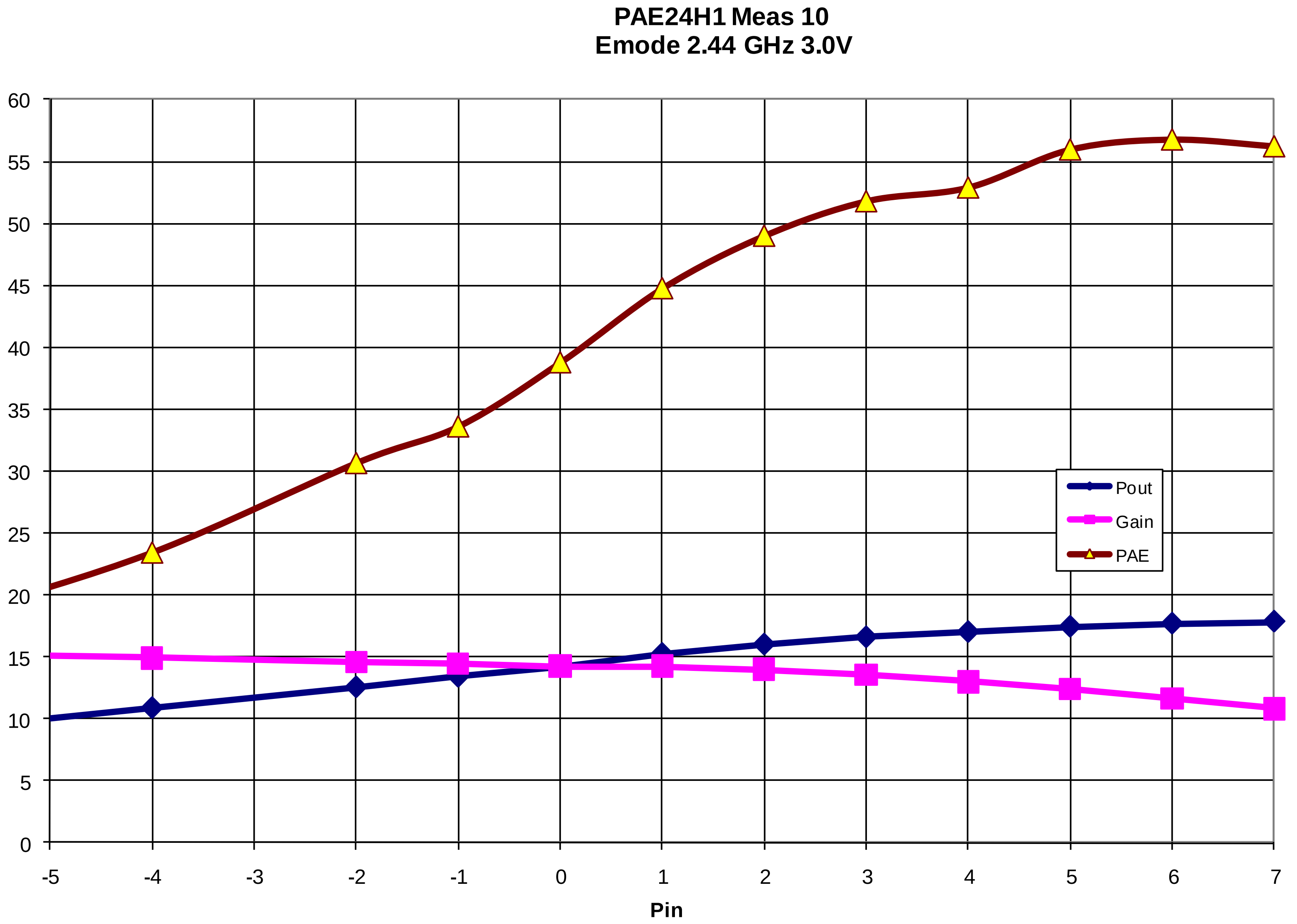




Fundamental only match (H1)

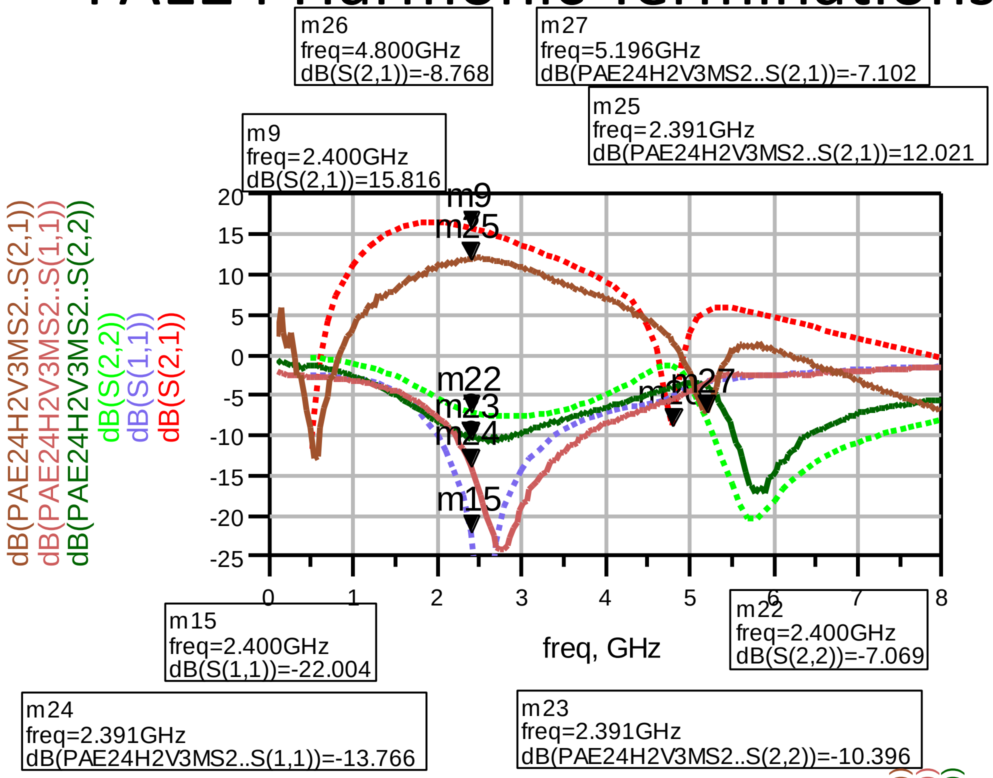
Good comparison between measurements (solid) and Simulations (dot)

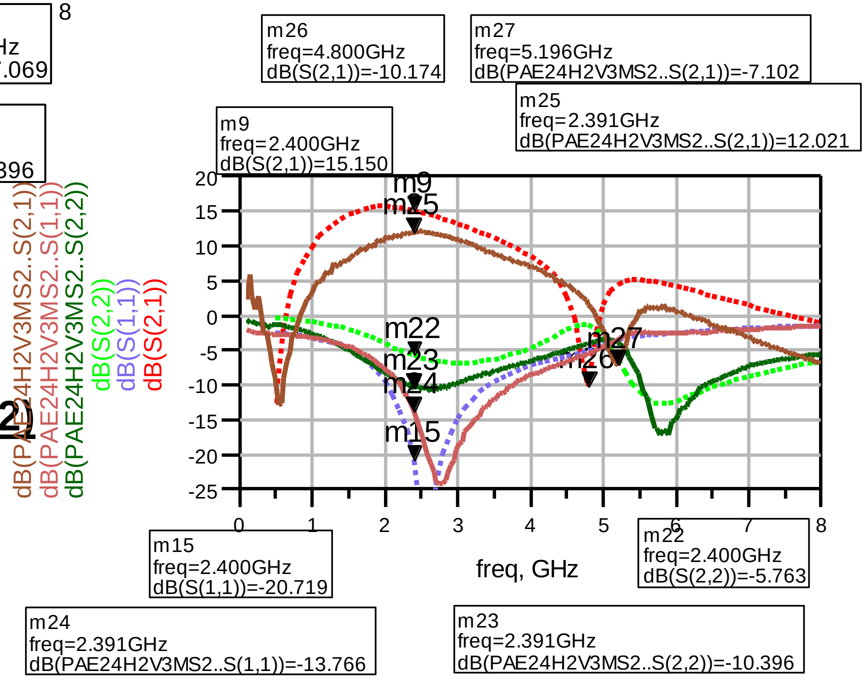
PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)



<u>Fundamental only Match (H1) with Good Efficiency (2.44 GHz)</u>

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)



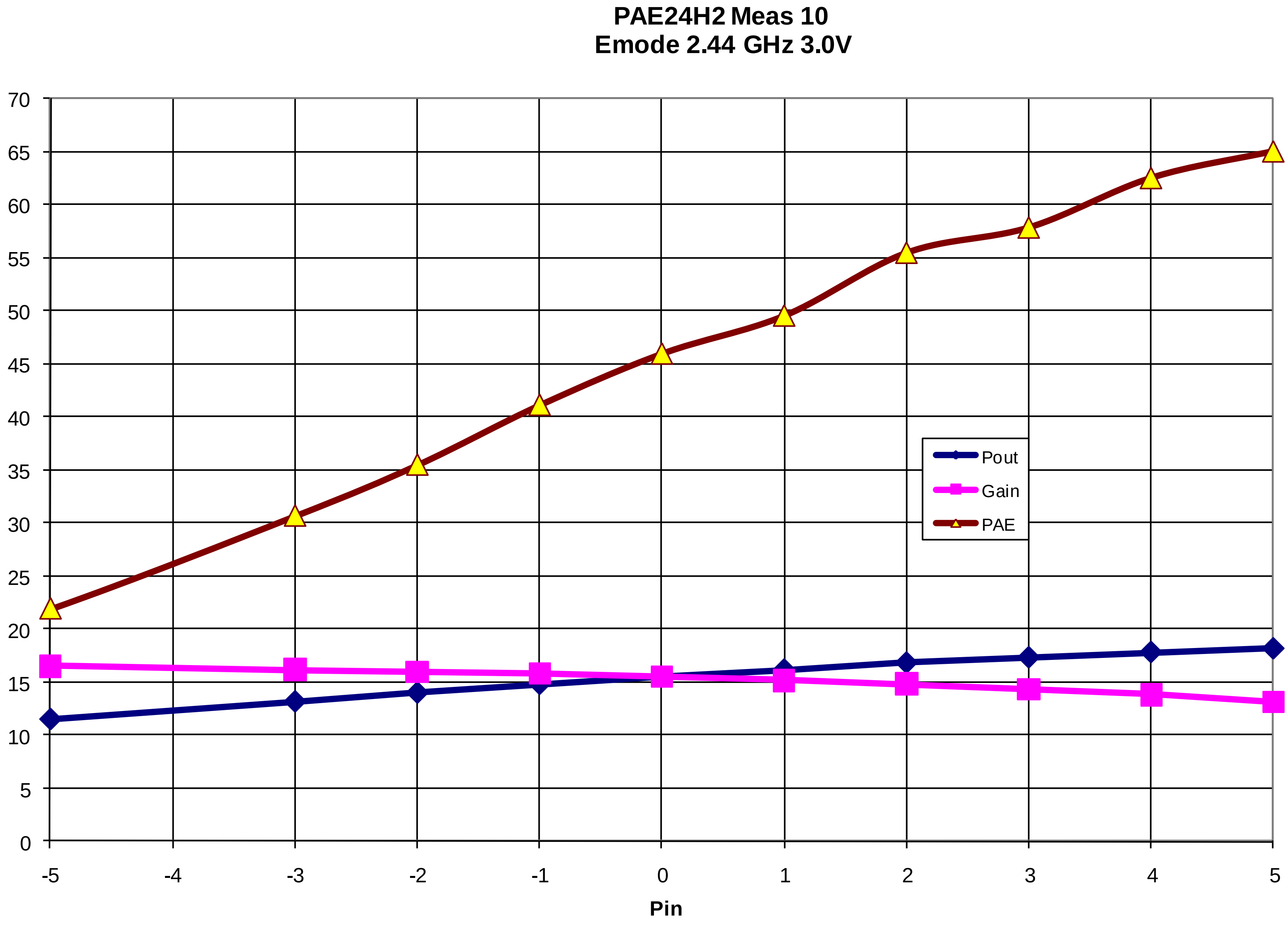


Fundamental plus Short Circuit 2nd Harm (H2)

Poor gain as measured (solid) vs. Simulations (dot) Measured slightly compressed (marginal stability!)

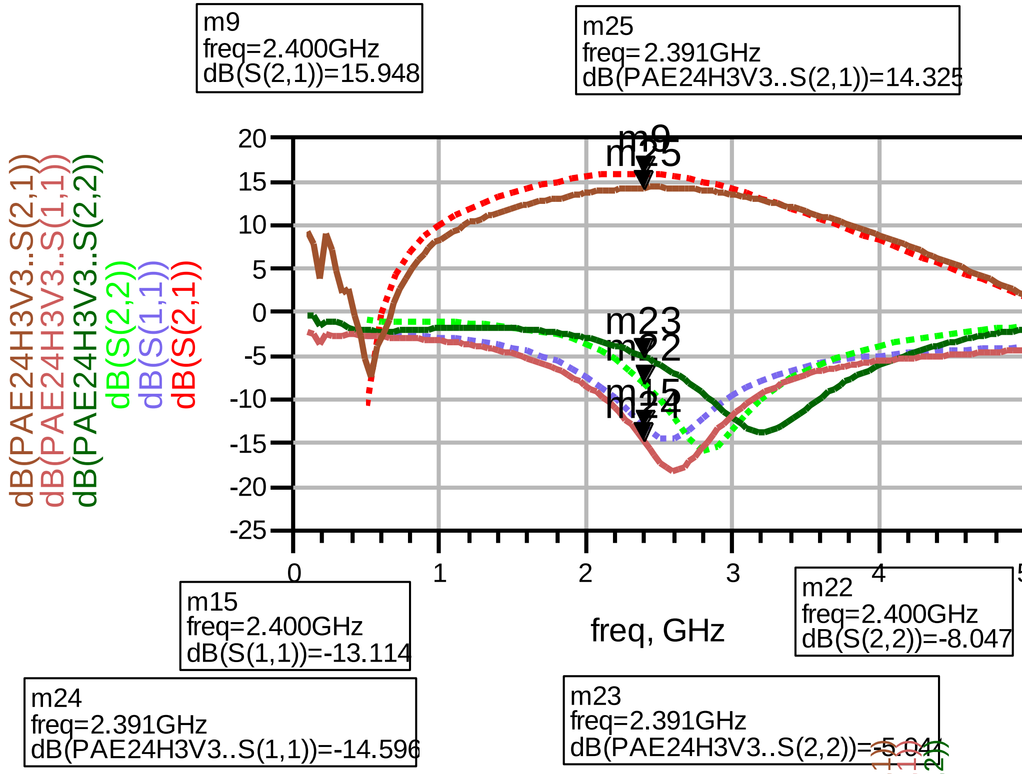
Simulation With Typical NL PHEMT and Measured—Similar Results.

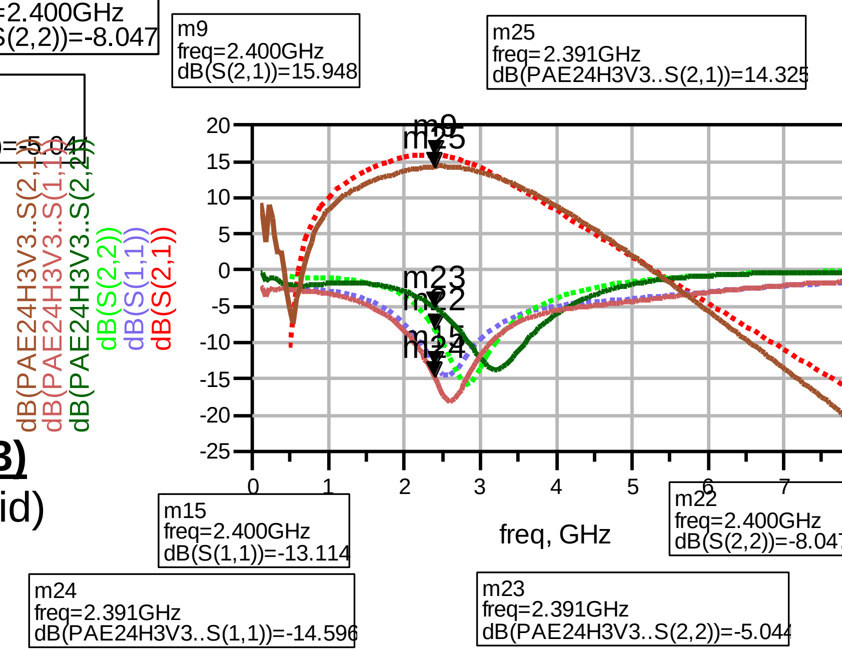
PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)



<u>Fundamental plus Short Circuit 2nd Harm (H2) with Excellent Efficiency (2.44 GHz)</u>

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)

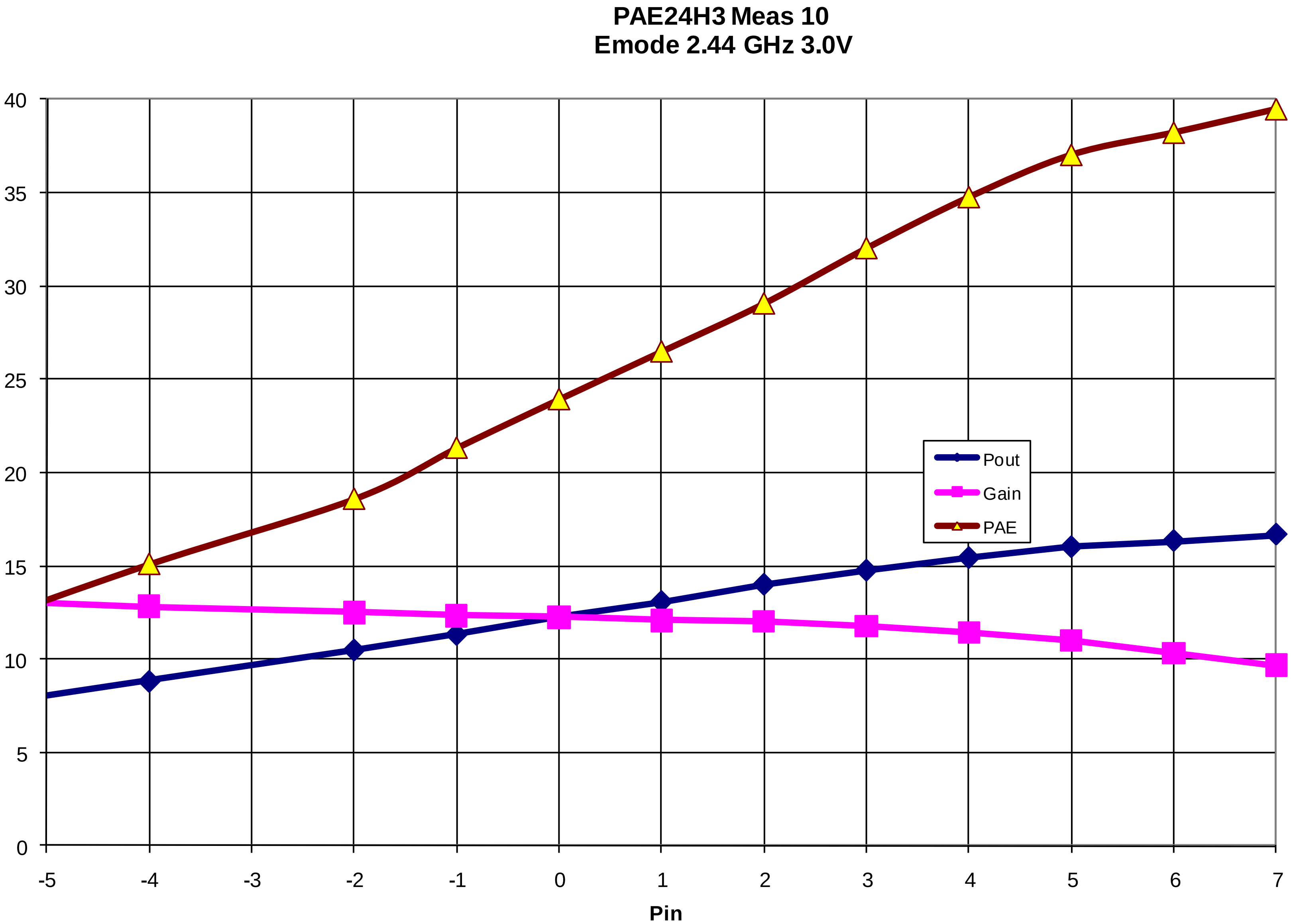




Fundamental plus Open Circuit 3rd Harm (H3)

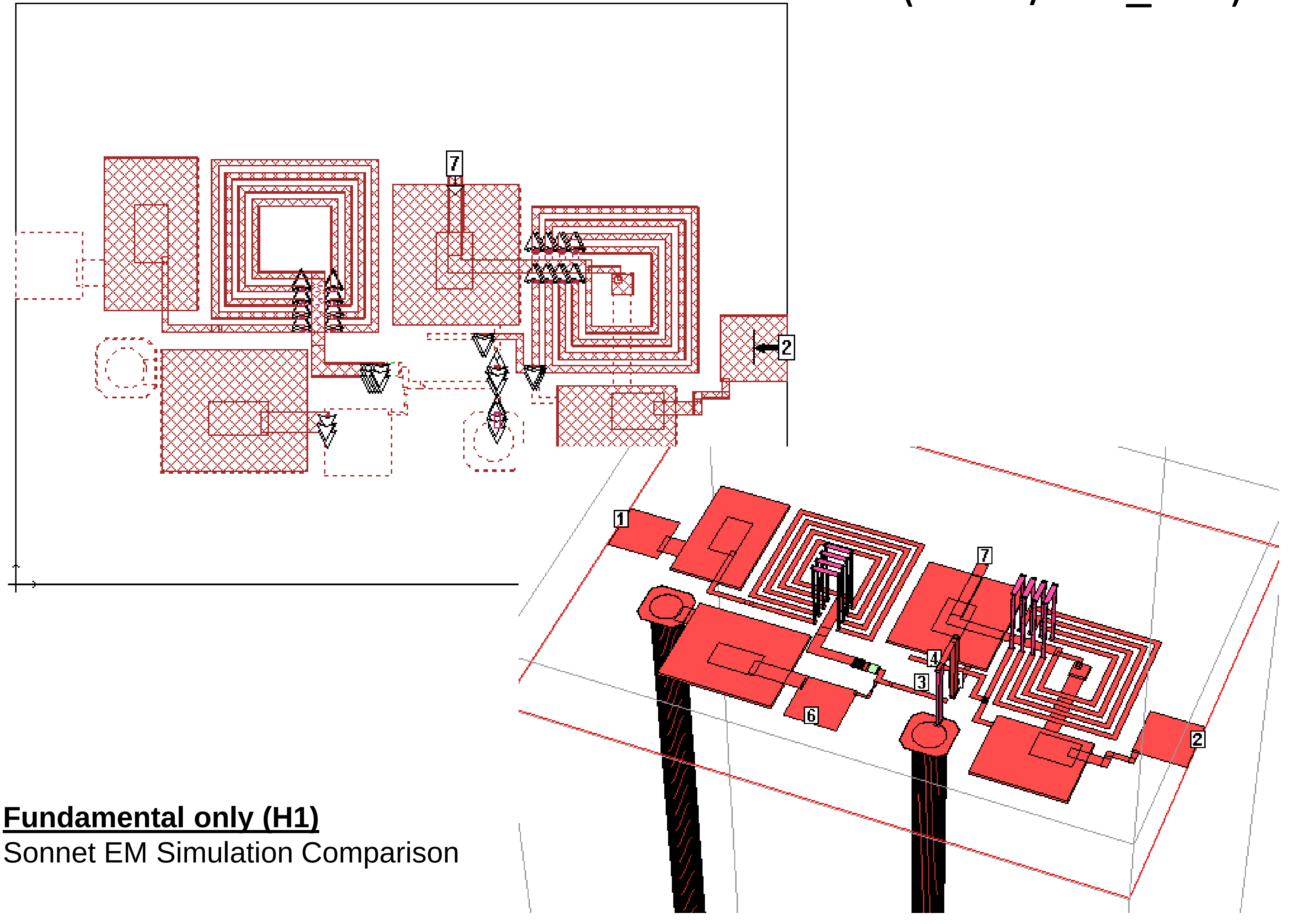
Good comparison between measurements (solid) and Simulations (dot)

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim)



Fundamental plus Open Circuit 3rd Harm (H3) with Moderate Efficiency (2.44 GHz)

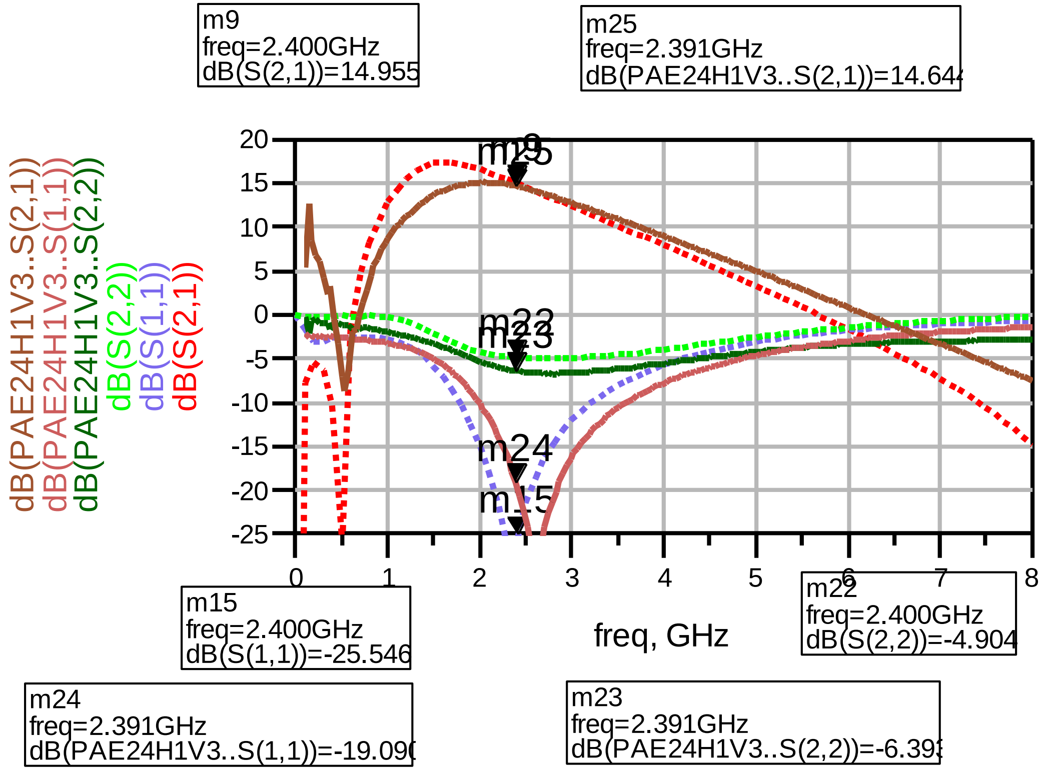
PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)

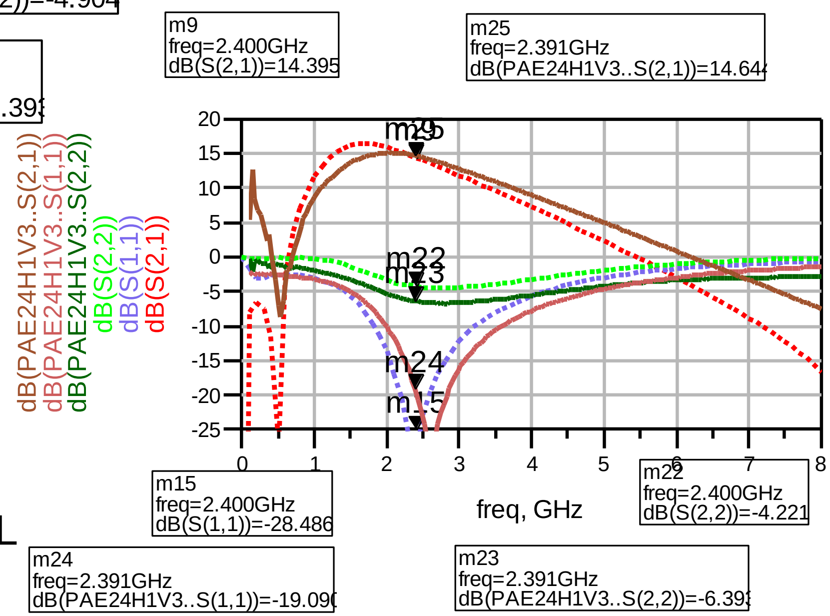


Fundamental only (H1)

Sonnet EM Simulation Comparison

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)





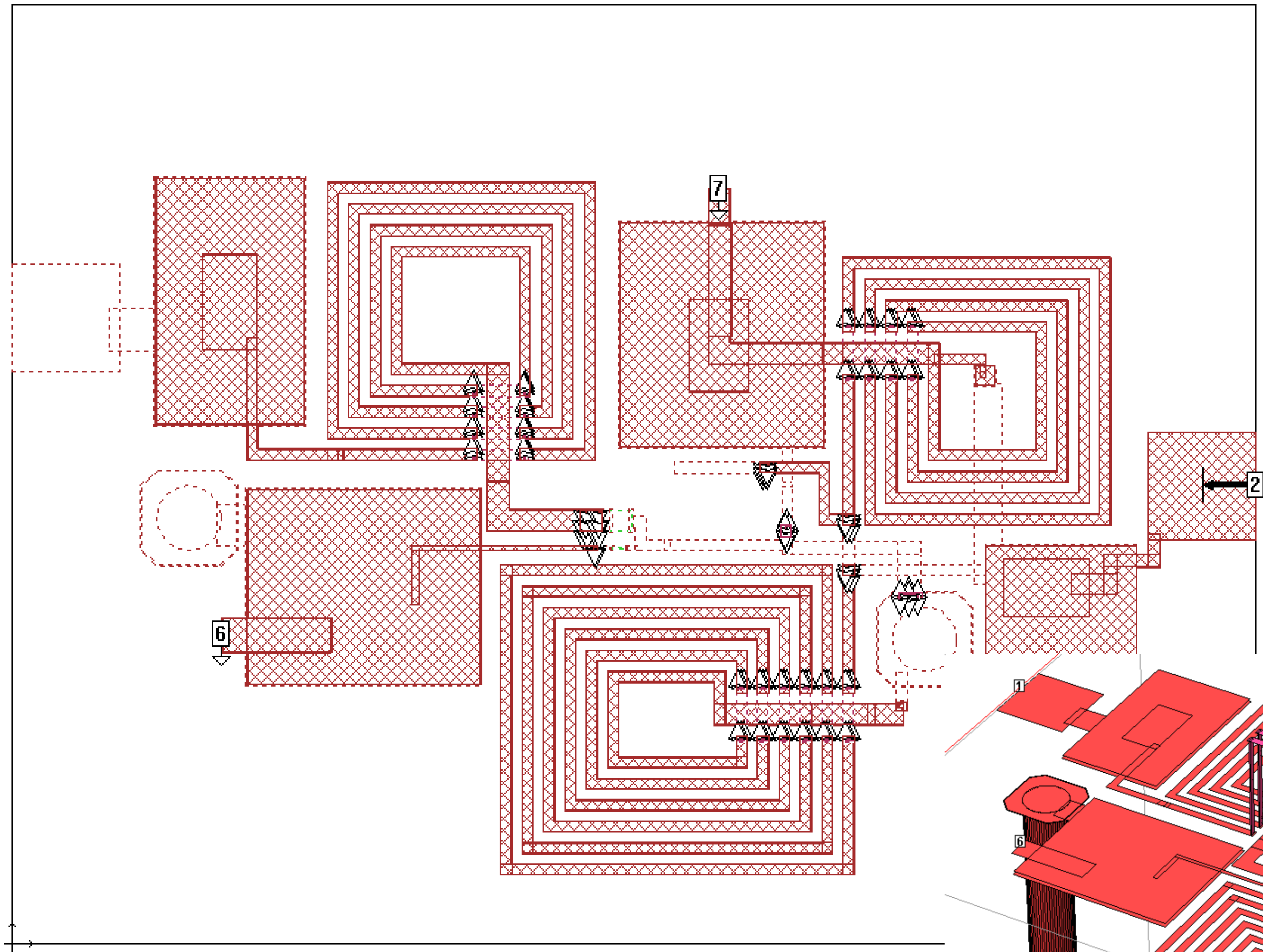
Fundamental only (H1)

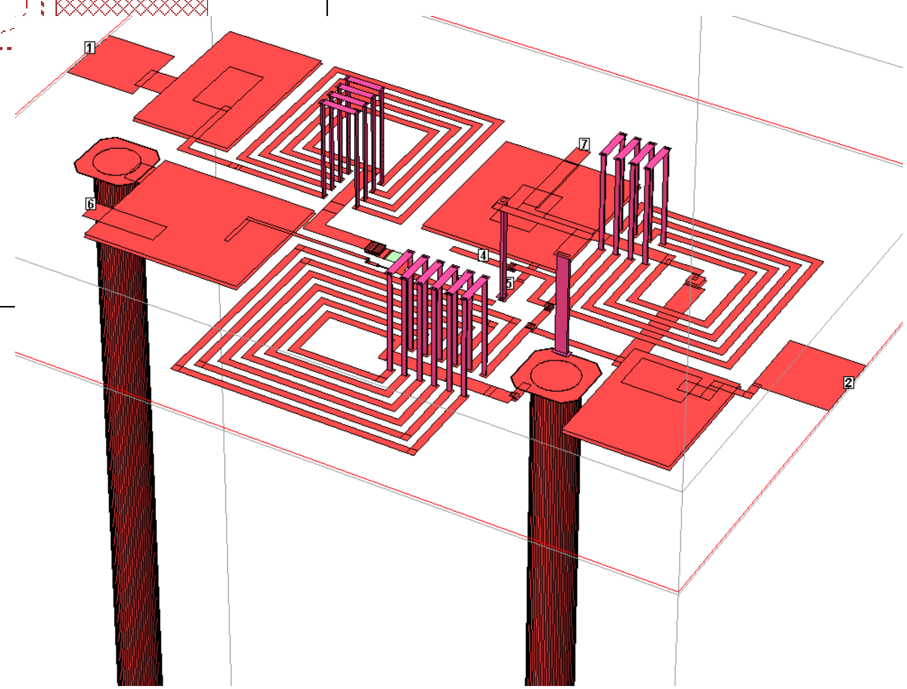
Sonnet EM Simulation

Top—Measured Results for H2 with measured PHEMT show

Bottom Right—Measured Results for H2 with NL PHEMT show similar results

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)

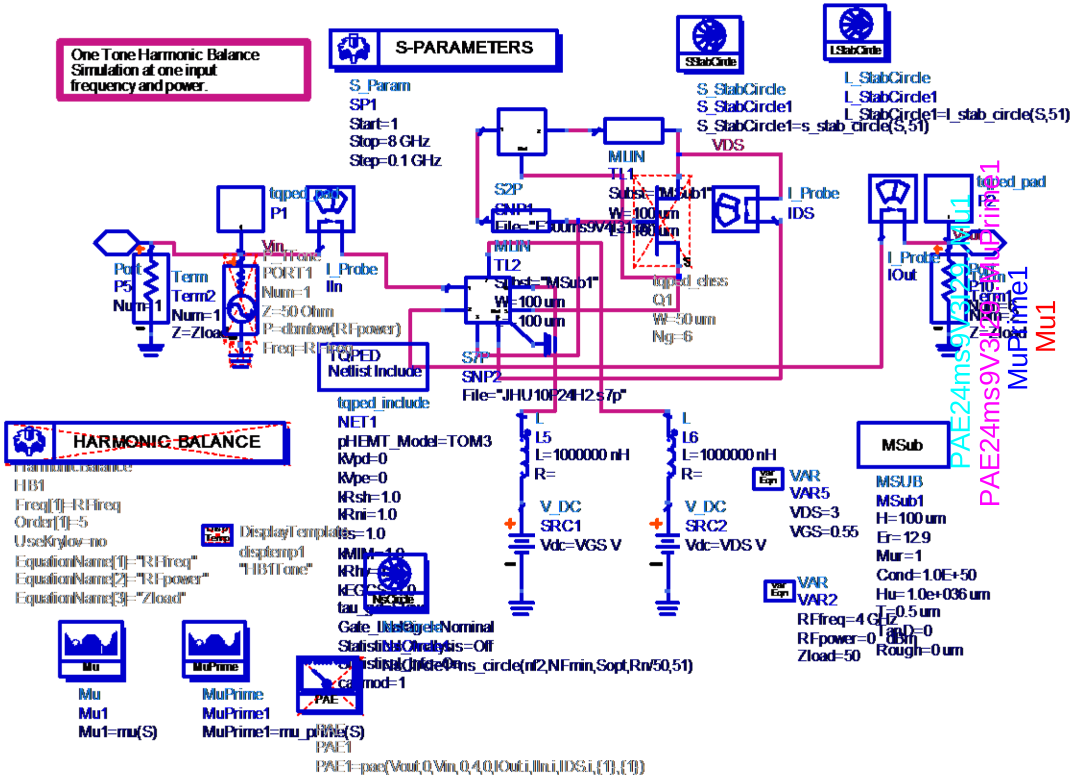


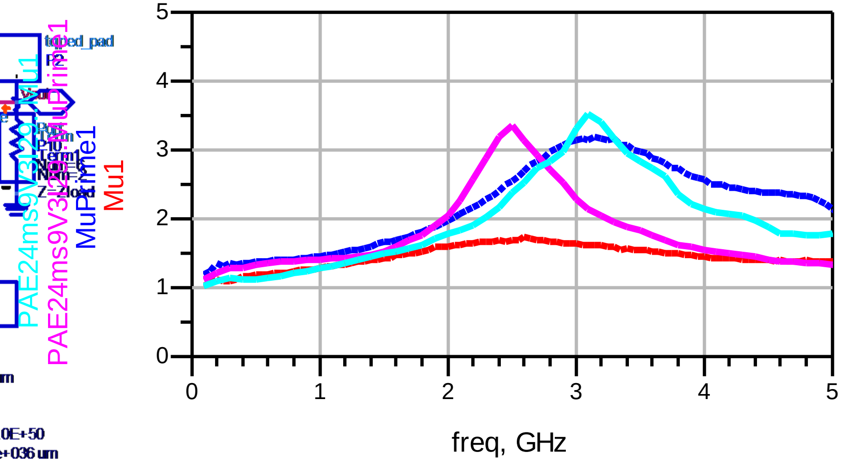


<u>Fundamental plus Short Circuit 2nd Harm (H2)</u>

Sonnet EM Simulation Comparison

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)



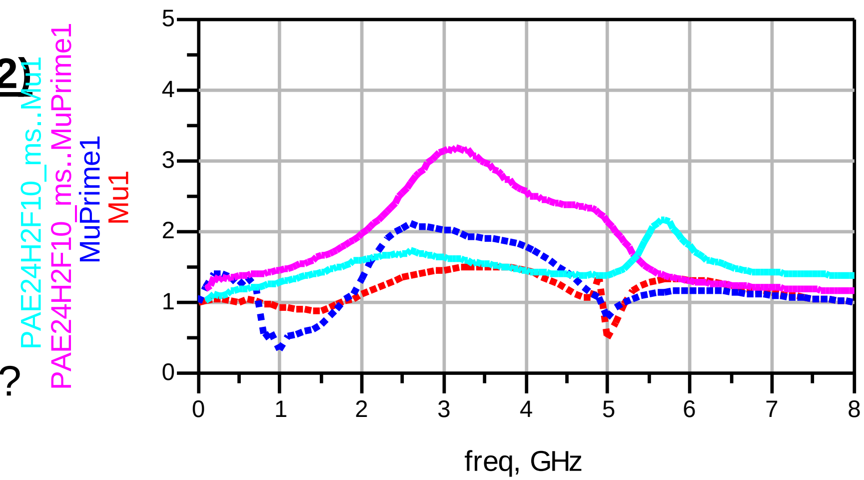


Fundamental plus Short Circuit 2nd Harm (H2)

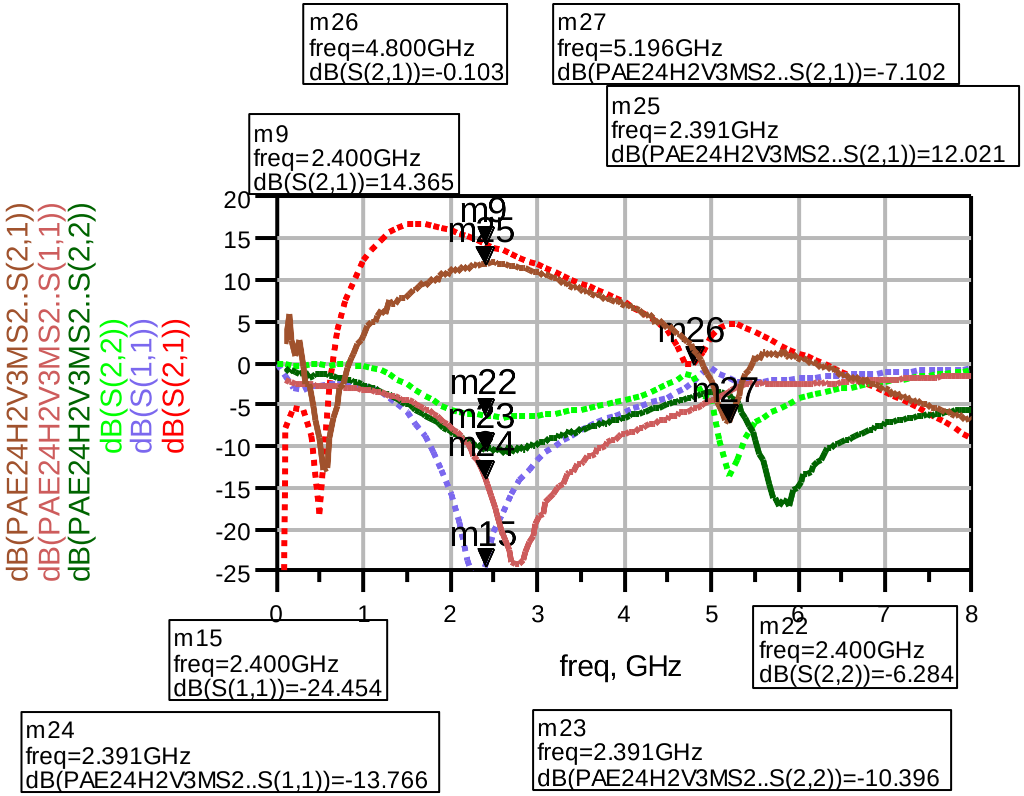
Sonnet EM Simulation With Typical NL PHEMT and Measured—Similar Results.

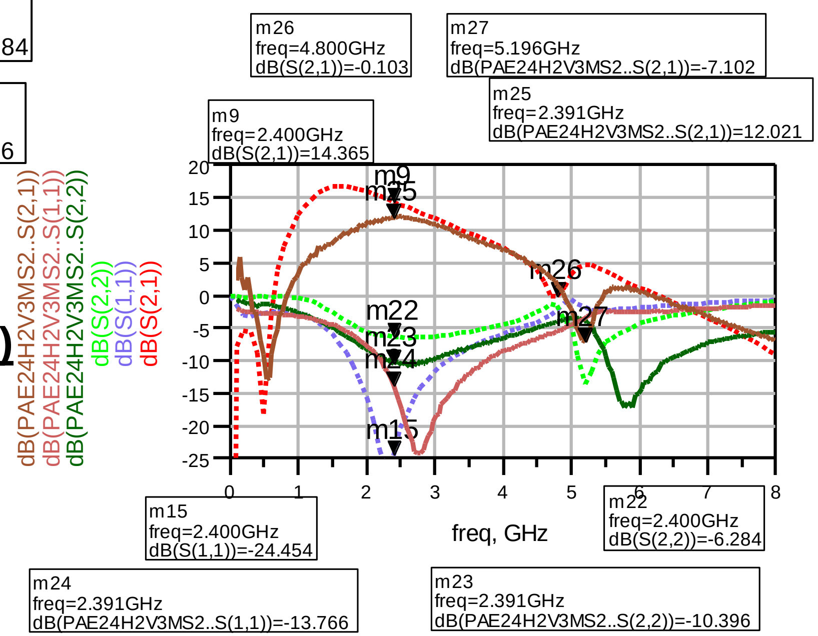
Top—Measured Results for H1, H2, H3 show unconditional stability.

Bottom—Sonnet Simulations show marginal stability at 1 and 5 GHz, need to re-measure H2?



PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)





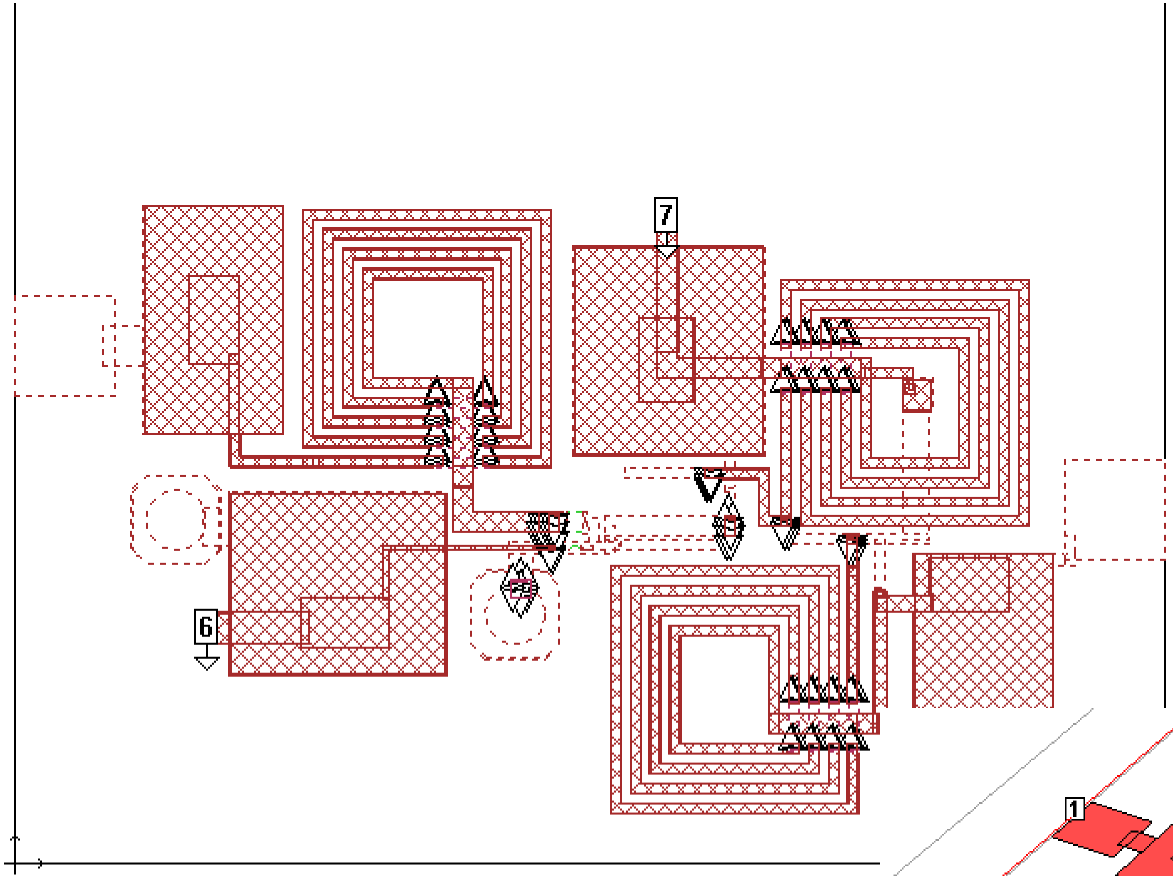
Fundamental plus Short Circuit 2nd Harm (H2)

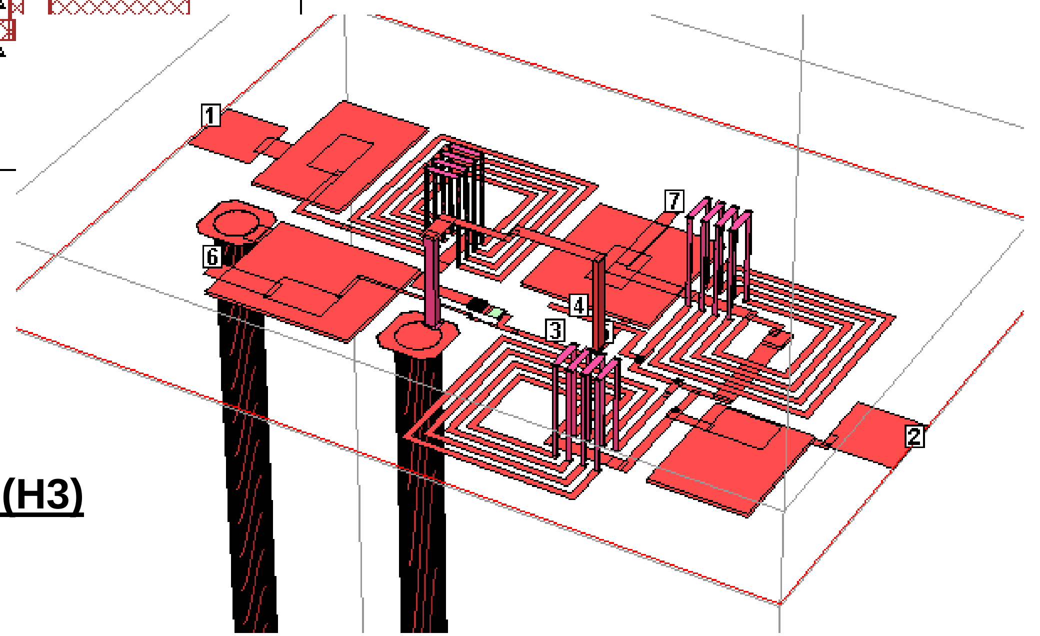
Sonnet EM Simulation

Top—Measured Results for H2 with measured PHEMT (overdriven due to stability issues)

Bottom Right—Measured Results for H2 with NL PHEMT show similar results

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)

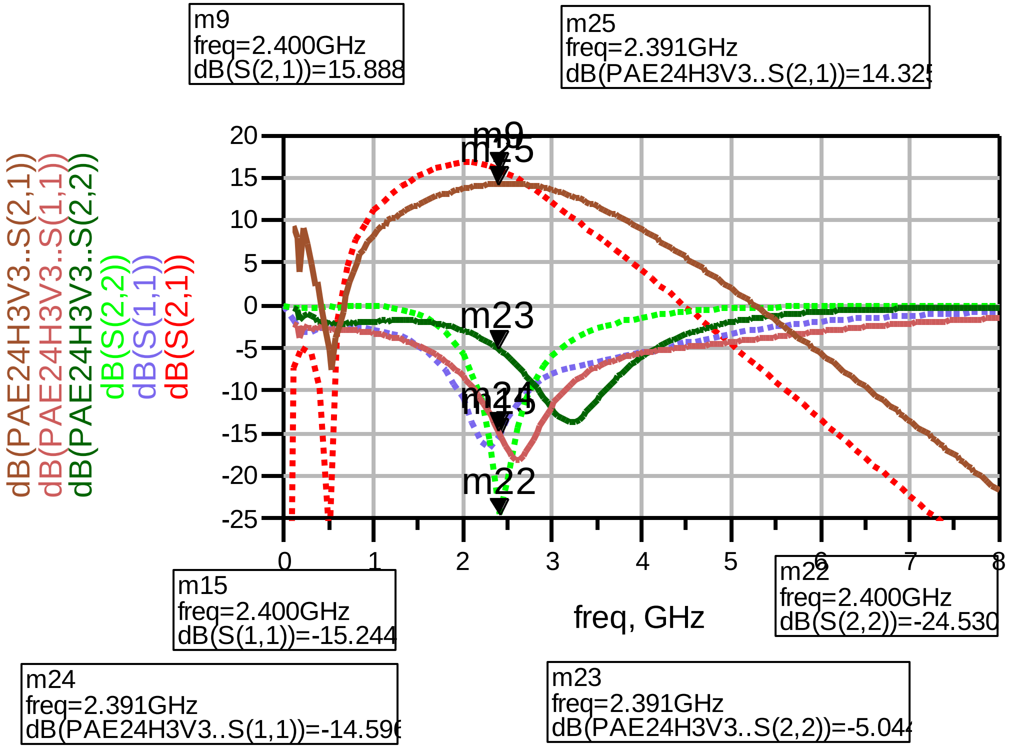


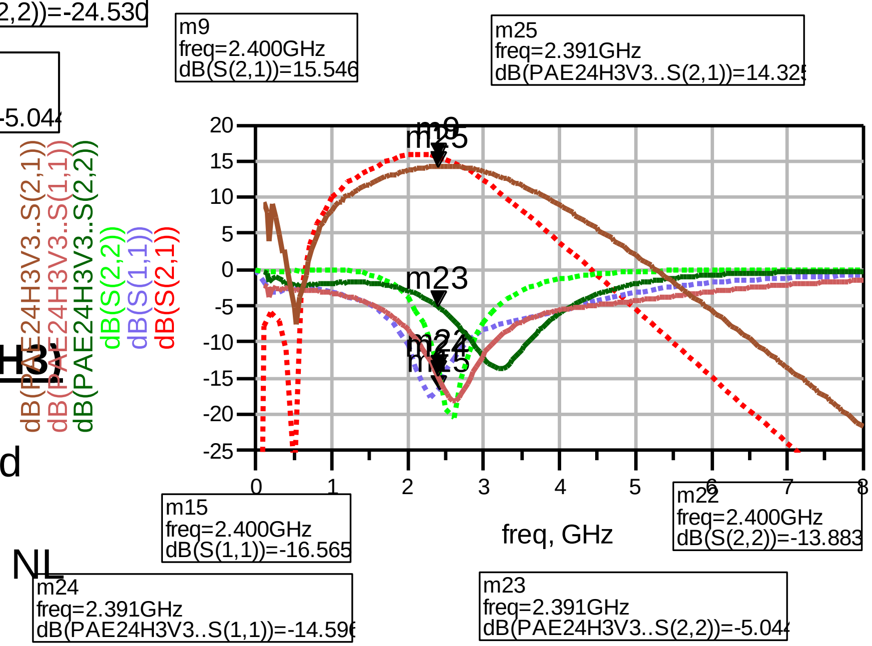


Fundamental plus Open Circuit 3rd Harm (H3)

Sonnet EM Simulation Comparison

PAE24 Harmonic Terminations JHU10P24 (Meas/Sim_Son)



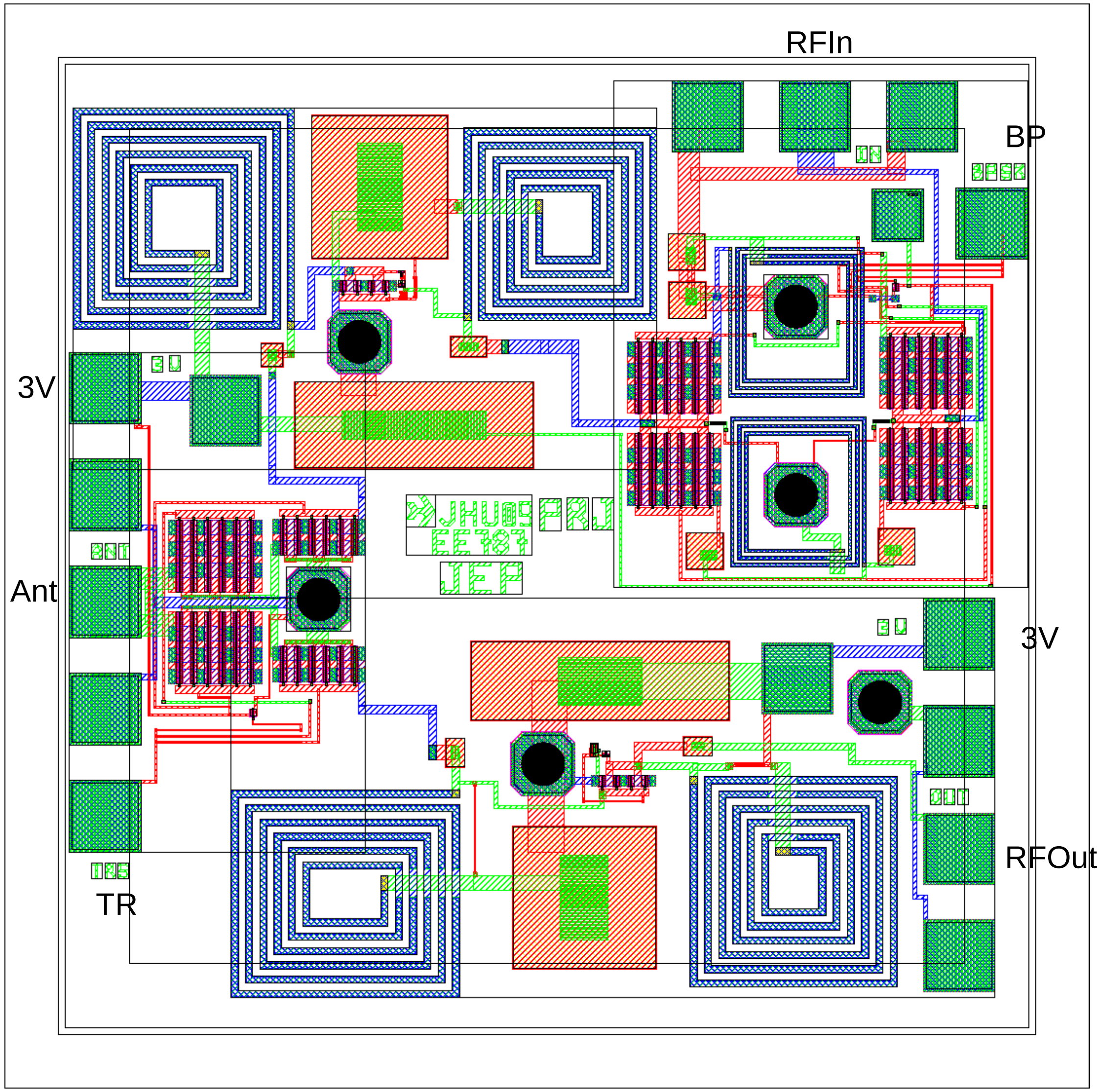


Fundamental plus Open Circuit 3rd Harm (H3)

Sonnet EM Simulation

Top—Measured Results for H2 with measured PHEMT show

Bottom Right—Measured Results for H2 with NL PHEMT show similar results

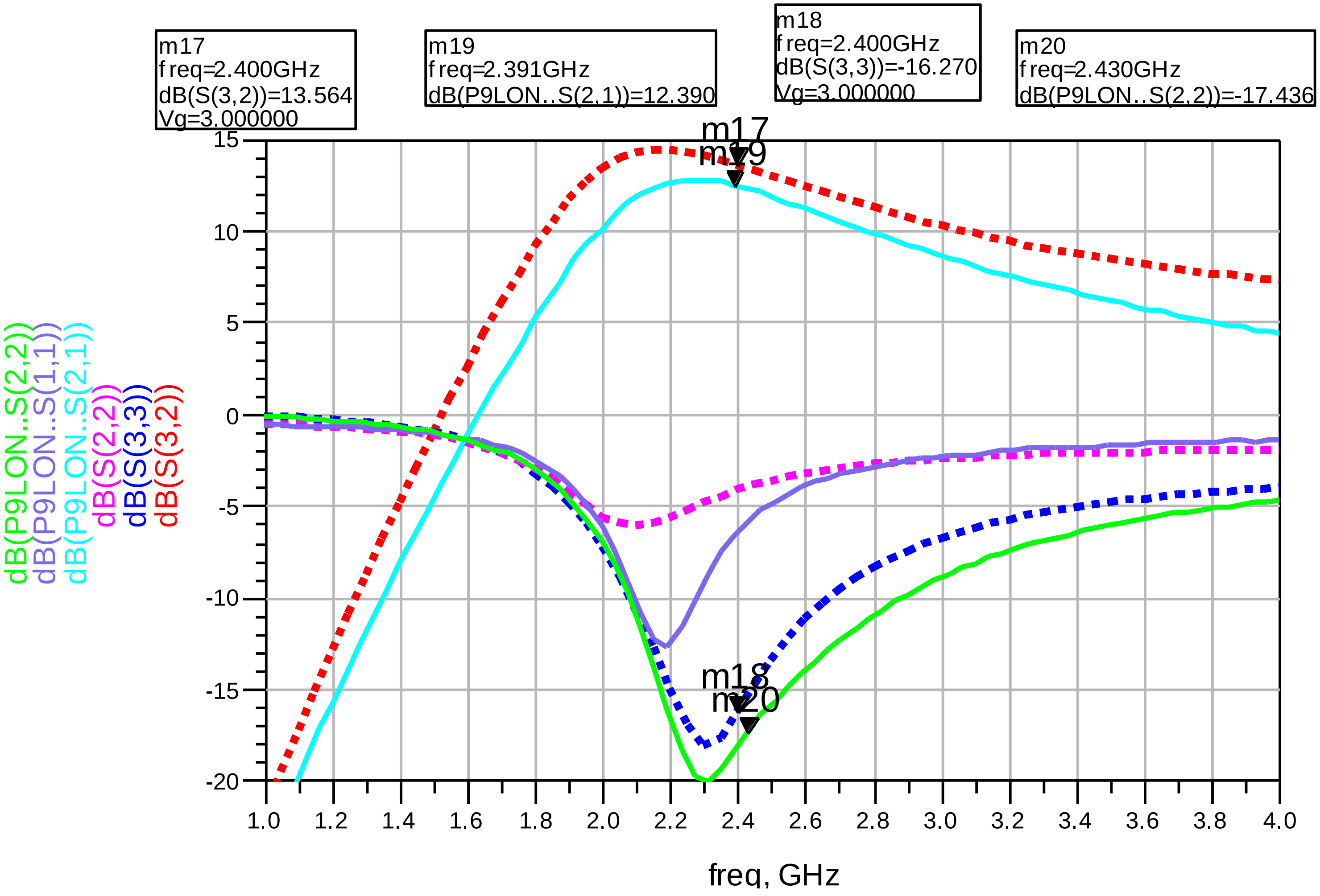


13) John Penn
JHU09PRJ "Corrected"
2.4 GHz Front End

This 2.4 GHz front end circuit was designed and tested in the fall 2009 class but had a slight flaw in the BPSK modulator. The fix was to add a 4K ohm resistor to ground as a DC reference to the switches. The original circuit was written up in the Jan/Feb 2011 Defense Electronics Magazine. The RF front end consists of a BPSK modulator, TR Switch, power amplifier, and a low noise amplifier.

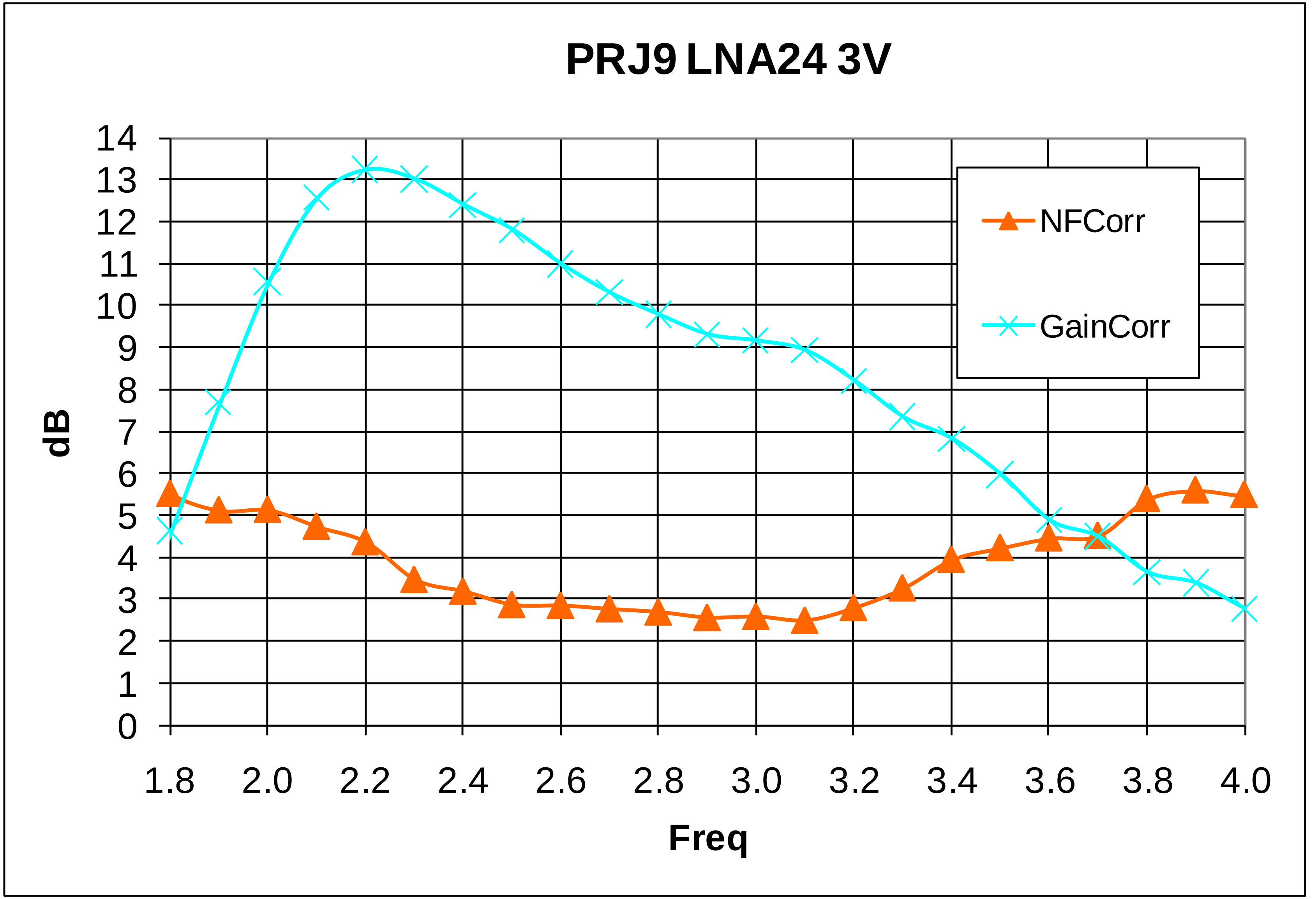
The actual gain of this circuit might be slightly higher as these small 4x15 um PHEMT based amplifiers tend to compress even at the lowest drive level (-10 dBm) of the 8510 NWA used for the measurements.

JHU09PRJ: RF Front End 2.4 GHz



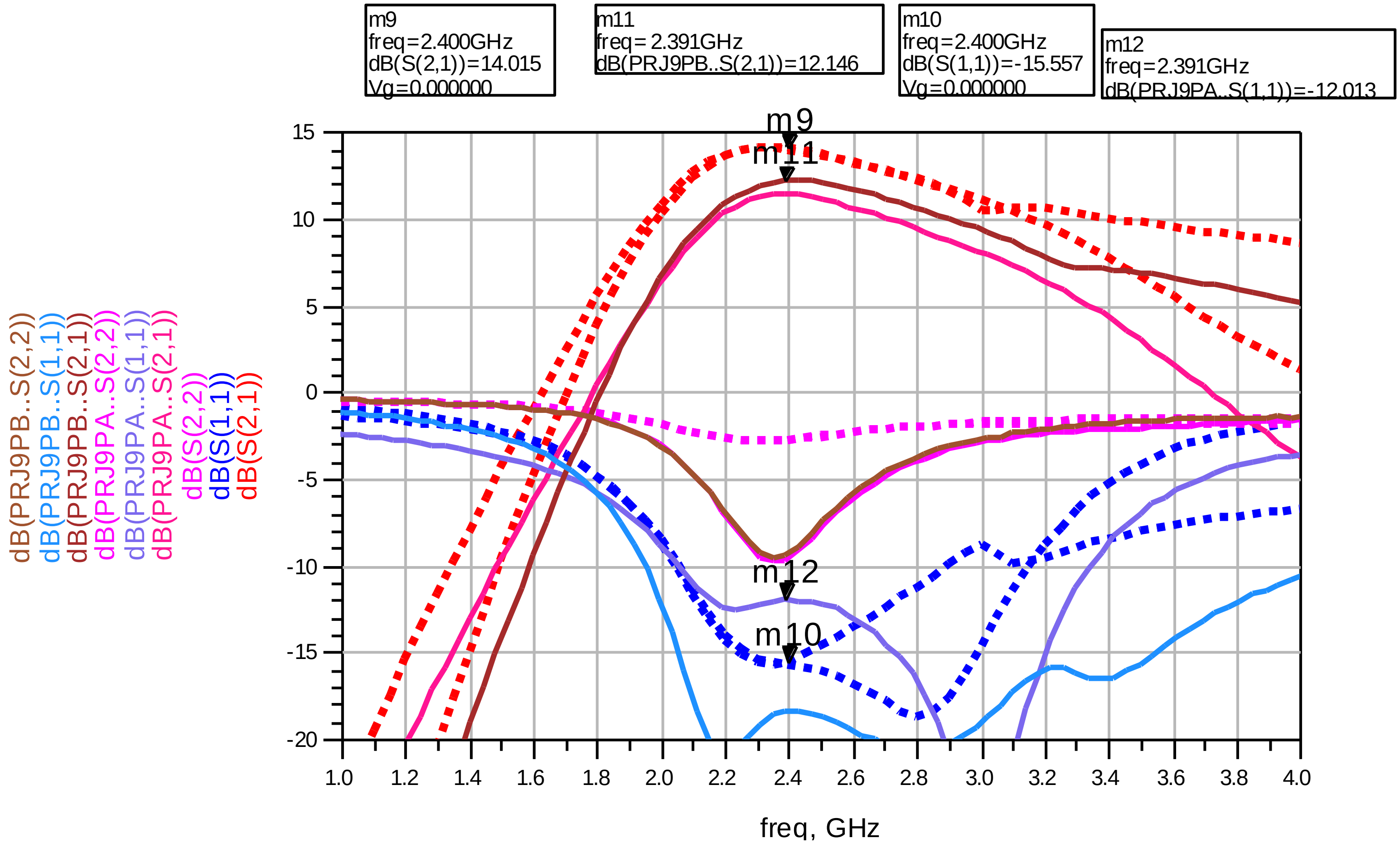
Measured Receive (LNA+TRS) at 3V ~10 mA (solid-meas, sim-dot)

JHU09PRJ: RF Front End 2.4 GHz

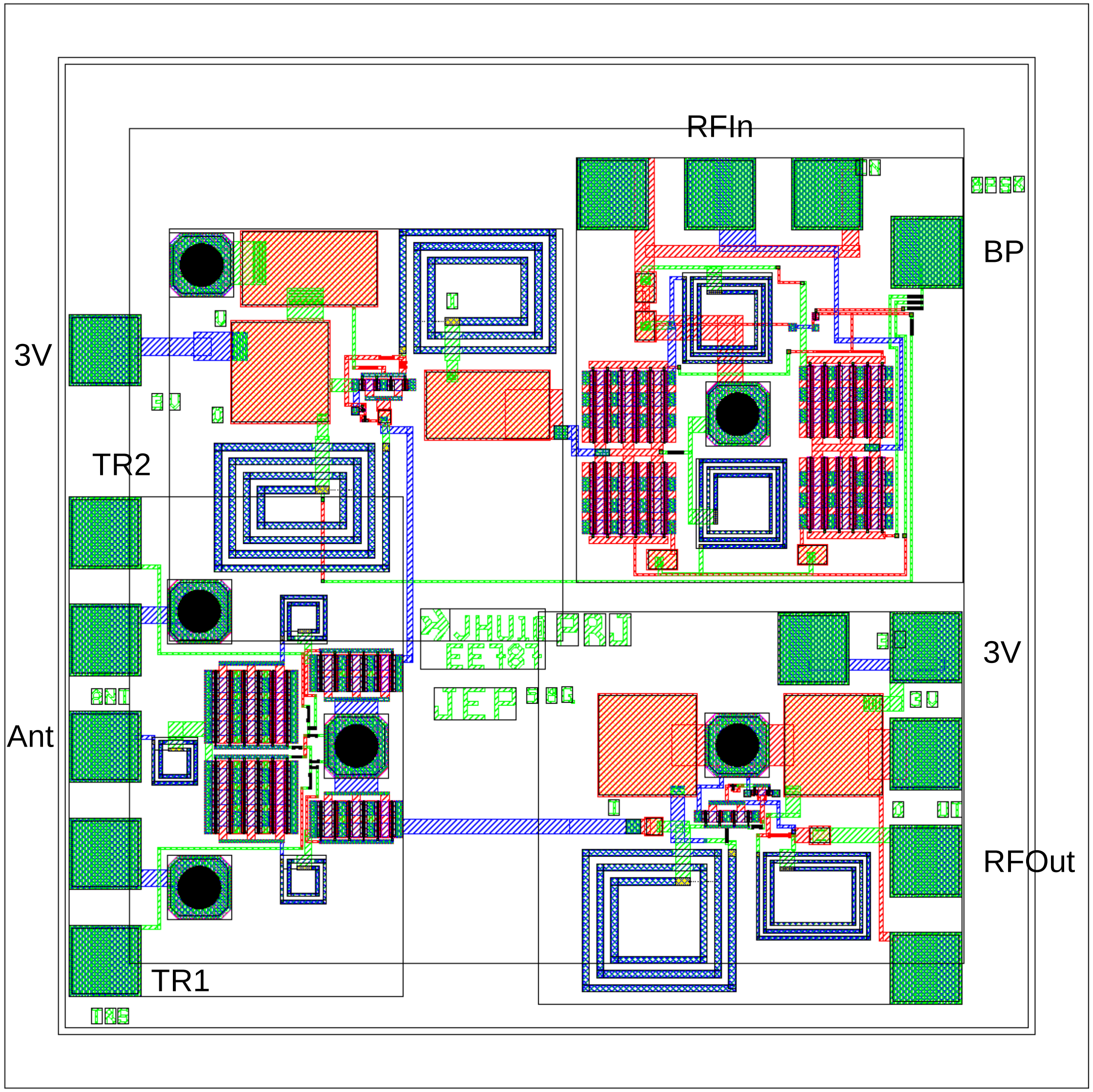


Measured Noise Figure Receive (LNA+TRS) ~3dB at 3V ~10 mA

JHU09PRJ: RF Front End 2.4 GHz



Measured Transmit (BPSK+PA+TRS) at 3V ~10 mA (solid-meas, sim-dot)

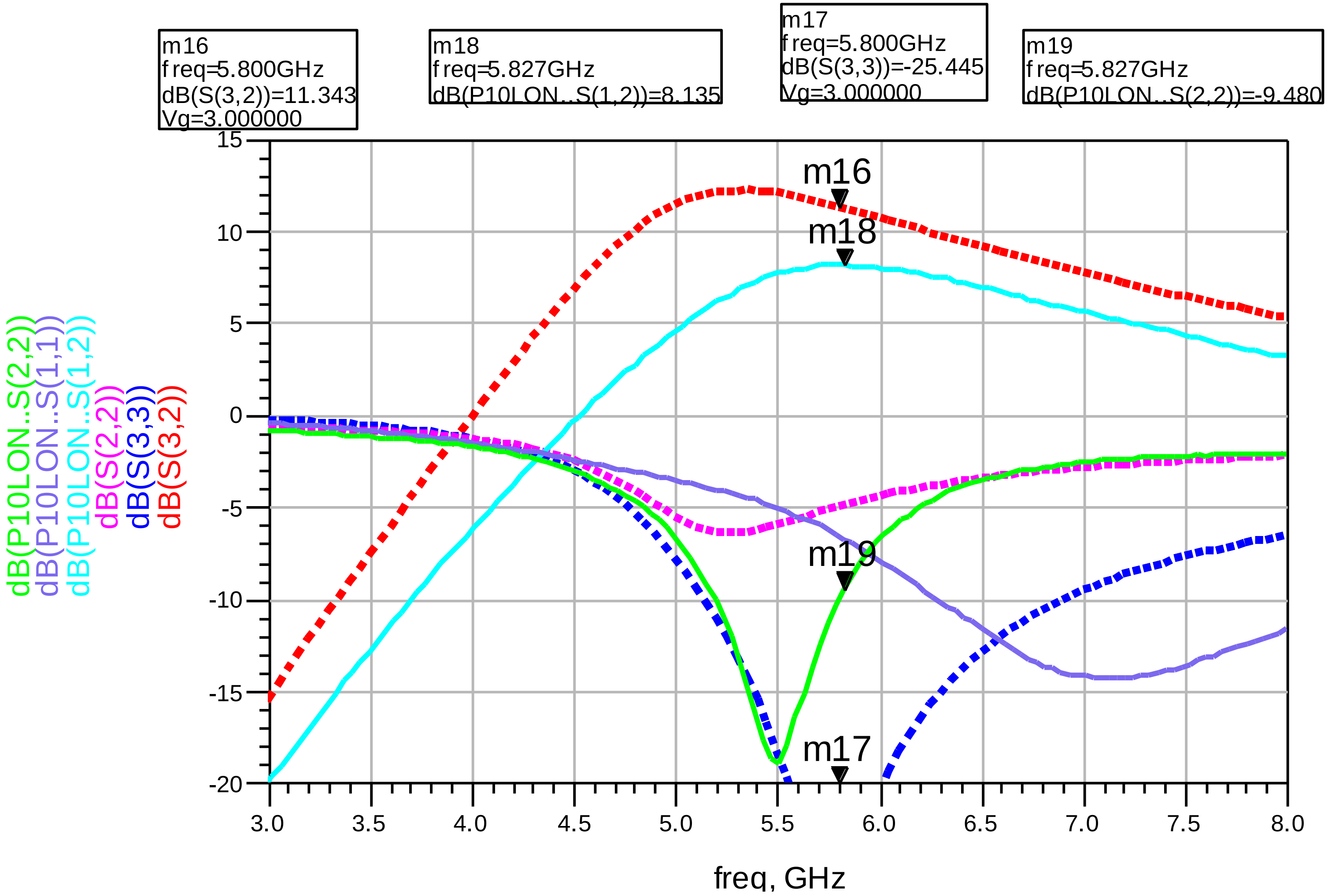


14) John Penn JHU10PRJ 5.8 GHz Front End

This 5.8 GHz RF front end circuit is similar to the 2.4 GHz front end designed and tested in the fall 2009. The RF front end consists of a BPSK modulator, TR Switch, power amplifier, and a low noise amplifier. At the higher 5.8 GHz frequency, the interconnect parasitics are more critical. Since this was a test circuit, additional optimization of the interconnect affects on the combined circuit was ignored. This may be why the gains tend to be lower than the simulations and also shifted somewhat in frequency.

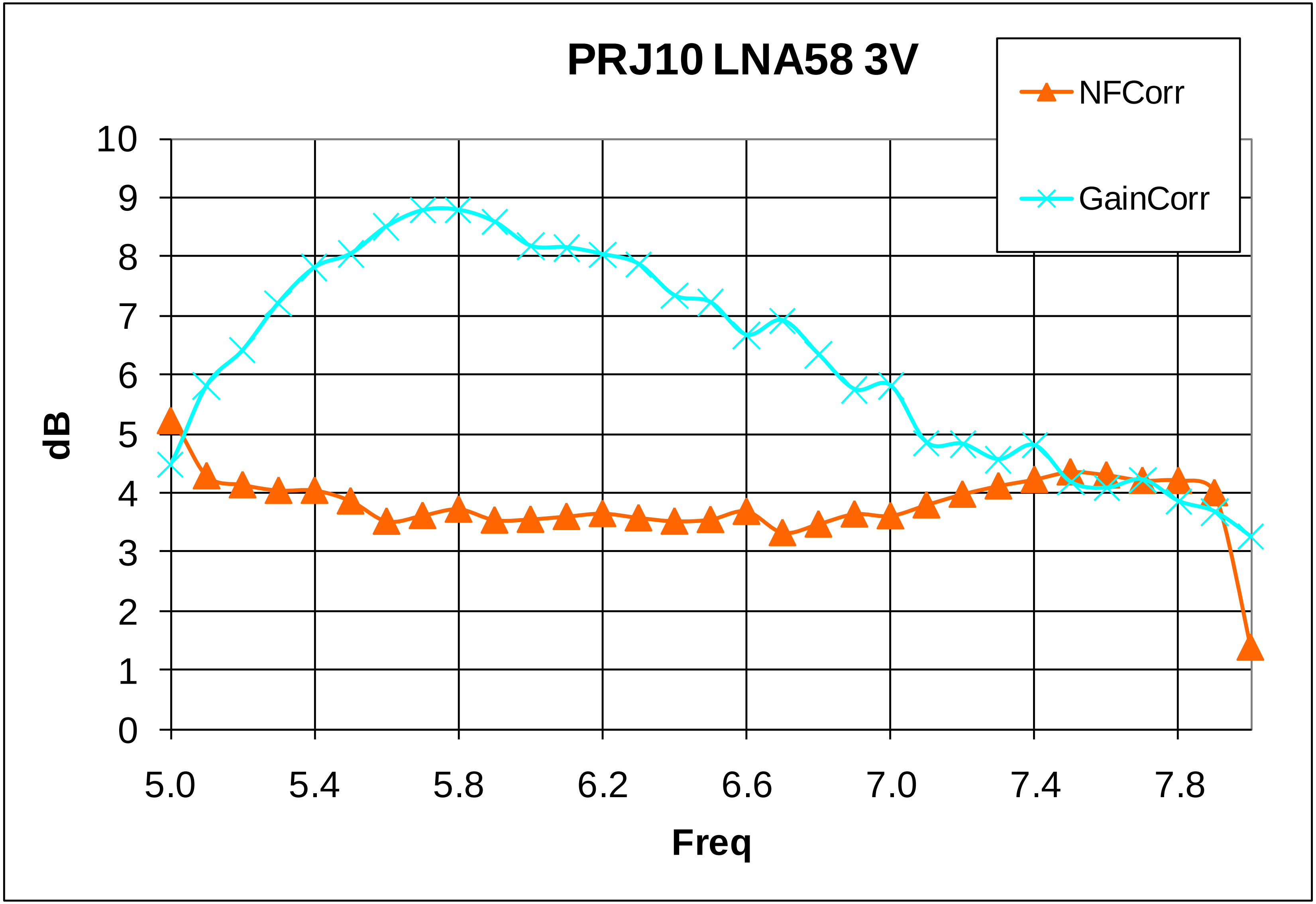
The actual gain of this circuit might be slightly higher as these small 4x15 um PHEMT based amplifiers tend to compress even at the lowest drive level (-10 dBm) of the 8510 NWA used for the measurements.

JHU10PRJ: RF Front End 5.8 GHz



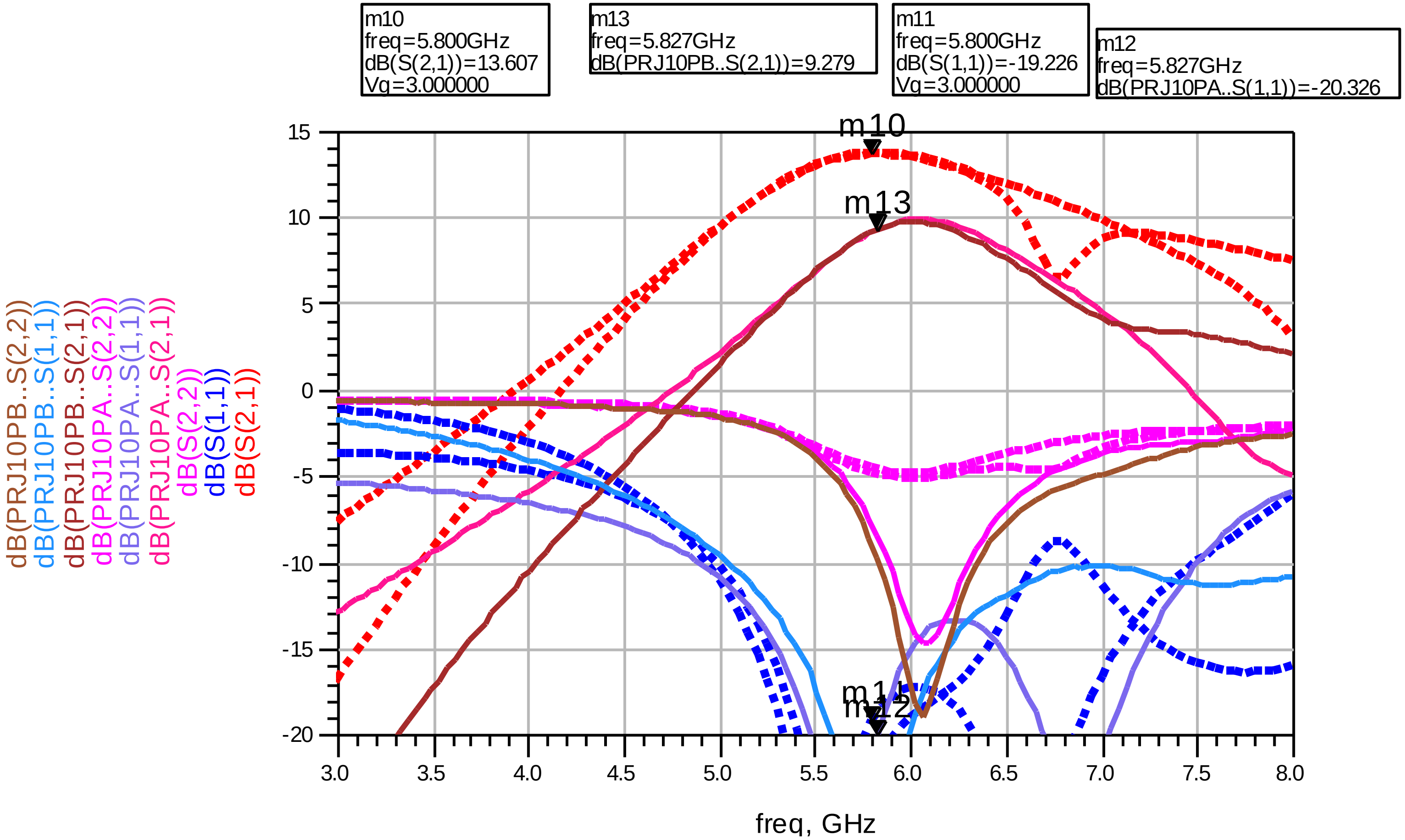
Measured Receive (LNA+TRS) at 3V ~10 mA (solid-meas, sim-dot)

JHU10PRJ: RF Front End 5.8 GHz

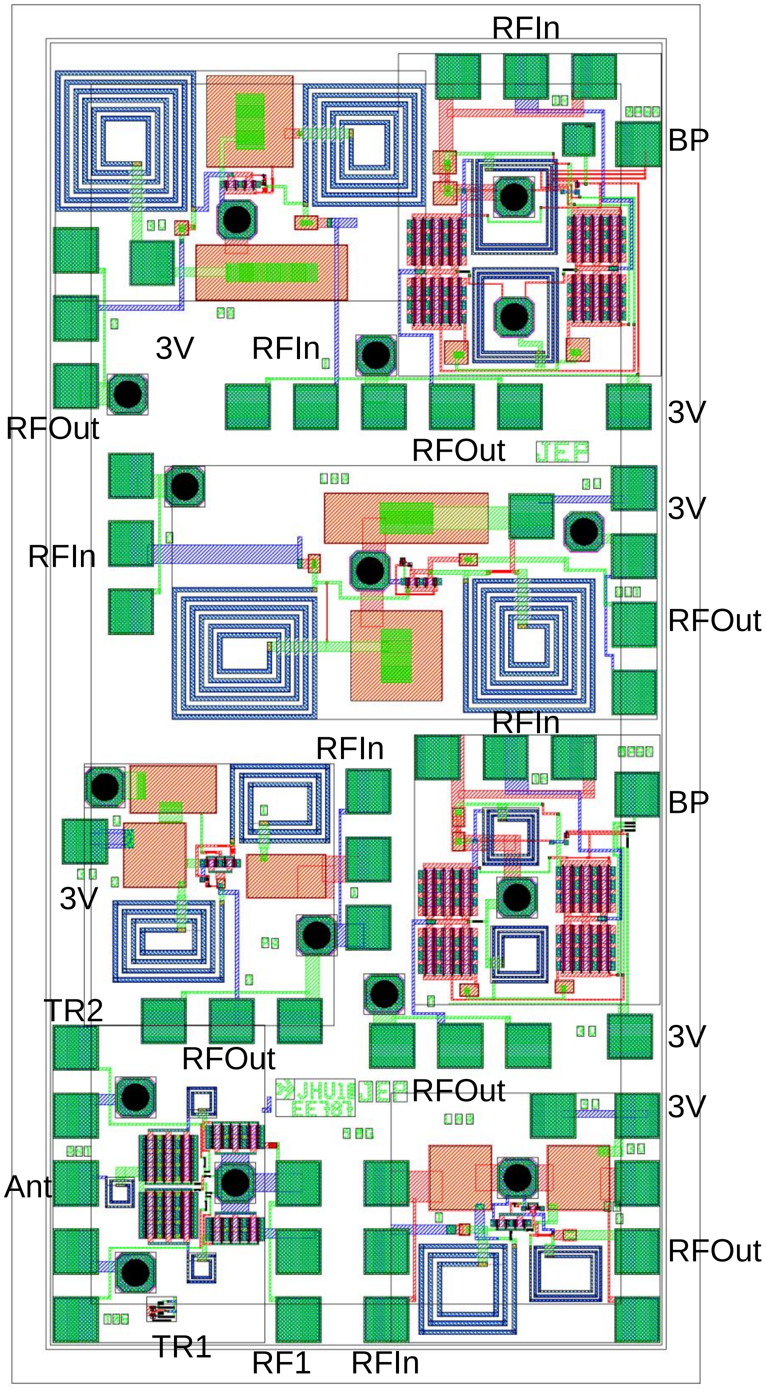


Measured Noise Figure Receive (LNA+TRS) ~3.5 dB at 3V ~10 mA

JHU10PRJ: RF Front End 5.8 GHz



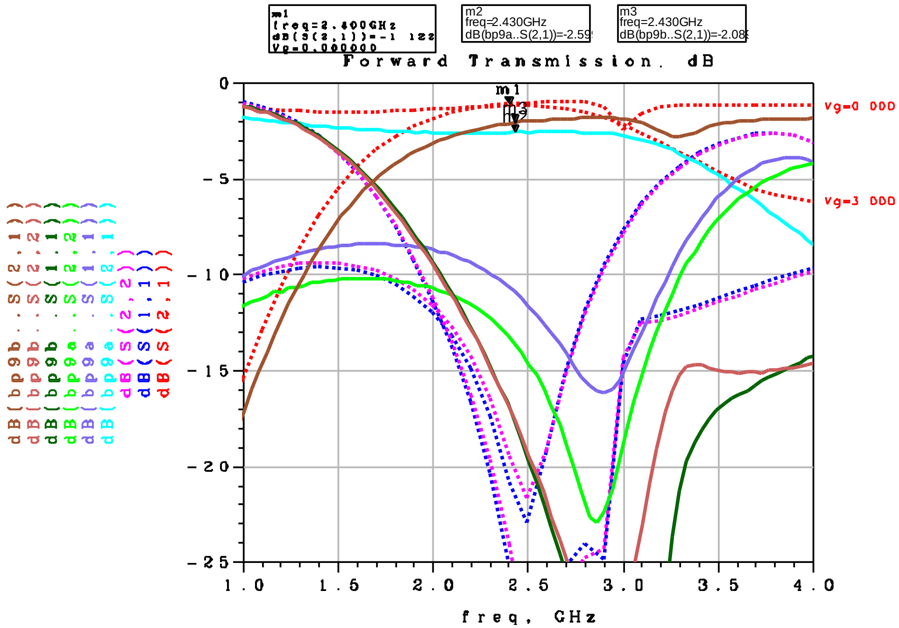
Measured Transmit (BPSK+PA+TRS) at 3V ~10 mA (solid-meas, sim-dot)

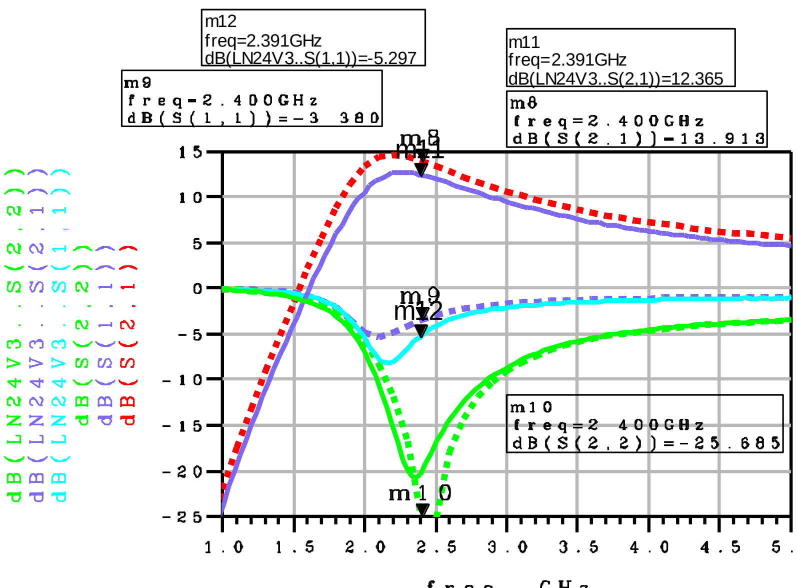


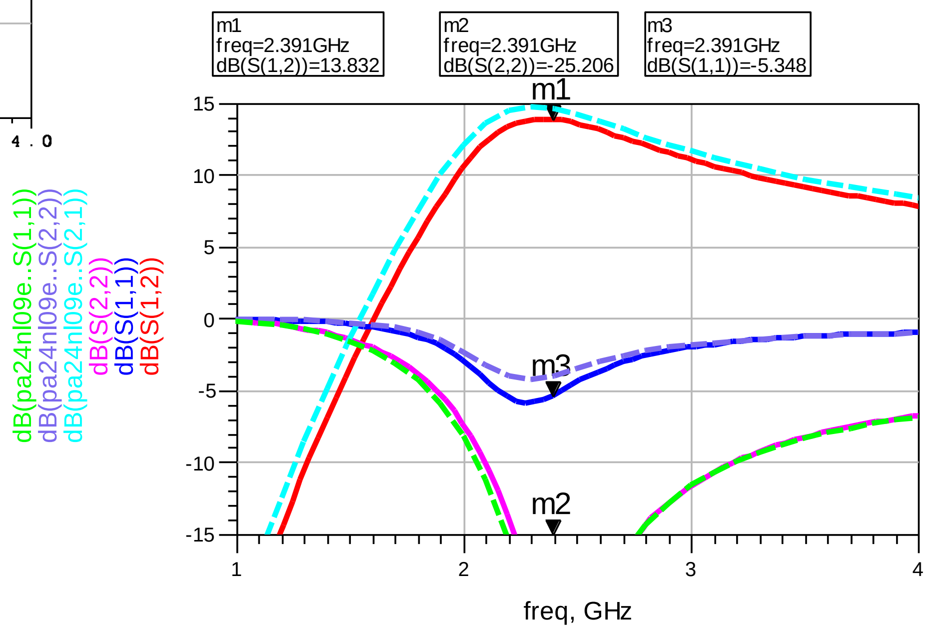
15) John Penn
JHU10JEP
2.4/5.8 GHz RF Front End Test Circuits

These were individual test circuits from the 2.4 GHz and 5.8 GHz RF Front End designs. All of these circuits worked as expected and were intended to “debug” any issues with the full combined RF front end circuits which both worked well. Included here are the 2.4 GHz BPSK modulator, Power Amp, and Low Noise Amp. At 5.8 GHz, the BPSK modulator, Power Amp, Low Noise Amp, and TR Switch are included. Both LNAs are biased at 3V, 3 mA and the PAs at 3V, 7-8 mA.

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits

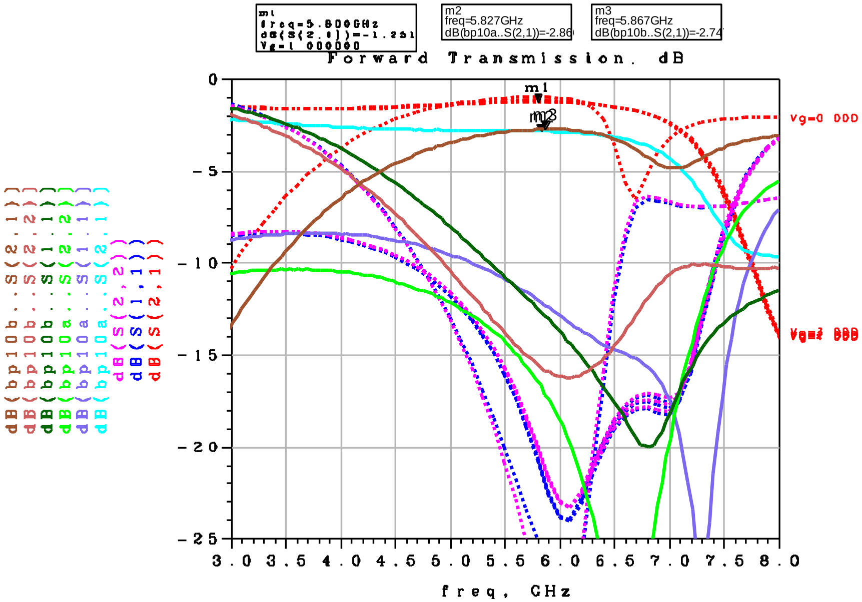


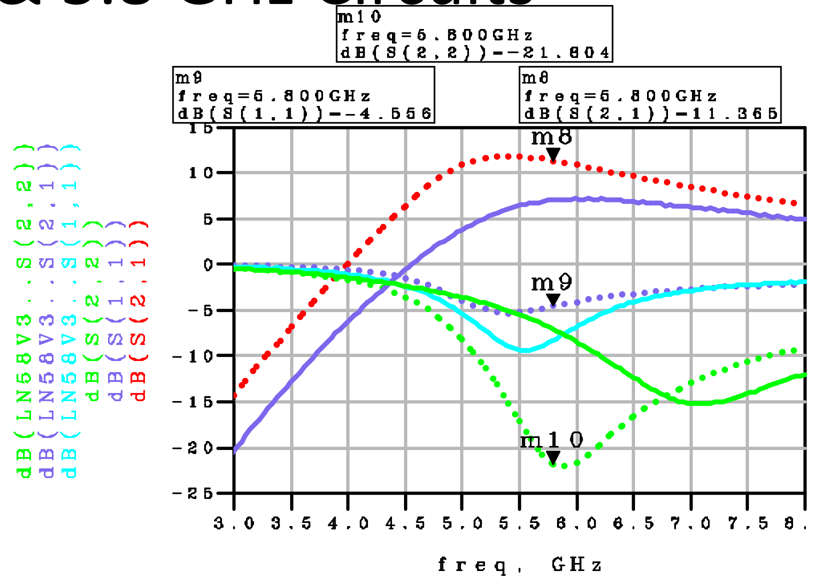


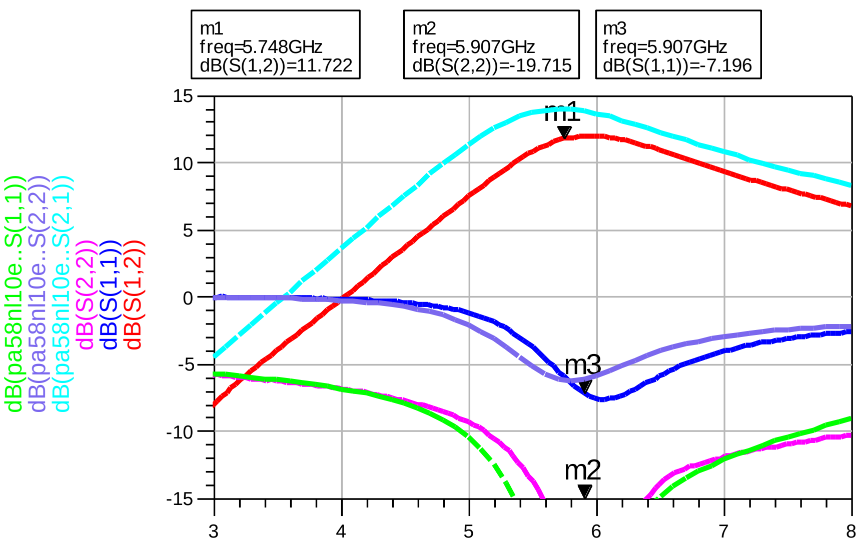


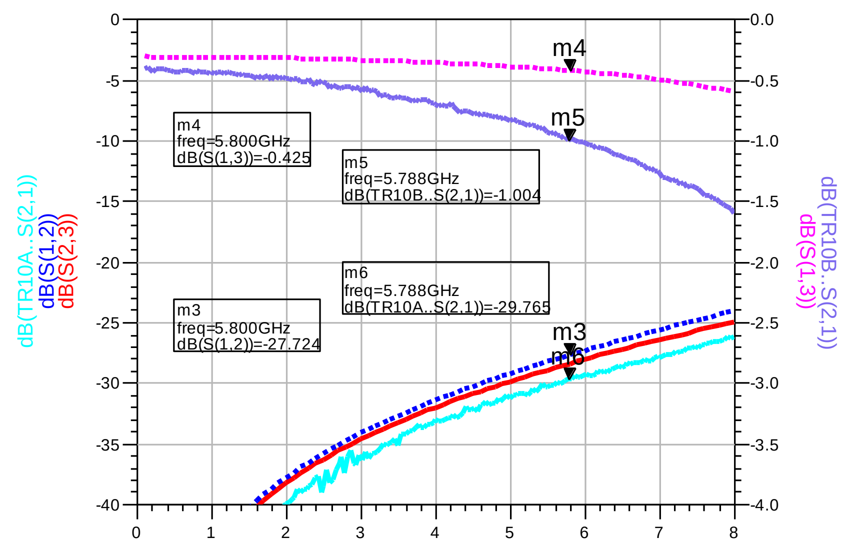
Measured 2.4 GHz Circuits (BPSK, LNA, PA) at 3V

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits



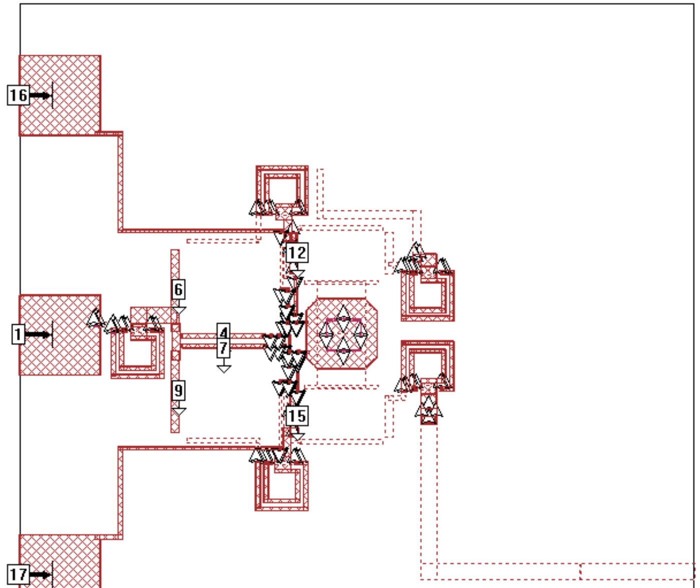


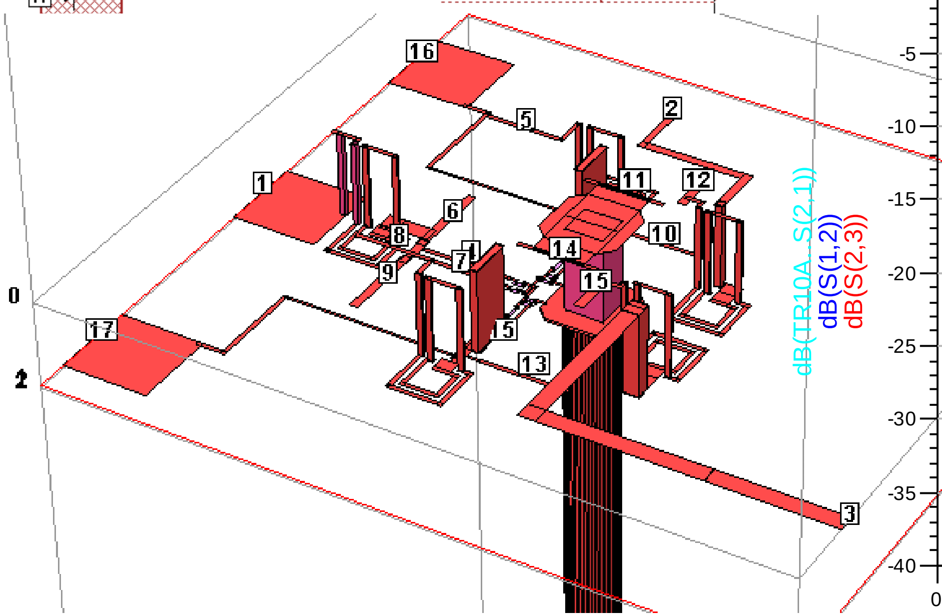


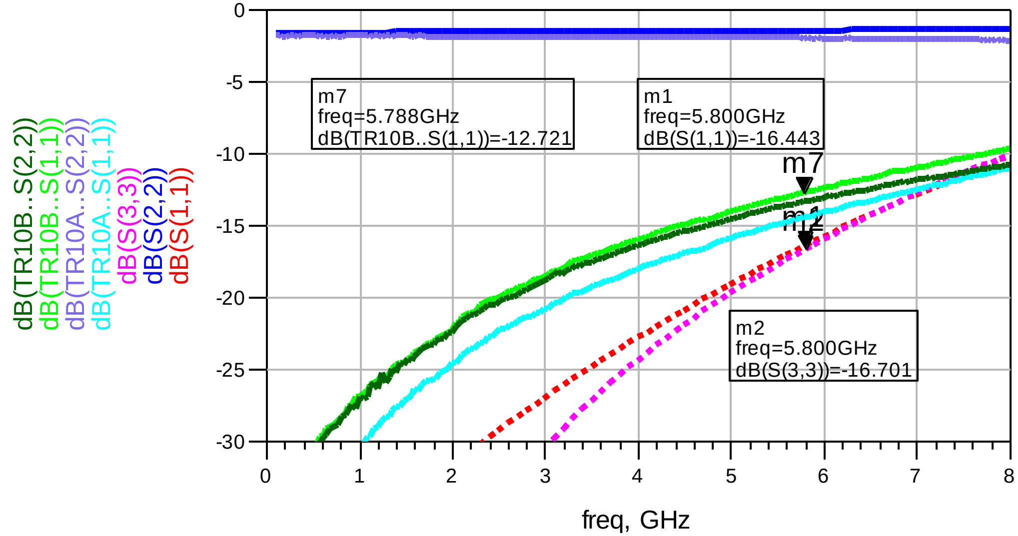


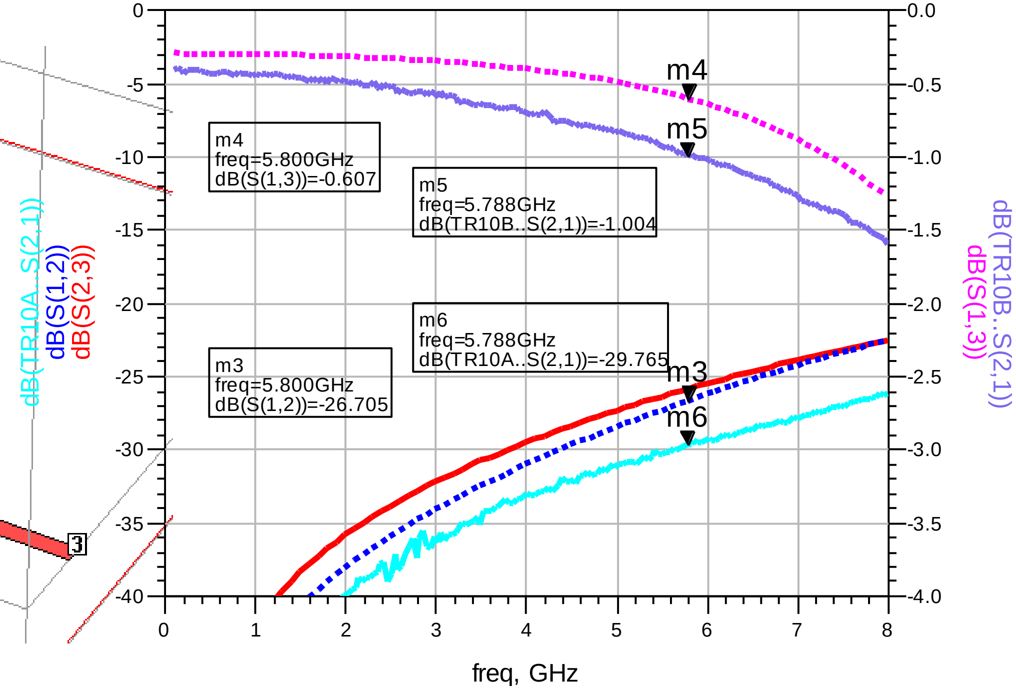
Measured 5.8 GHz Circuits (BPSK, LNA, PA, TRS) at 3V

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits



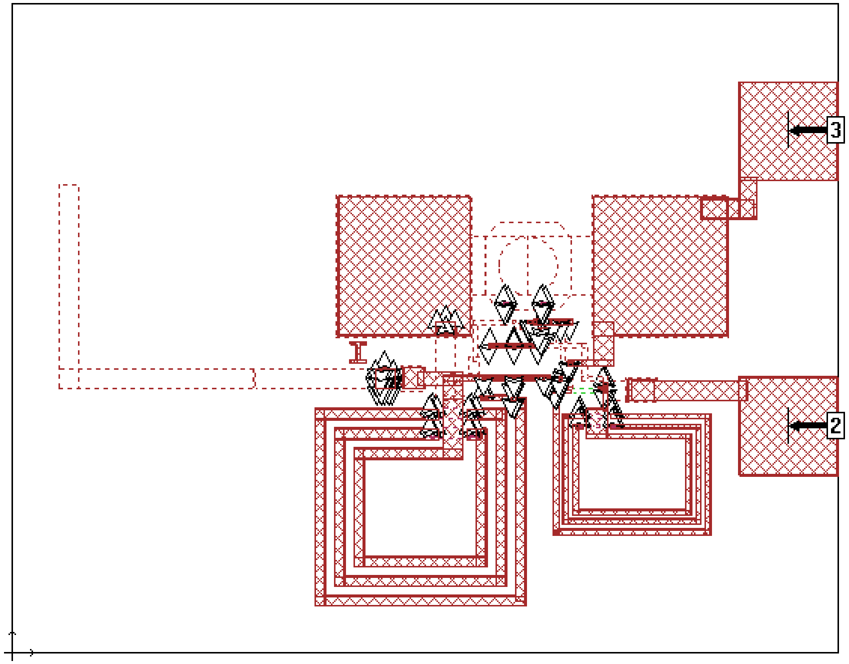


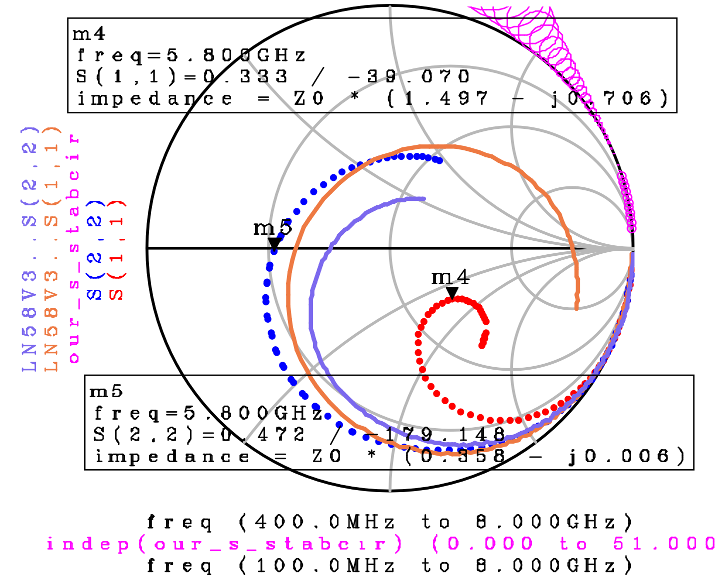


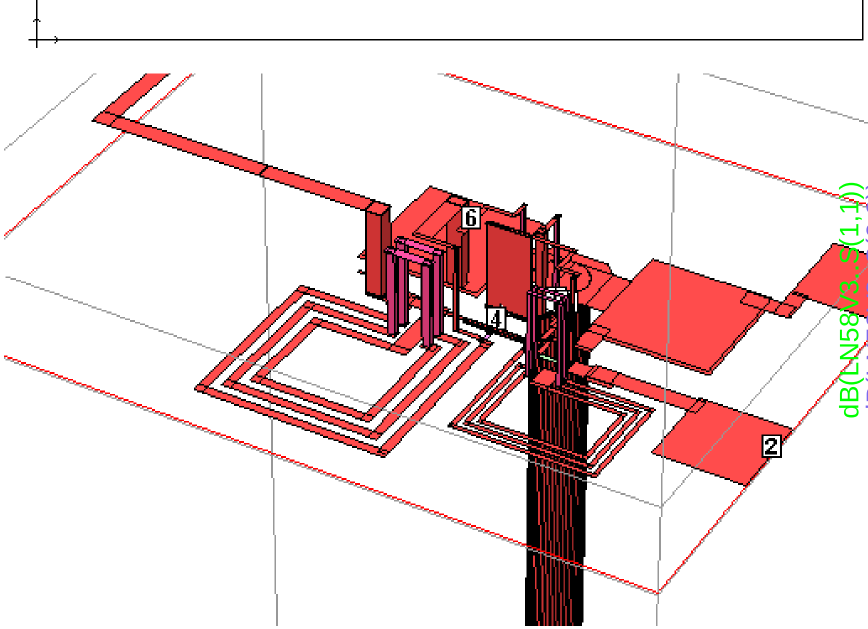


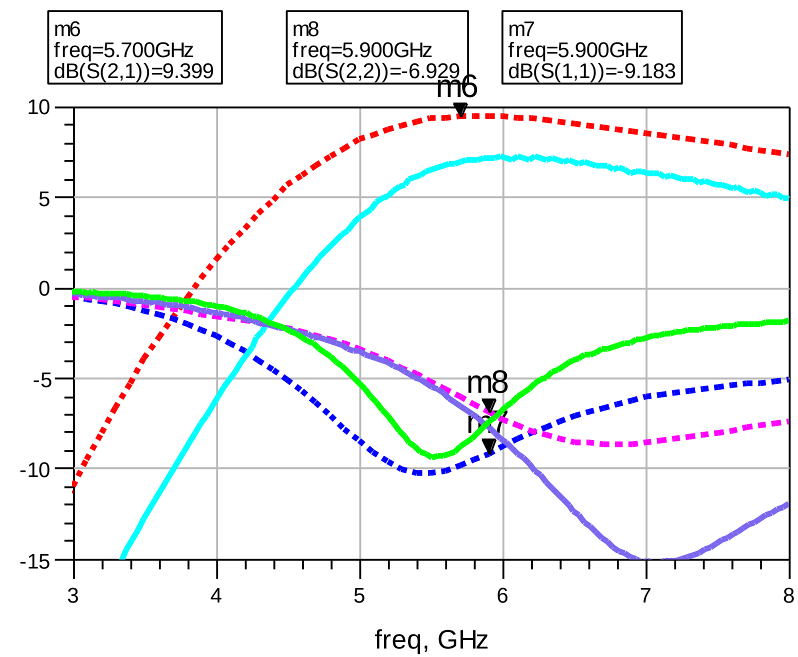
Measured 5.8 GHz TRS Circuit vs. Sonnet Sim (meas-solid)

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits



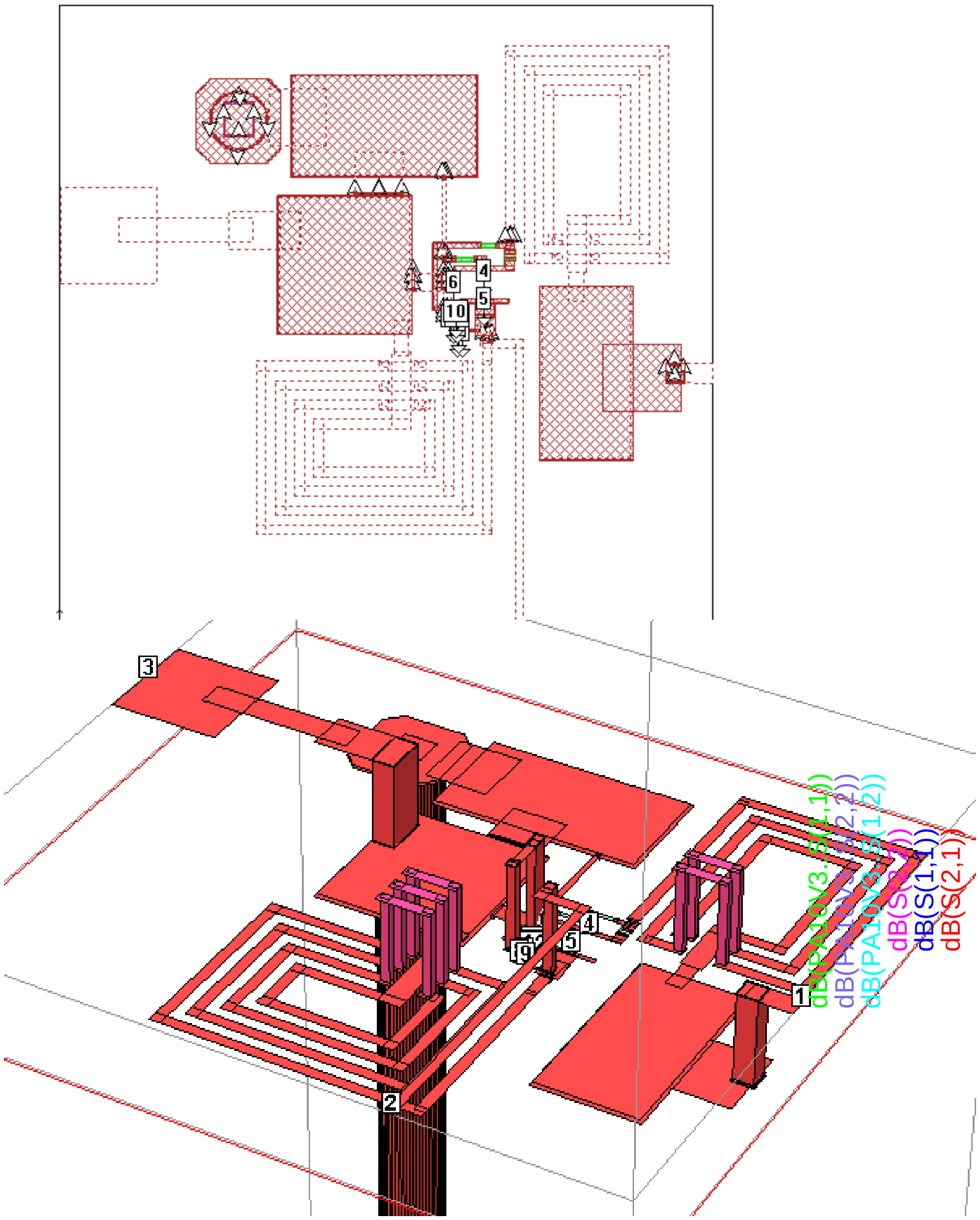


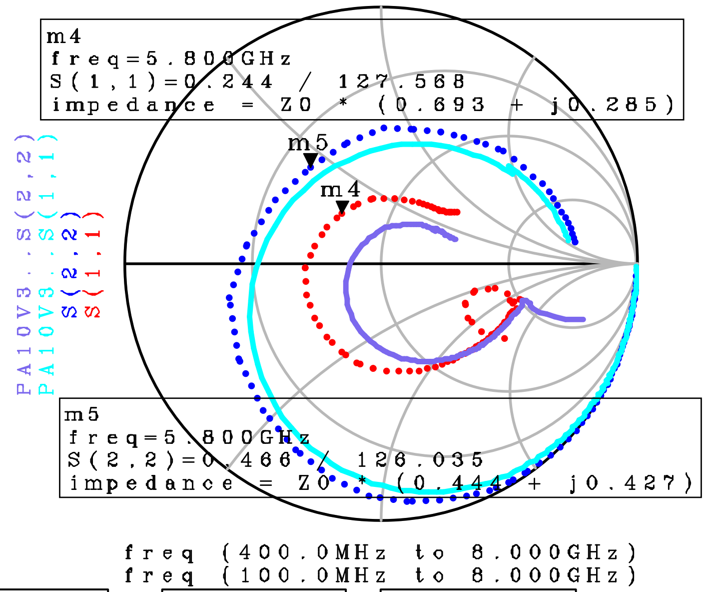


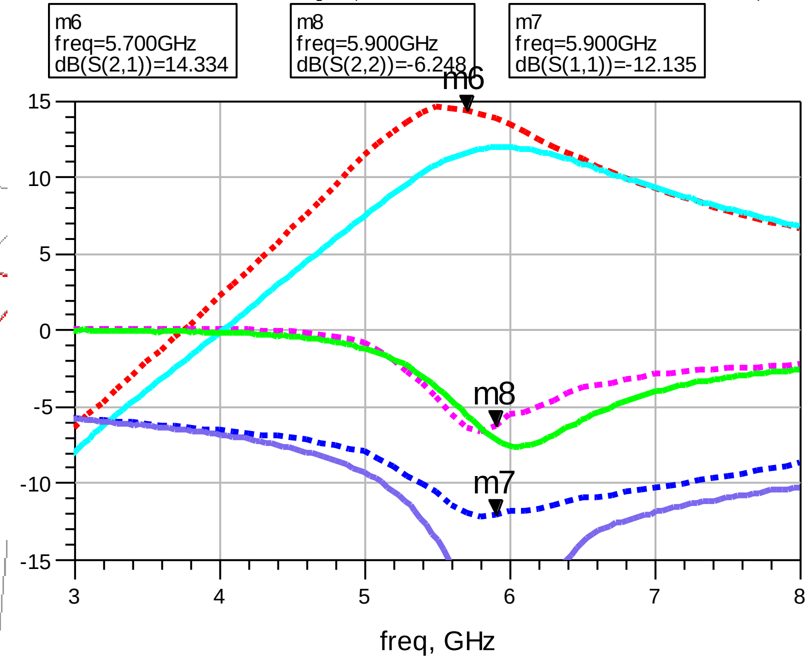


Measured 5.8 GHz LNA Circuit vs. Sonnet Sim (meas-solid)

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits

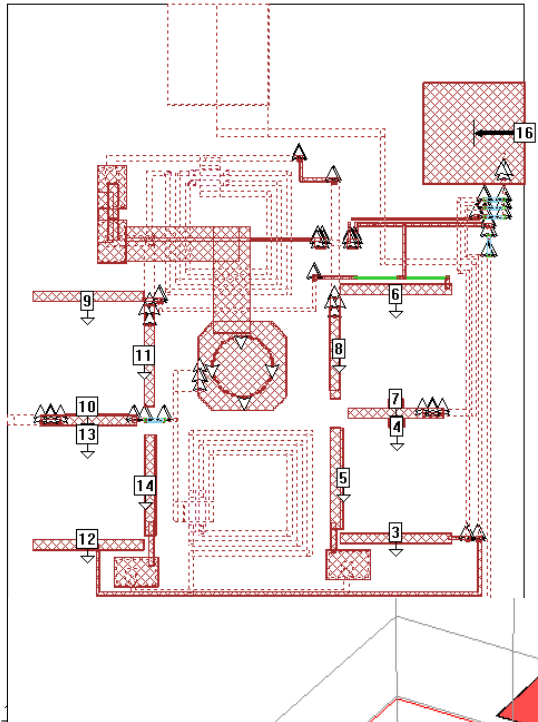


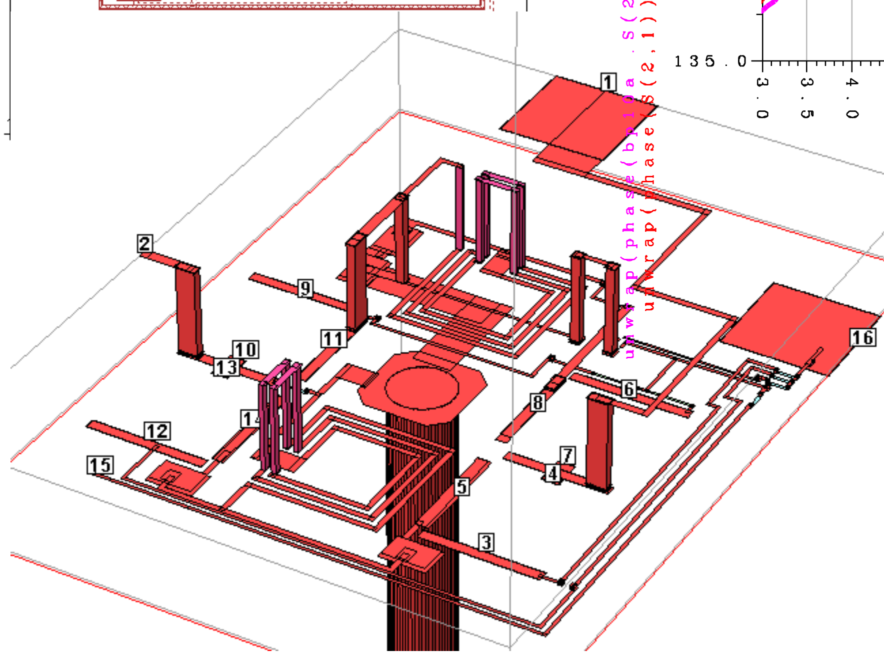


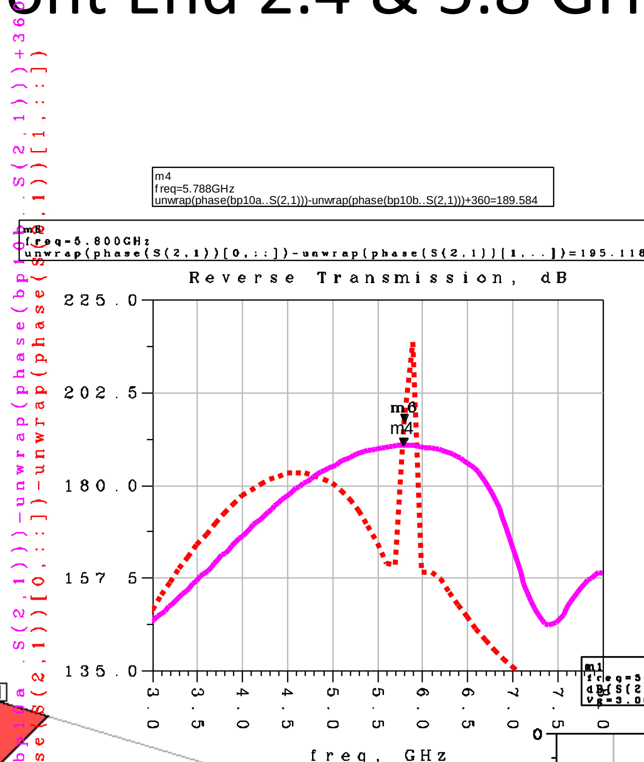


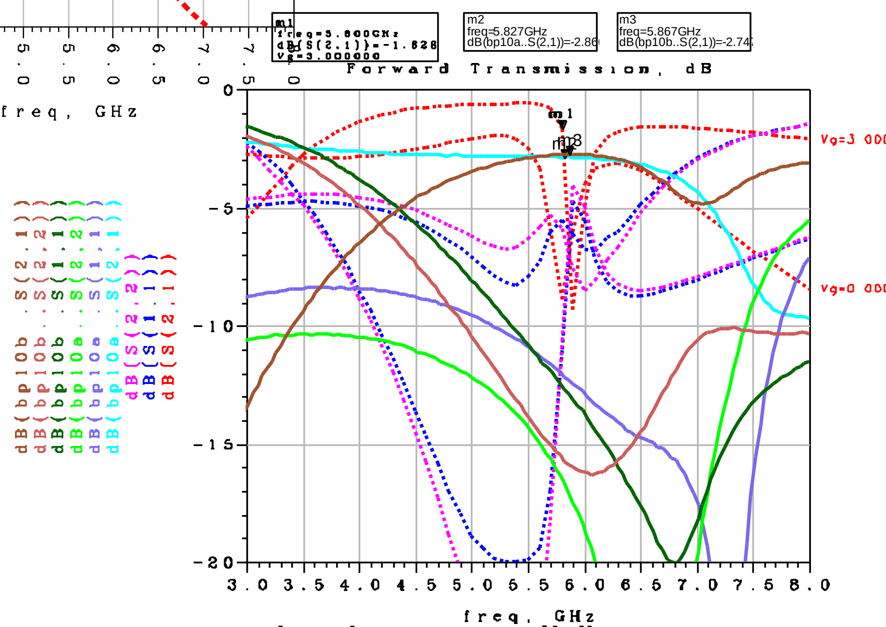
Measured 5.8 GHz PA Circuit vs. Sonnet Sim (meas-solid)

JHU10JEP: RF Front End 2.4 & 5.8 GHz Circuits



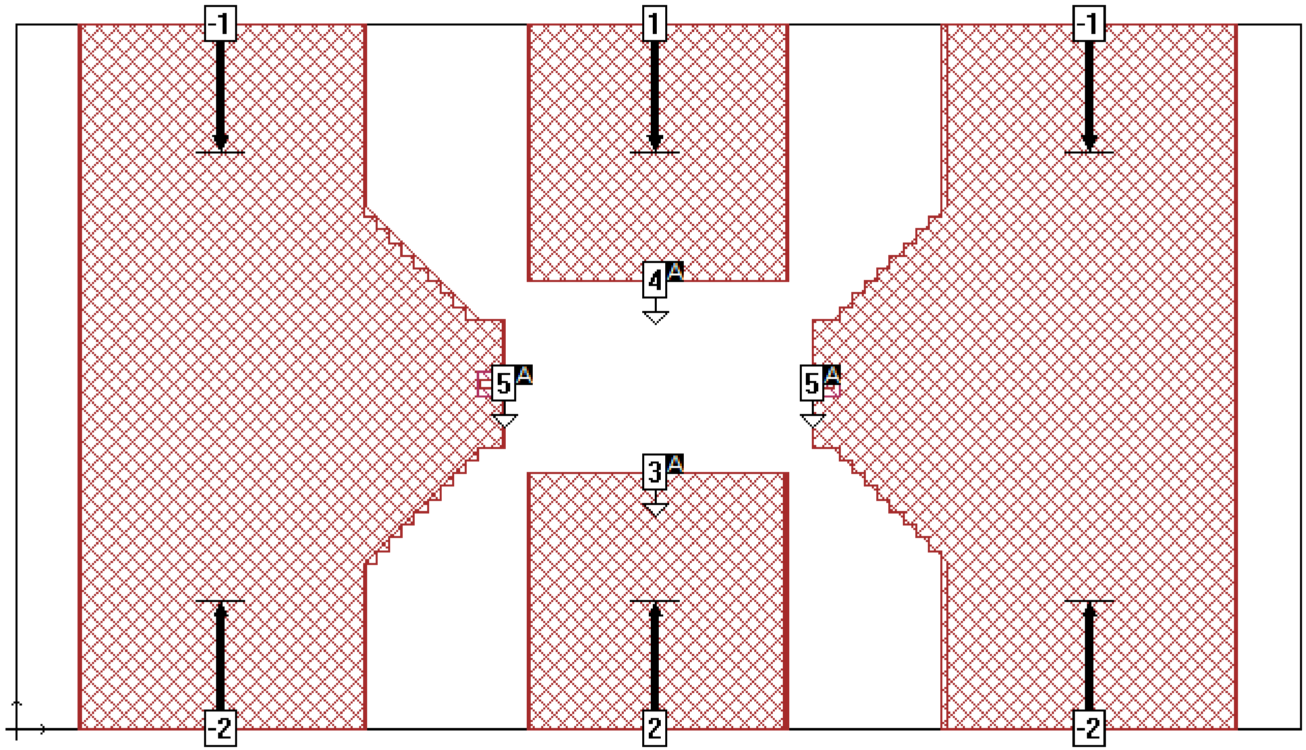




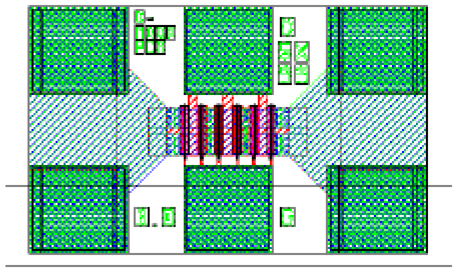


Measured 5.8 GHz BPSK Circuit vs. Sonnet Sim (meas-solid)

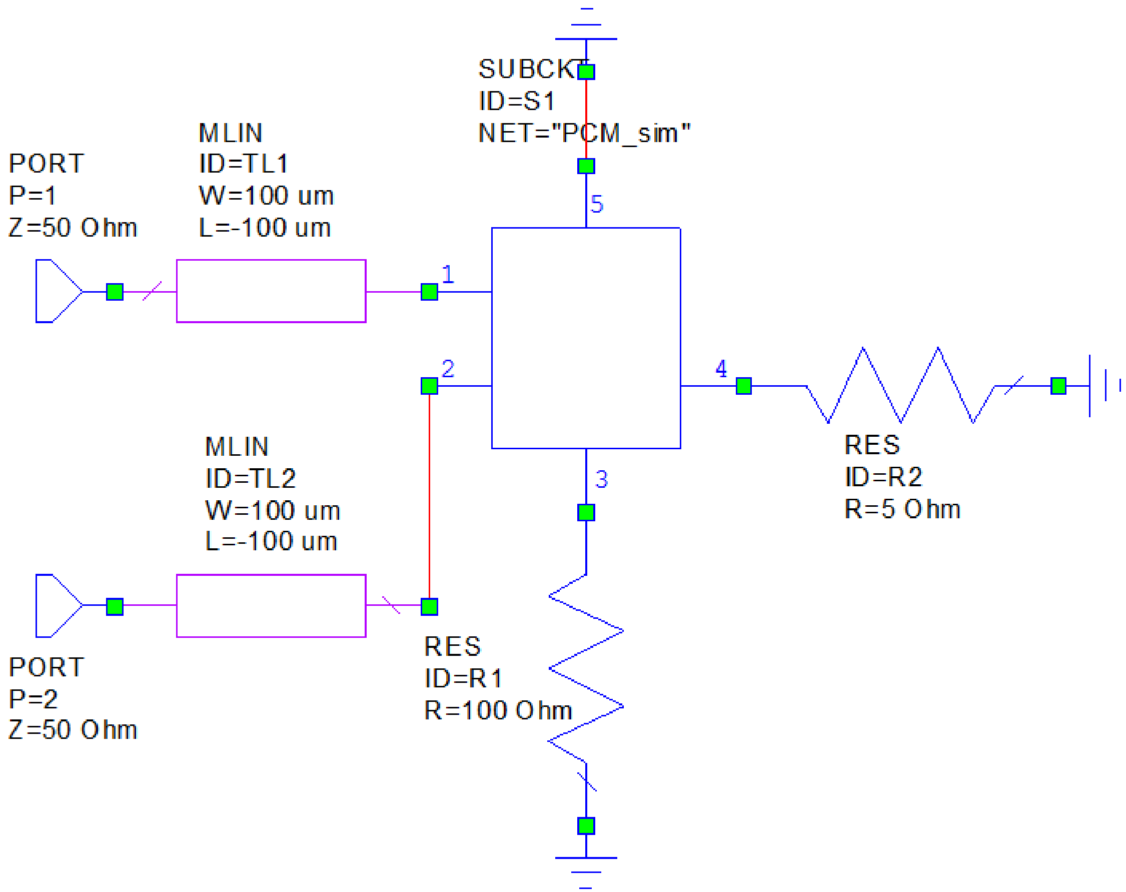
Test PHEMTs Fall 2010 TQPED

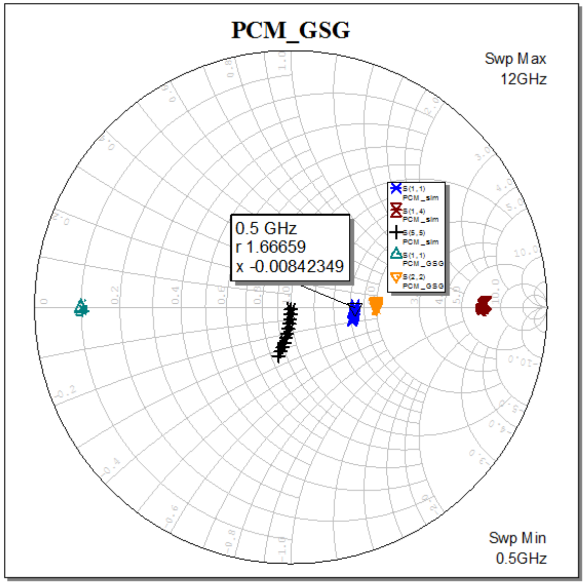


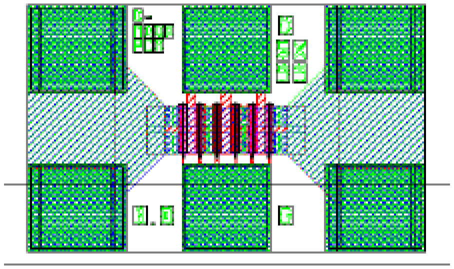
De-embed GSG Launch for Comparison to Measured Results
Smaller PHEMTs may be overdriven with NWA (8510 at -10 dBm)



Test PHEMTs Fall 2010 TQPED

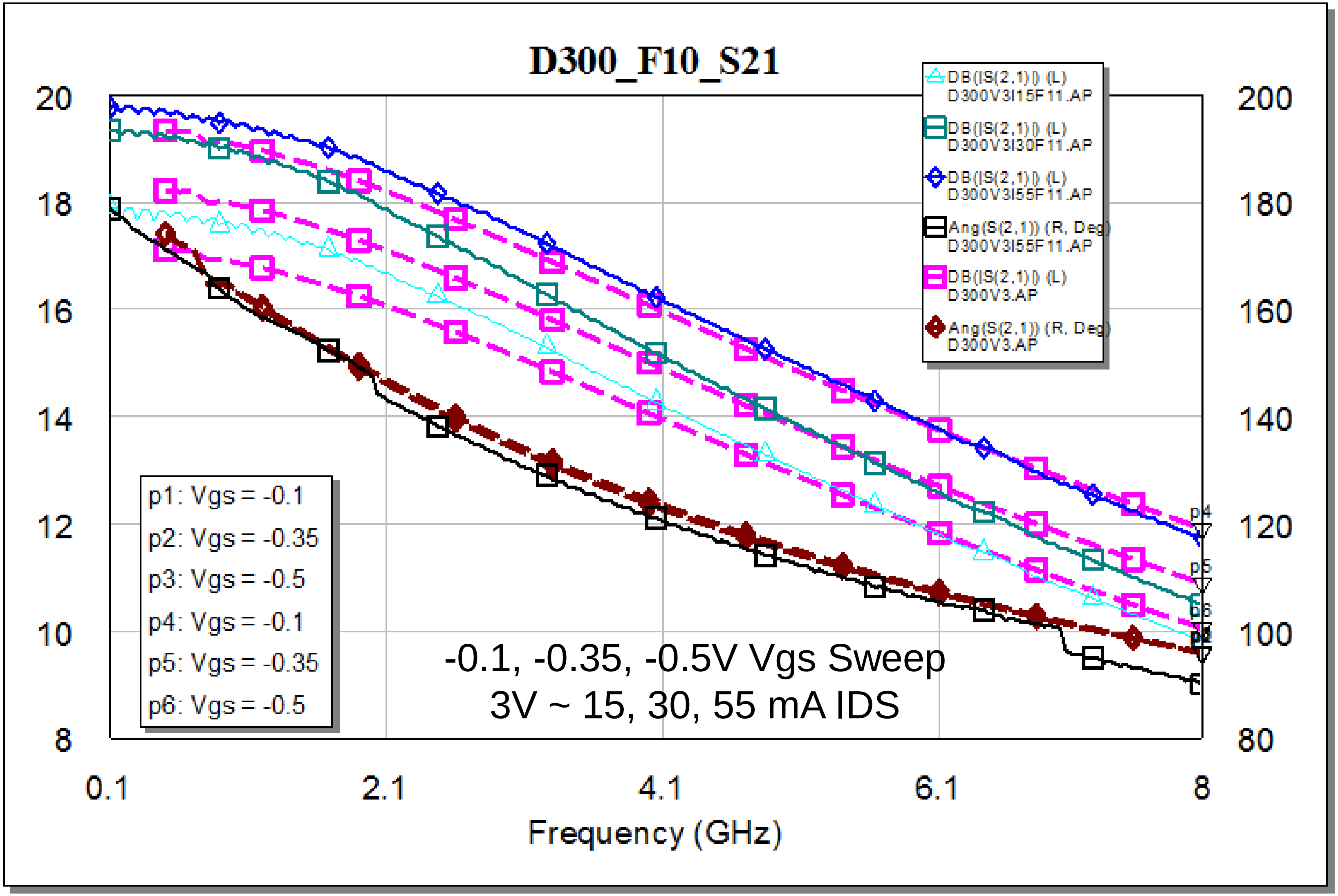






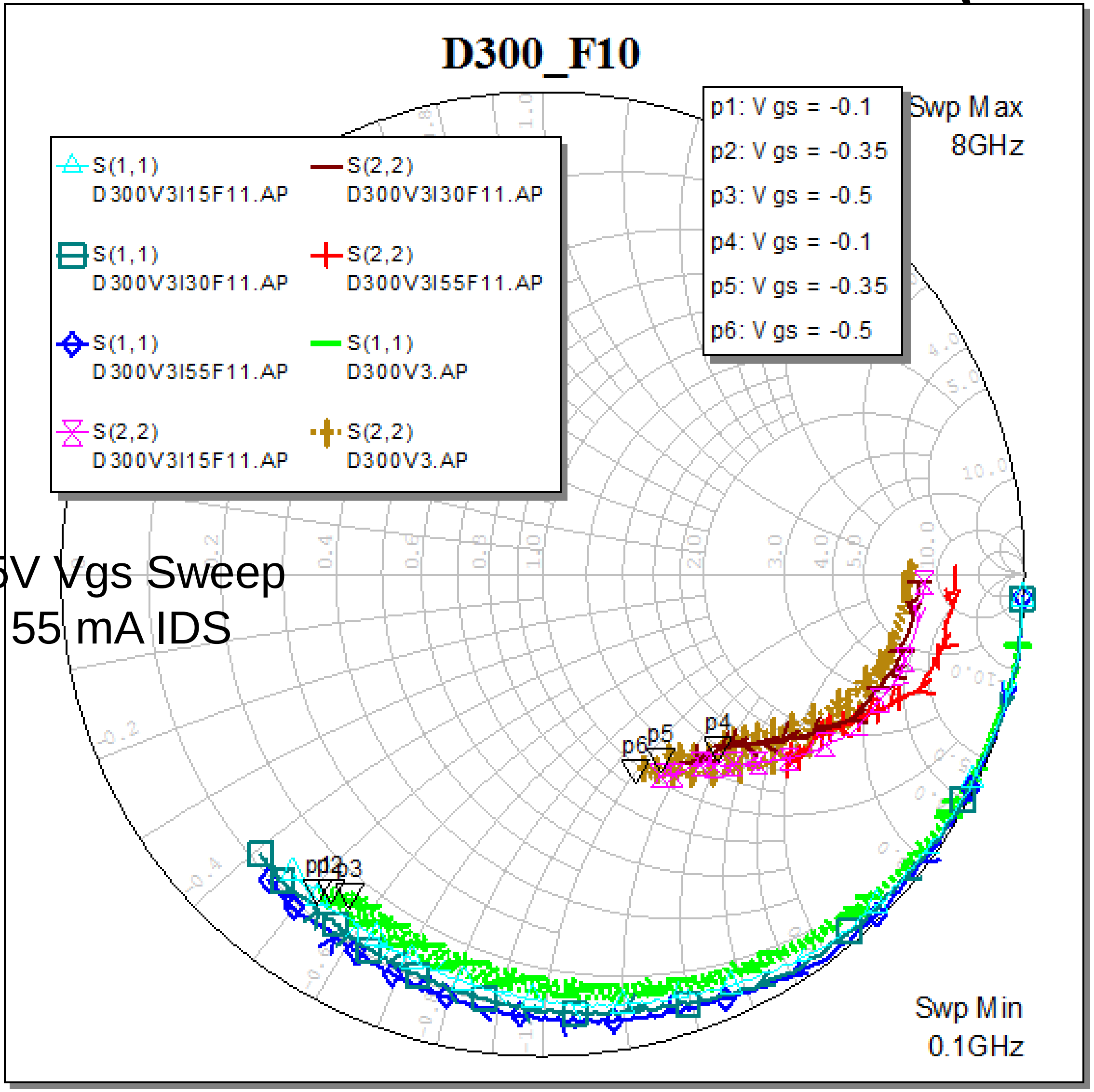
De-embed GSG Launch for Comparison to Measured Results
Seems to model as 100 um wide MLIN of -50 to -100 um length!
Had to vary length for other size PHEMTs/Launches

Test PHEMTs Fall 2010 D300 (6x50um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

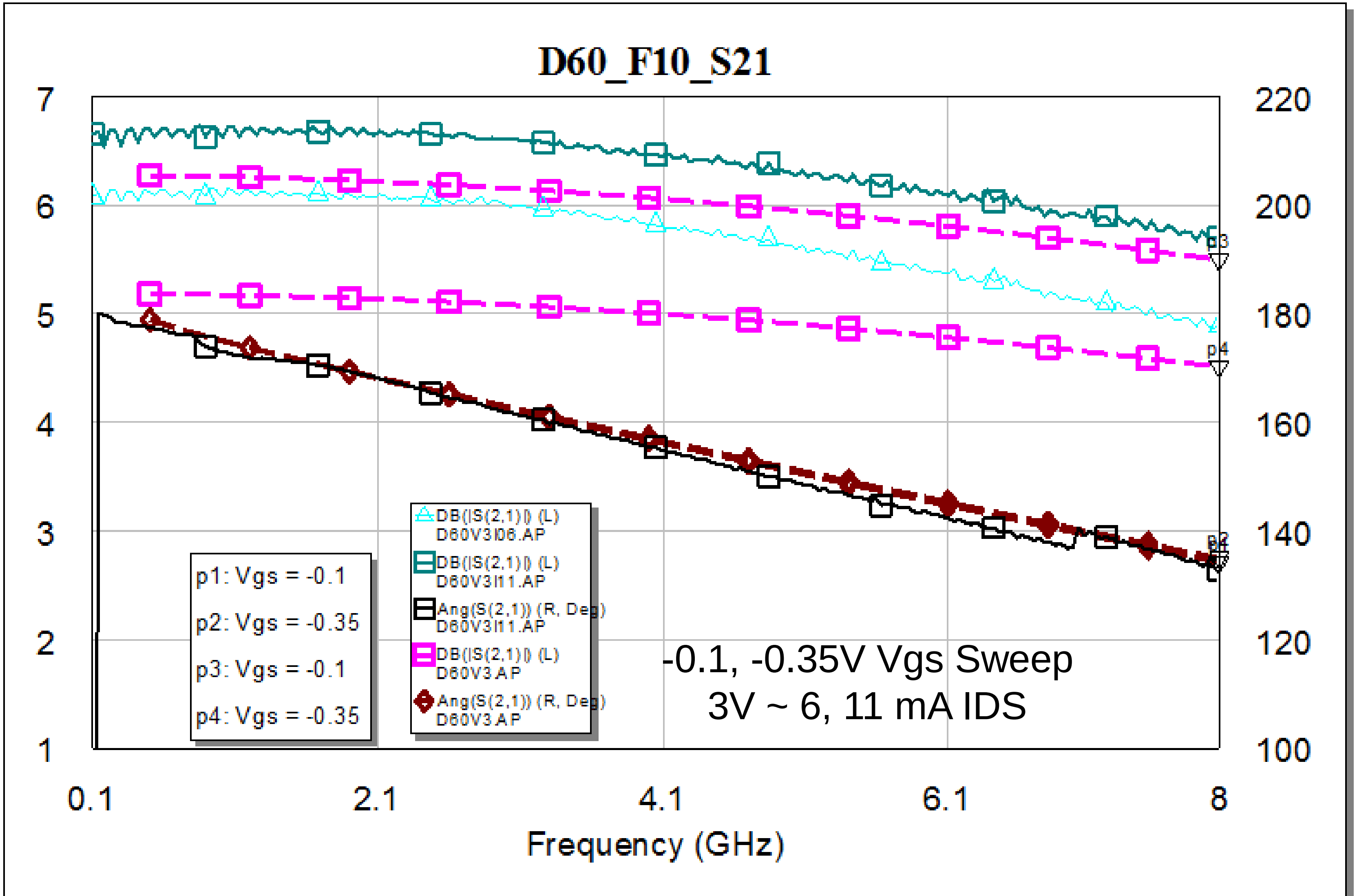
Test PHEMTs Fall 2010 D300 (6x50um)



-0.1, -0.35, -0.5V Vgs Sweep
3V ~ 15, 30, 55 mA IDS

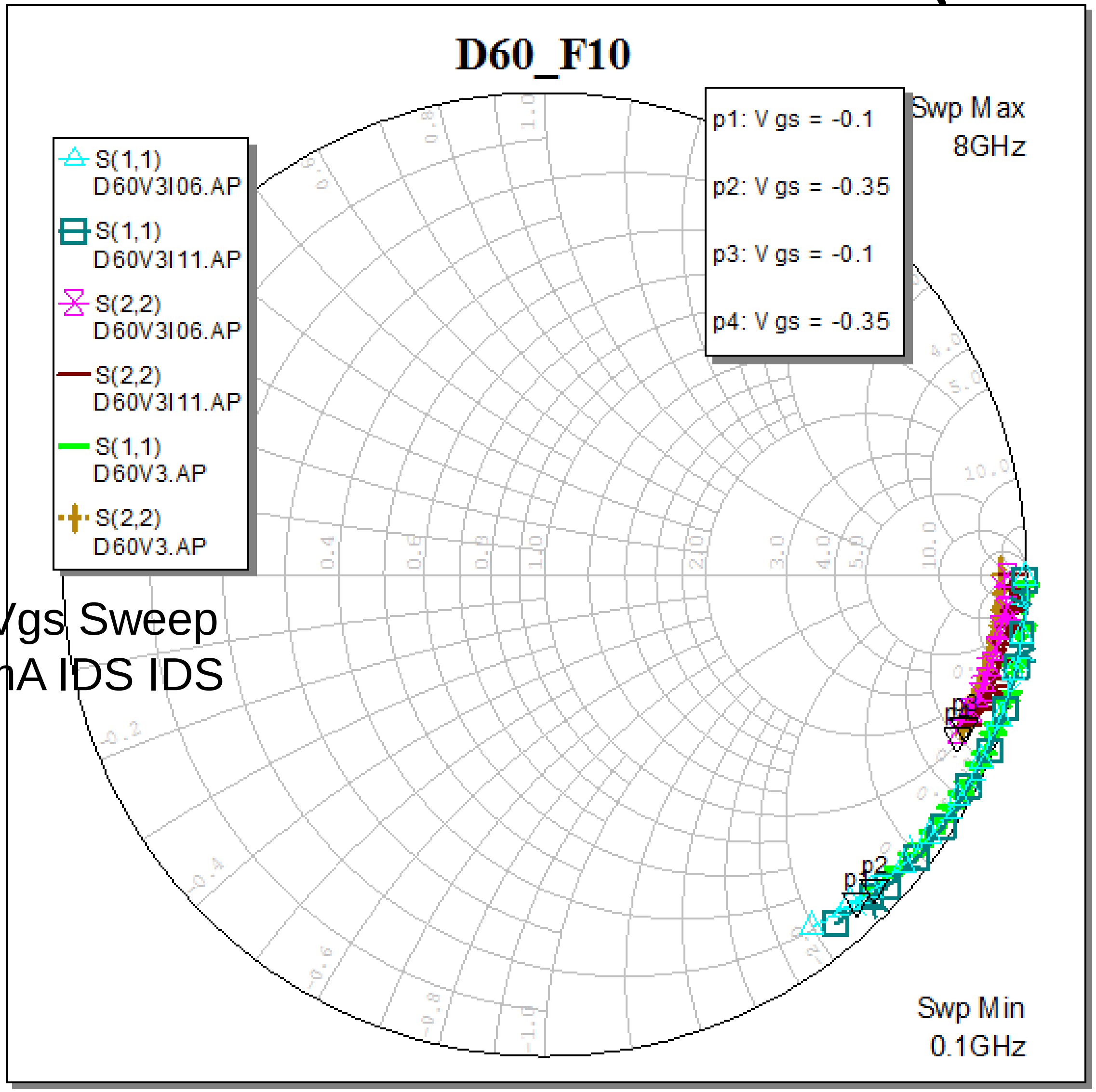
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 D60 (4x15um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

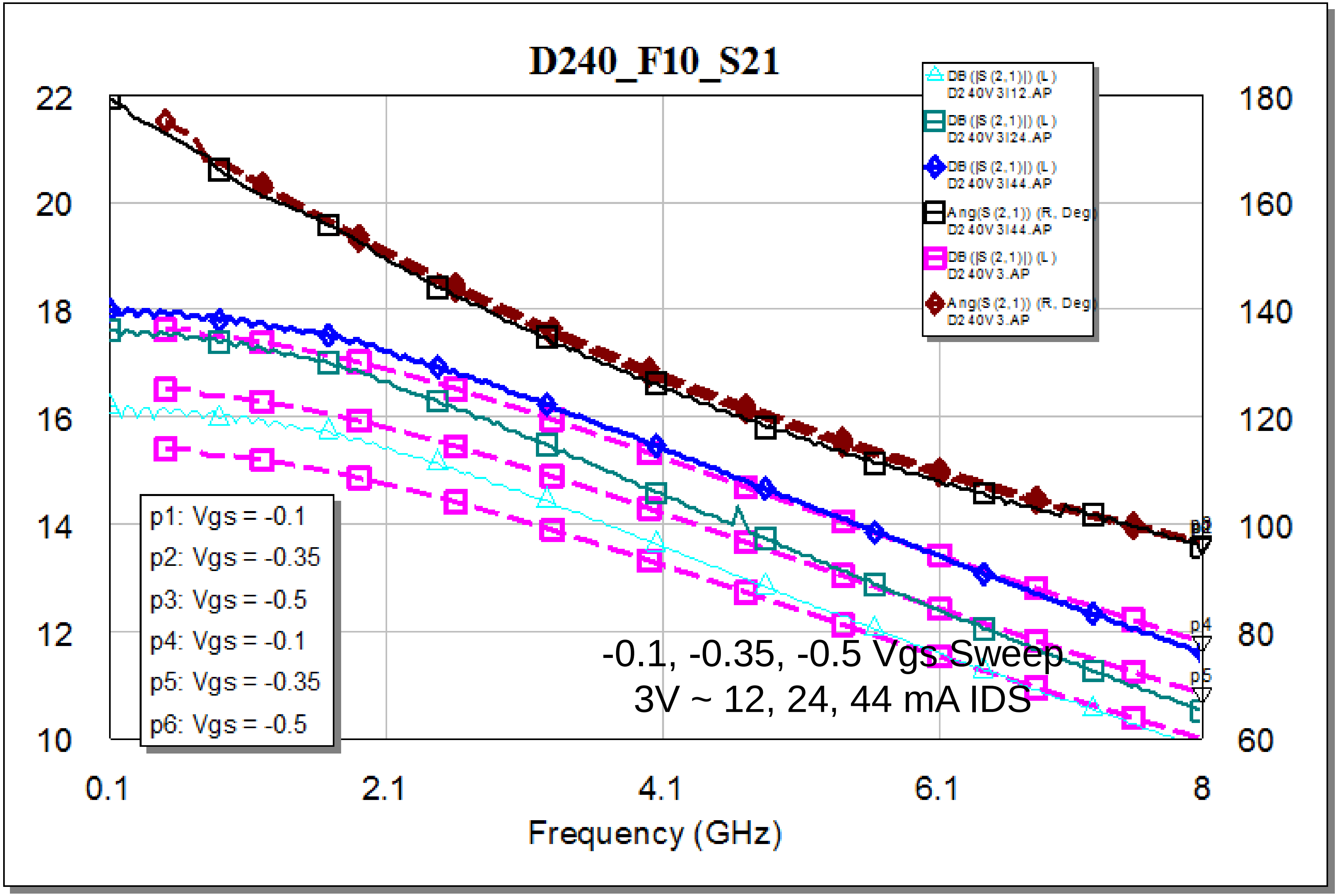
Test PHEMTs Fall 2010 D60 (4x15um)



-0.1, -0.35 Vgs Sweep
3V ~ 6, 11 mA IDS IDS

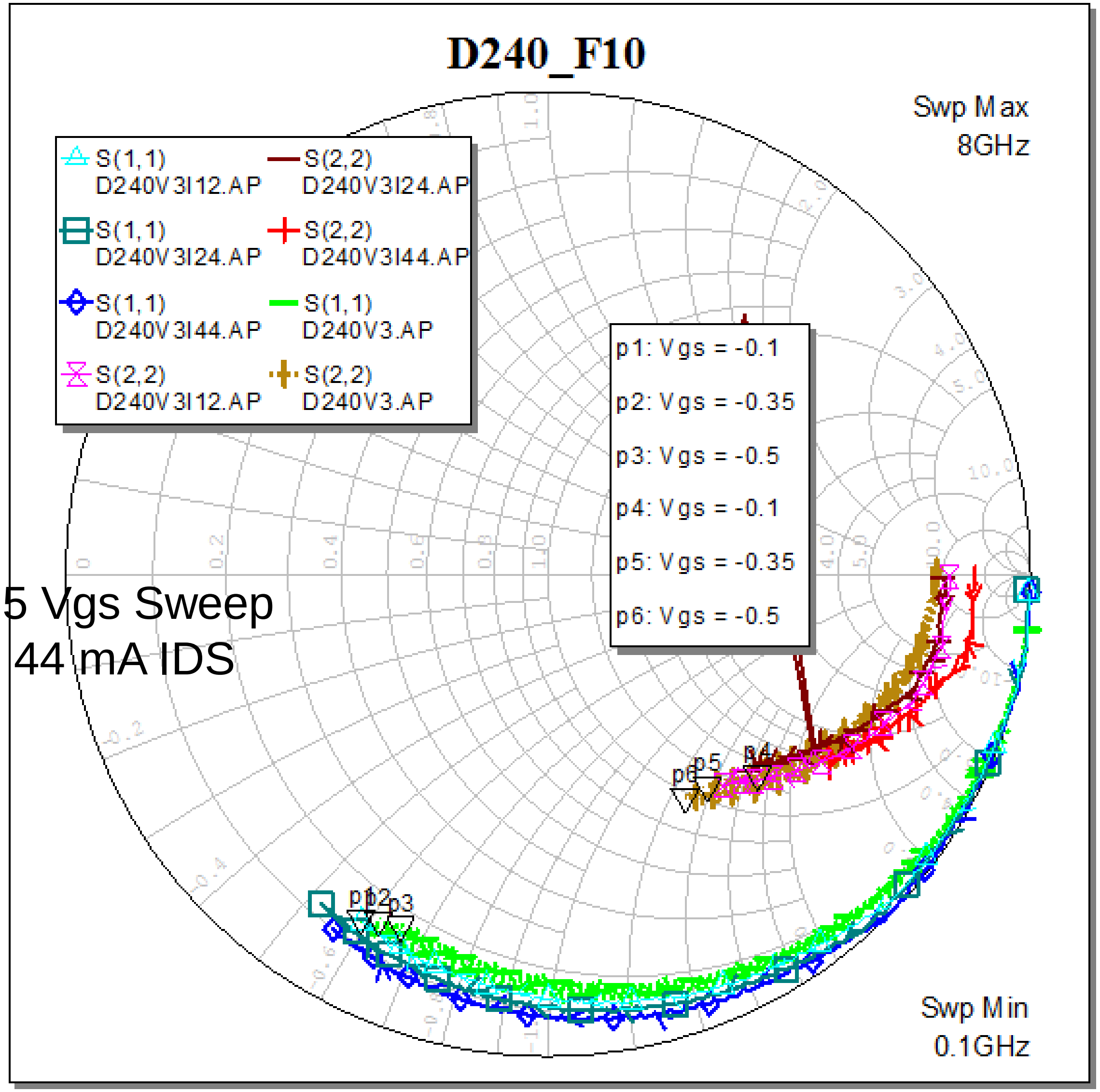
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 D240 (6x40um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

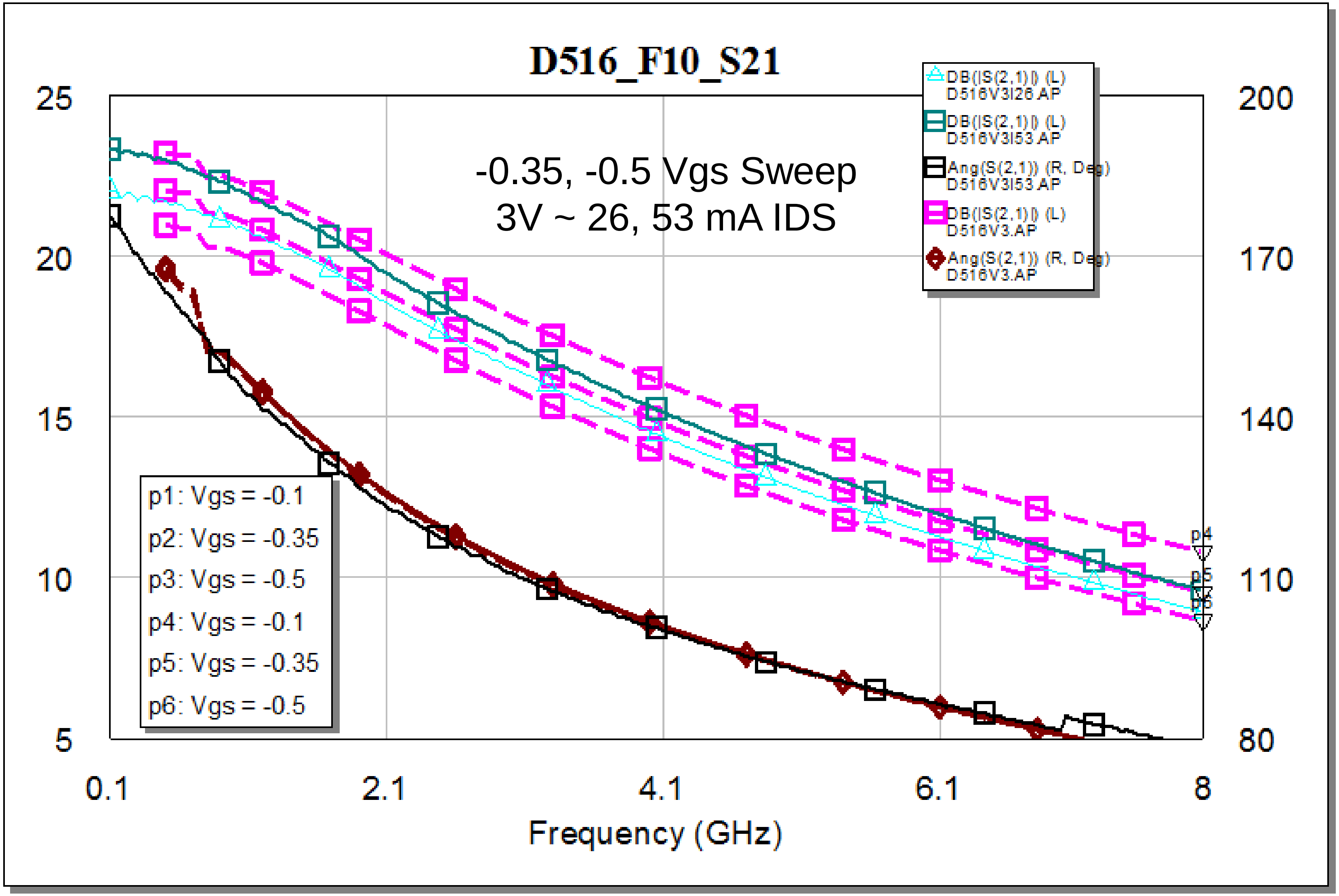
Test PHEMTs Fall 2010 D240 (6x40um)



-0.1, -0.35, -0.5 Vgs Sweep
3V ~ 12, 24, 44 mA IDS

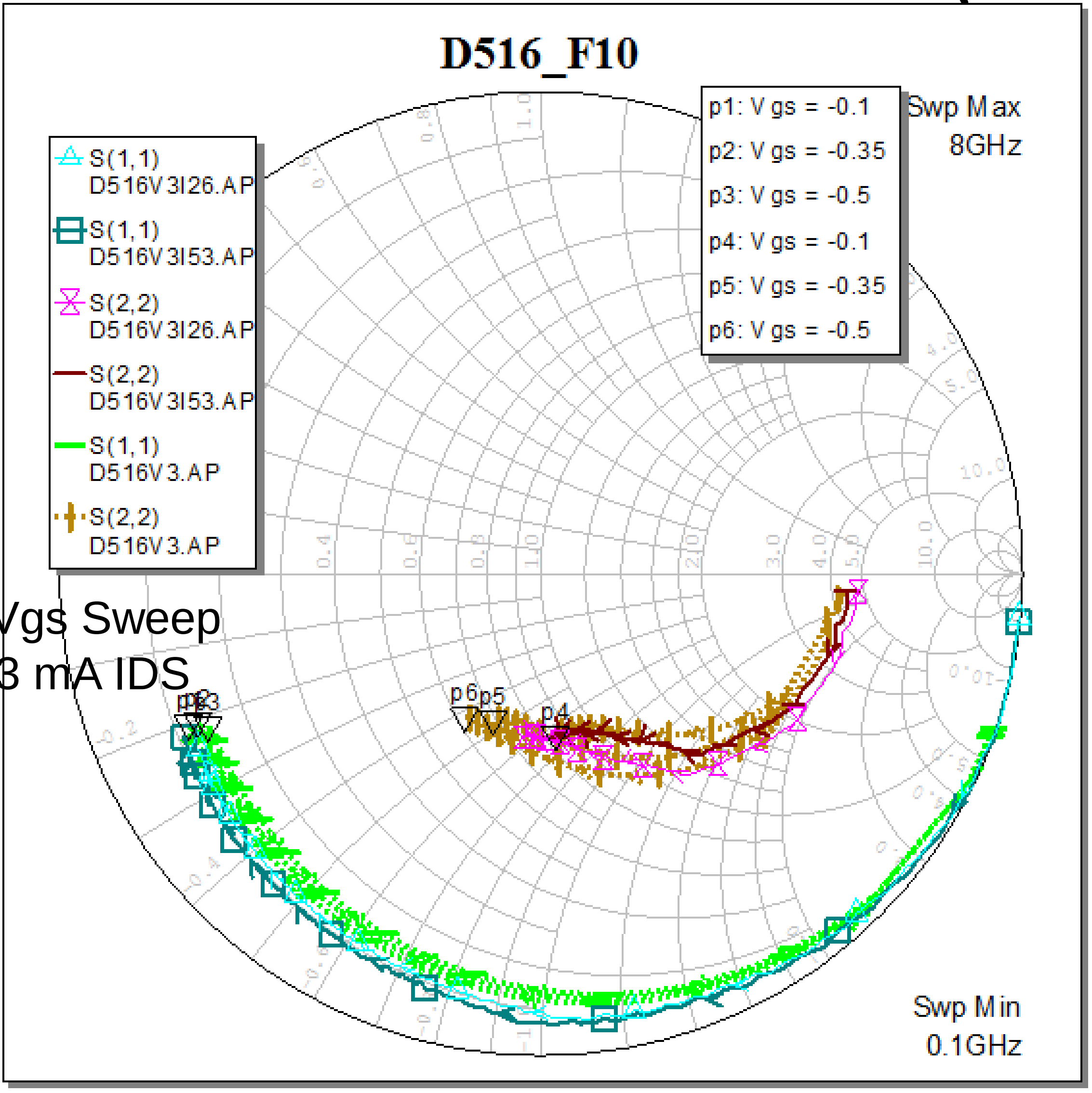
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 D516 (6x86um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

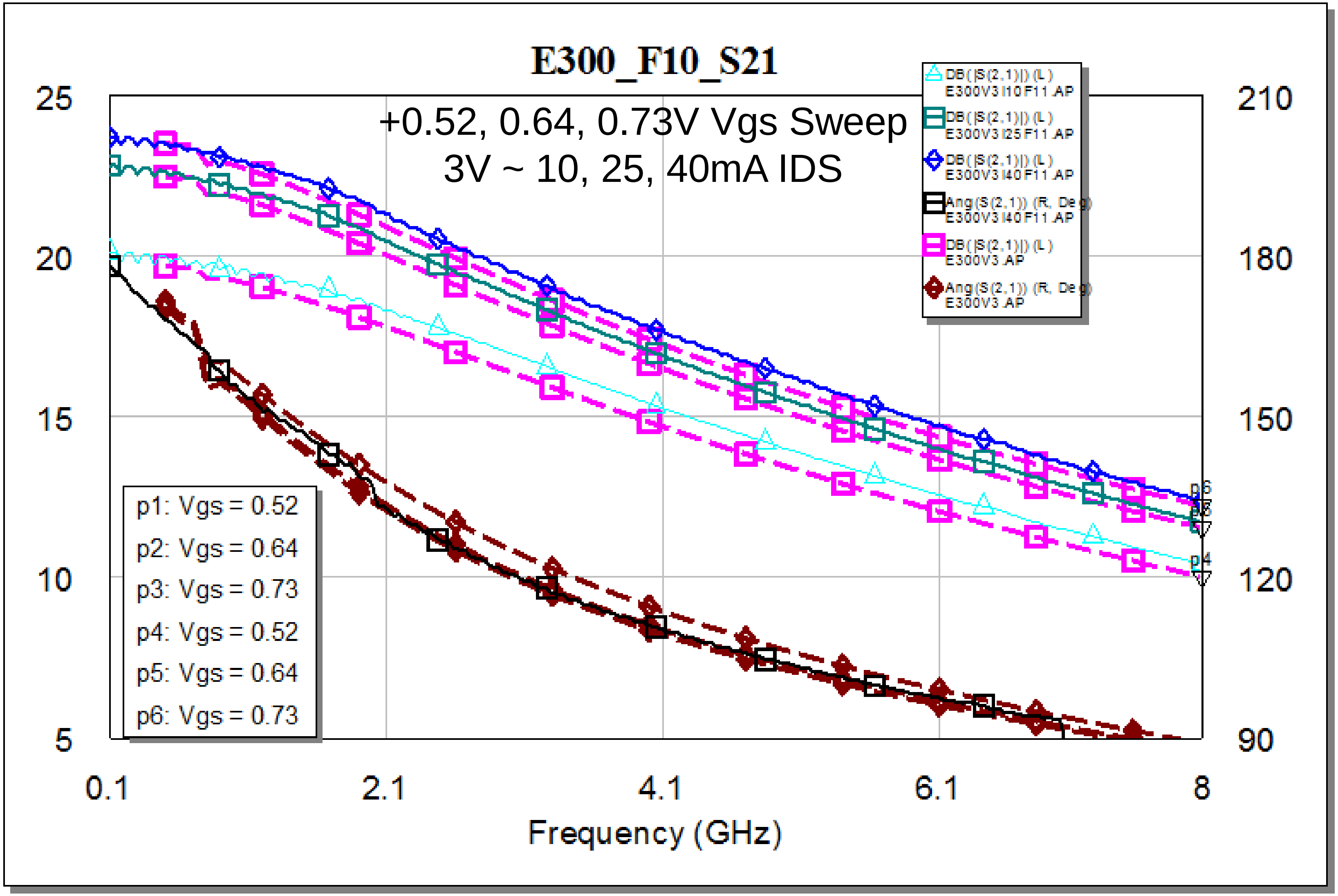
Test PHEMTs Fall 2010 D516 (6x86um)



-0.35, -0.5 Vgs Sweep
3V ~ 26, 53 mA IDS

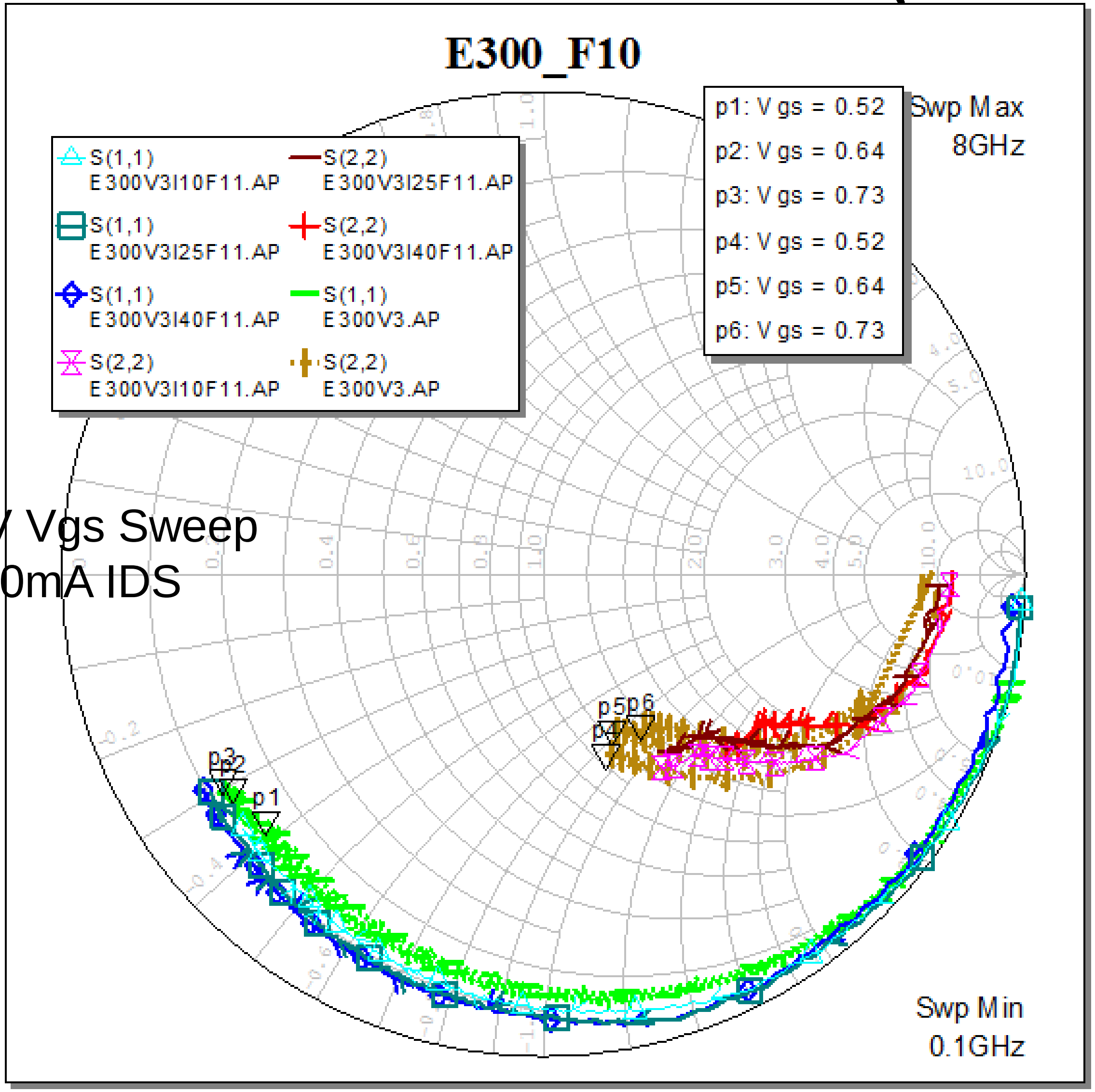
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E300 (6x50um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

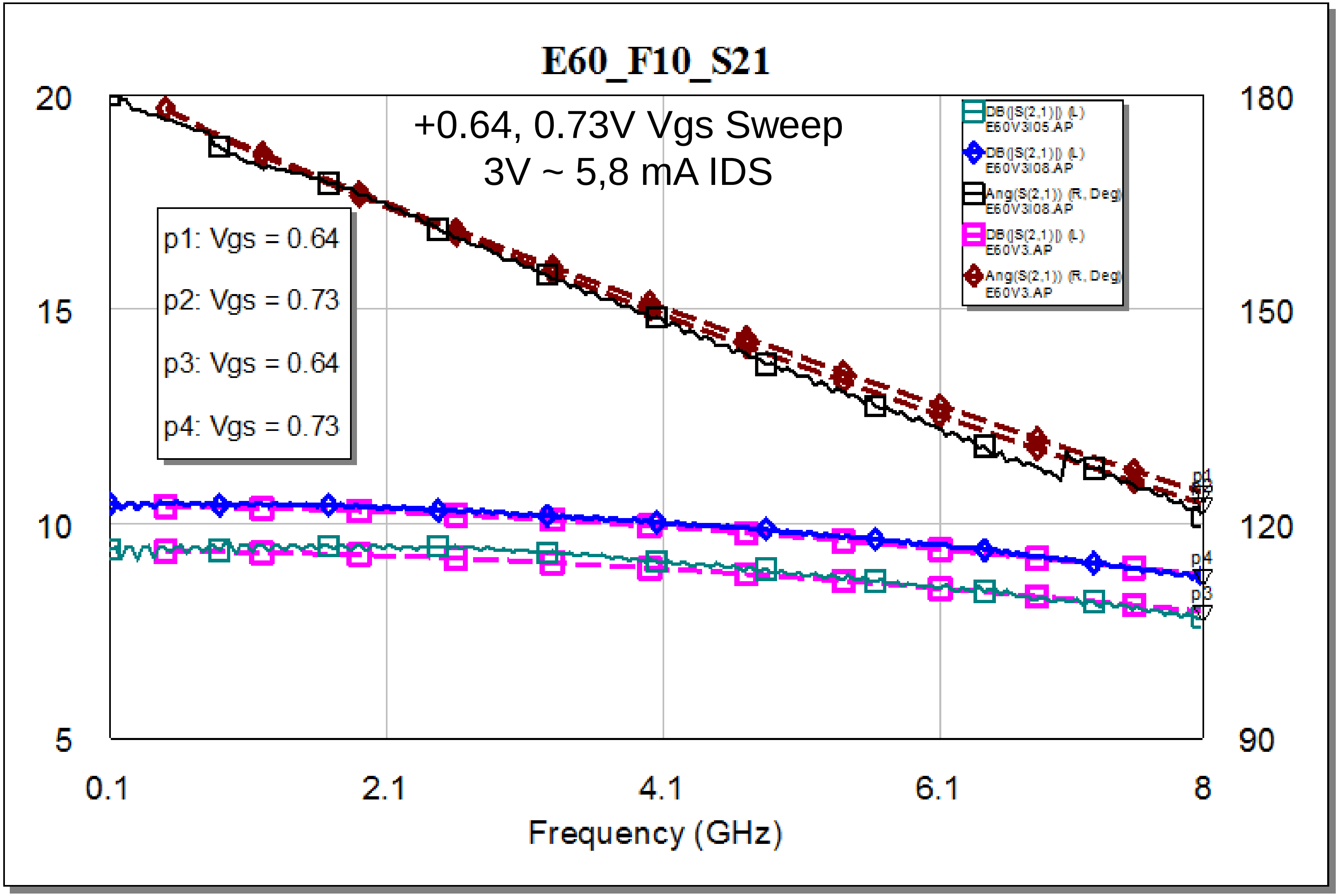
Test PHEMTs Fall 2010 E300 (6x50um)



+0.52, 0.64, 0.73V Vgs Sweep
3V ~ 10, 25, 40mA IDS

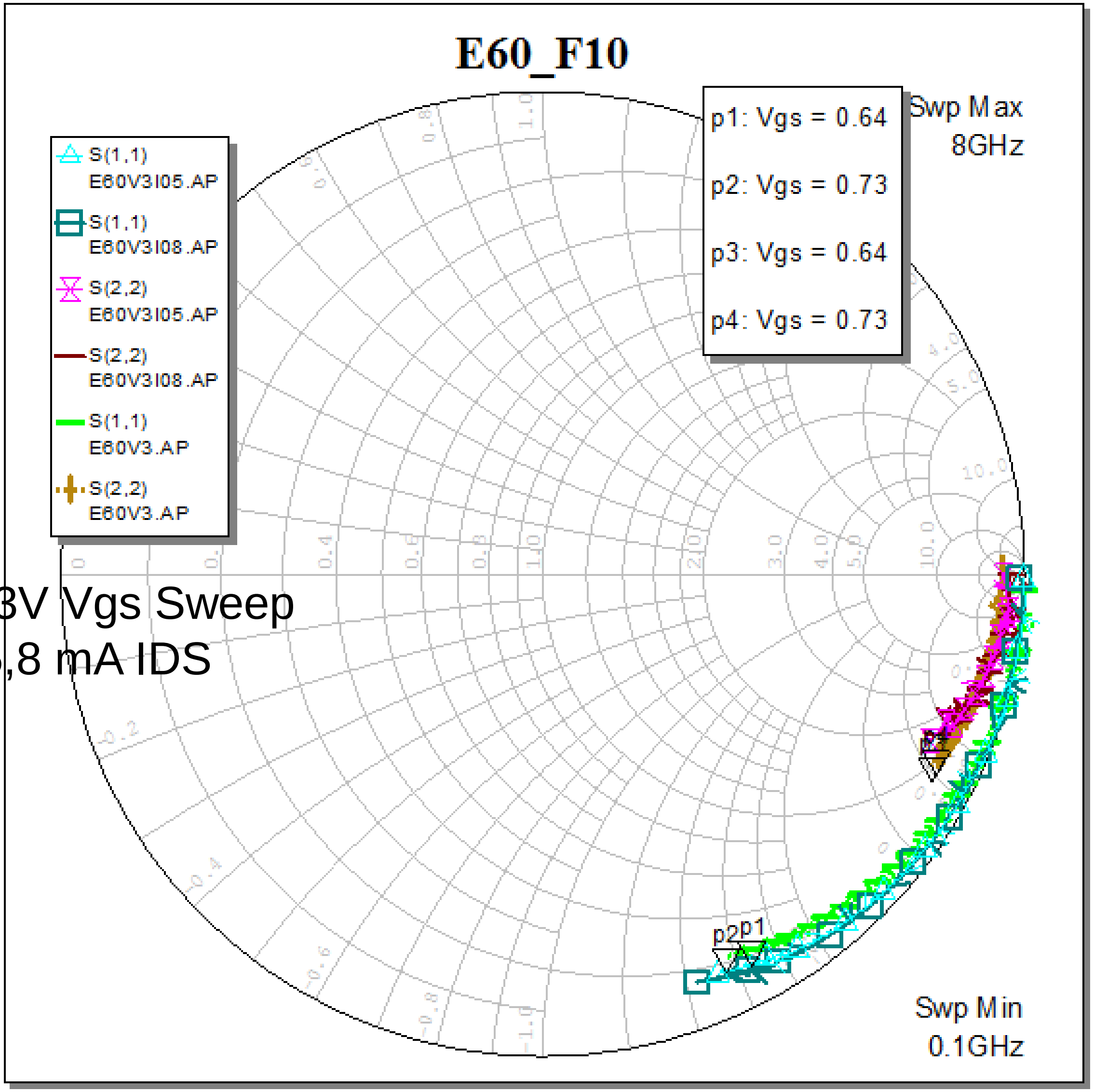
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E60 (4x15um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

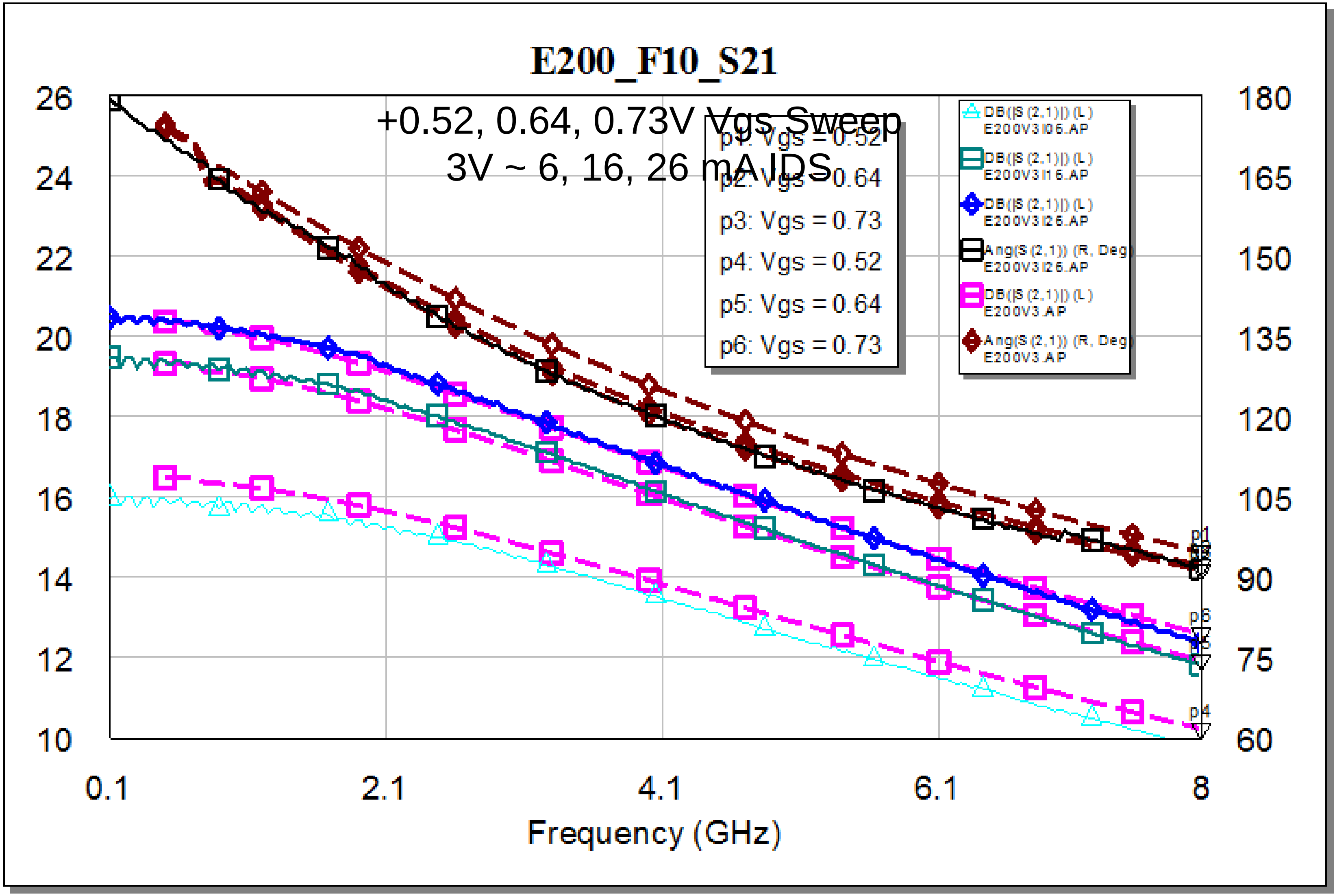
Test PHEMTs Fall 2010 E60 (4x15um)



+0.64, 0.73V Vgs Sweep
3V ~ 5,8 mA IDS

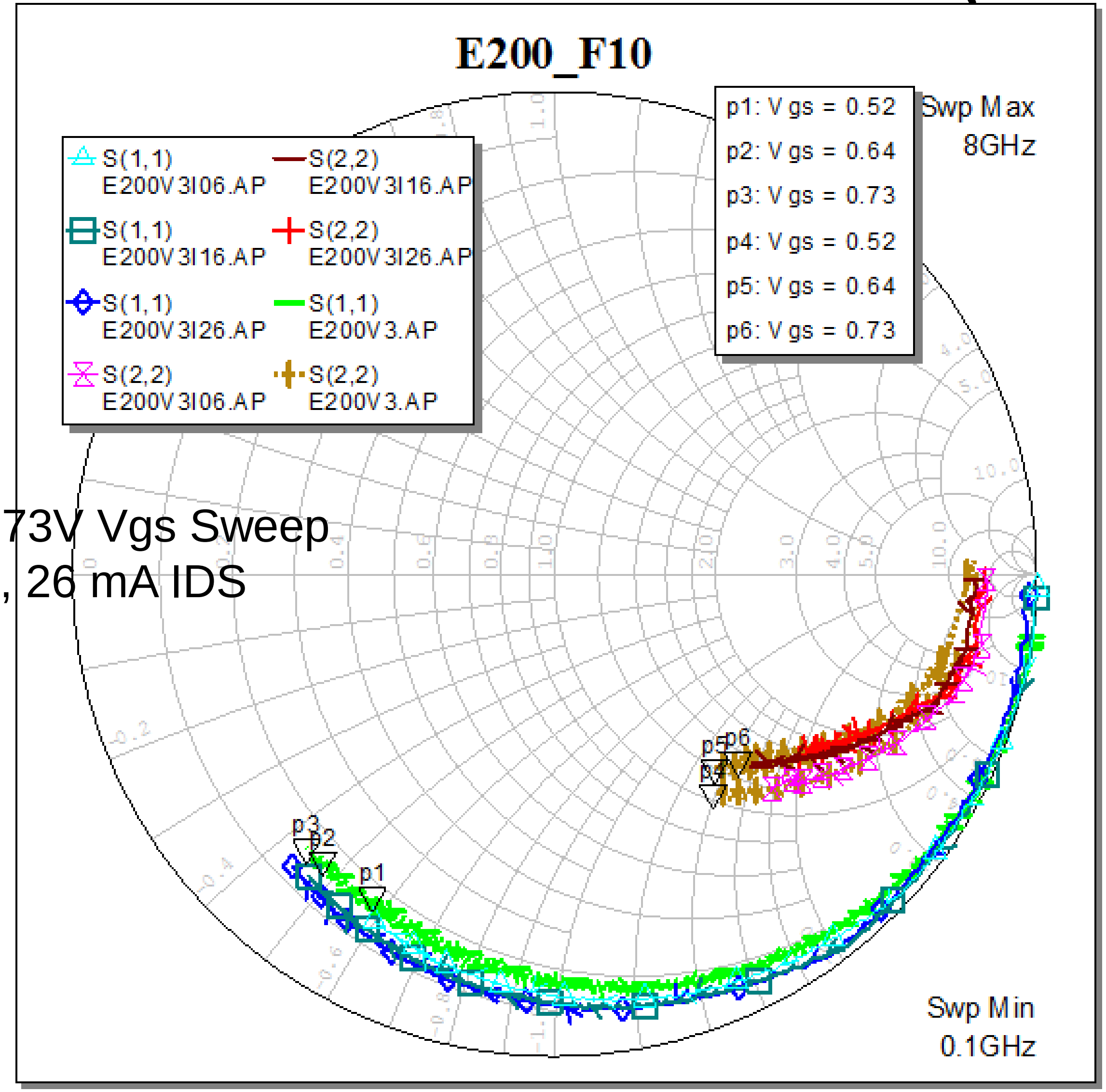
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E200 (2x50um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

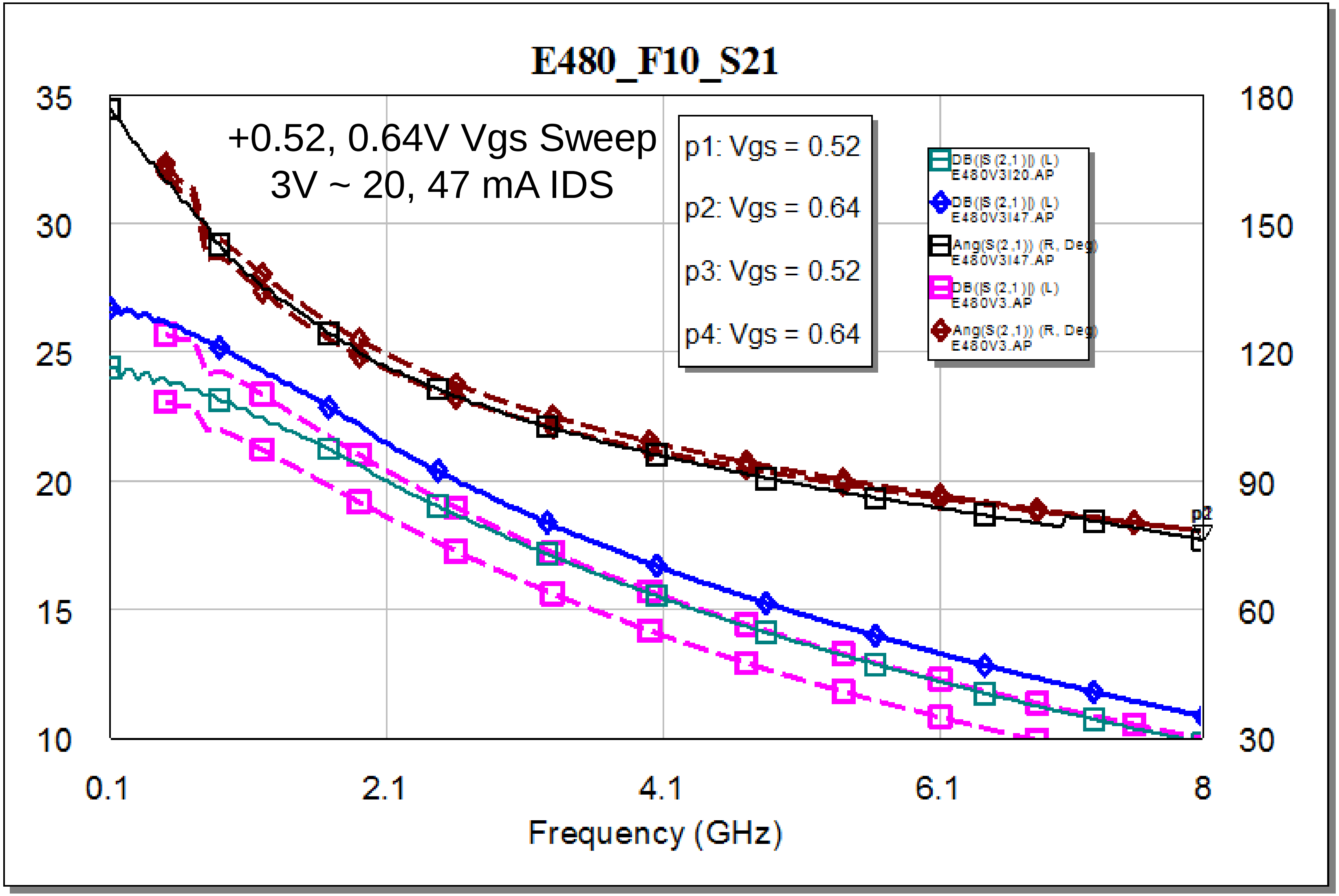
Test PHEMTs Fall 2010 E200 (2x50um)



+0.52, 0.64, 0.73V Vgs Sweep
3V ~ 6, 16, 26 mA IDS

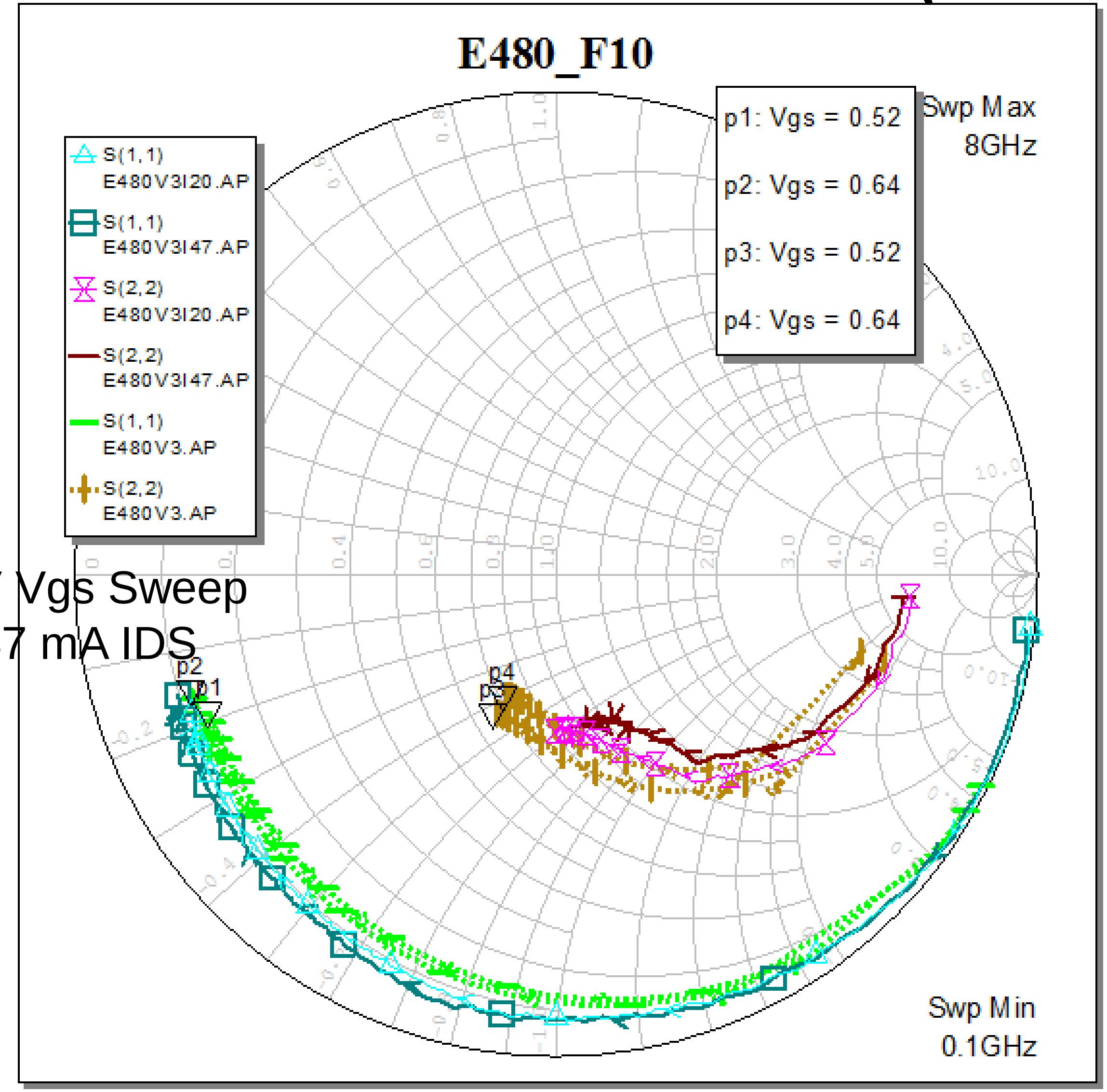
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E480 (6x80um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

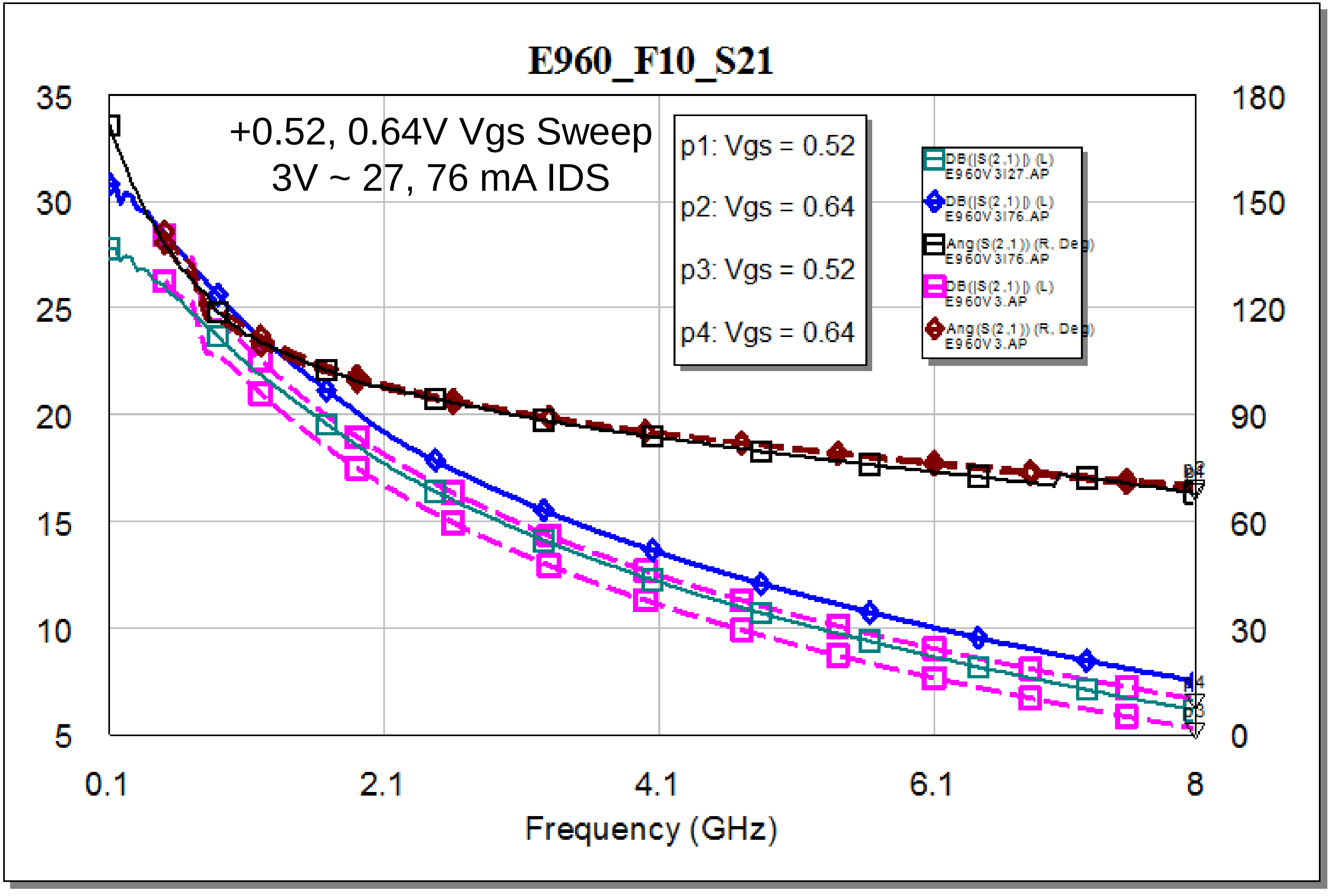
Test PHEMTs Fall 2010 E480 (6x80um)



+0.52, 0.64V Vgs Sweep
3V ~ 20, 47 mA IDS

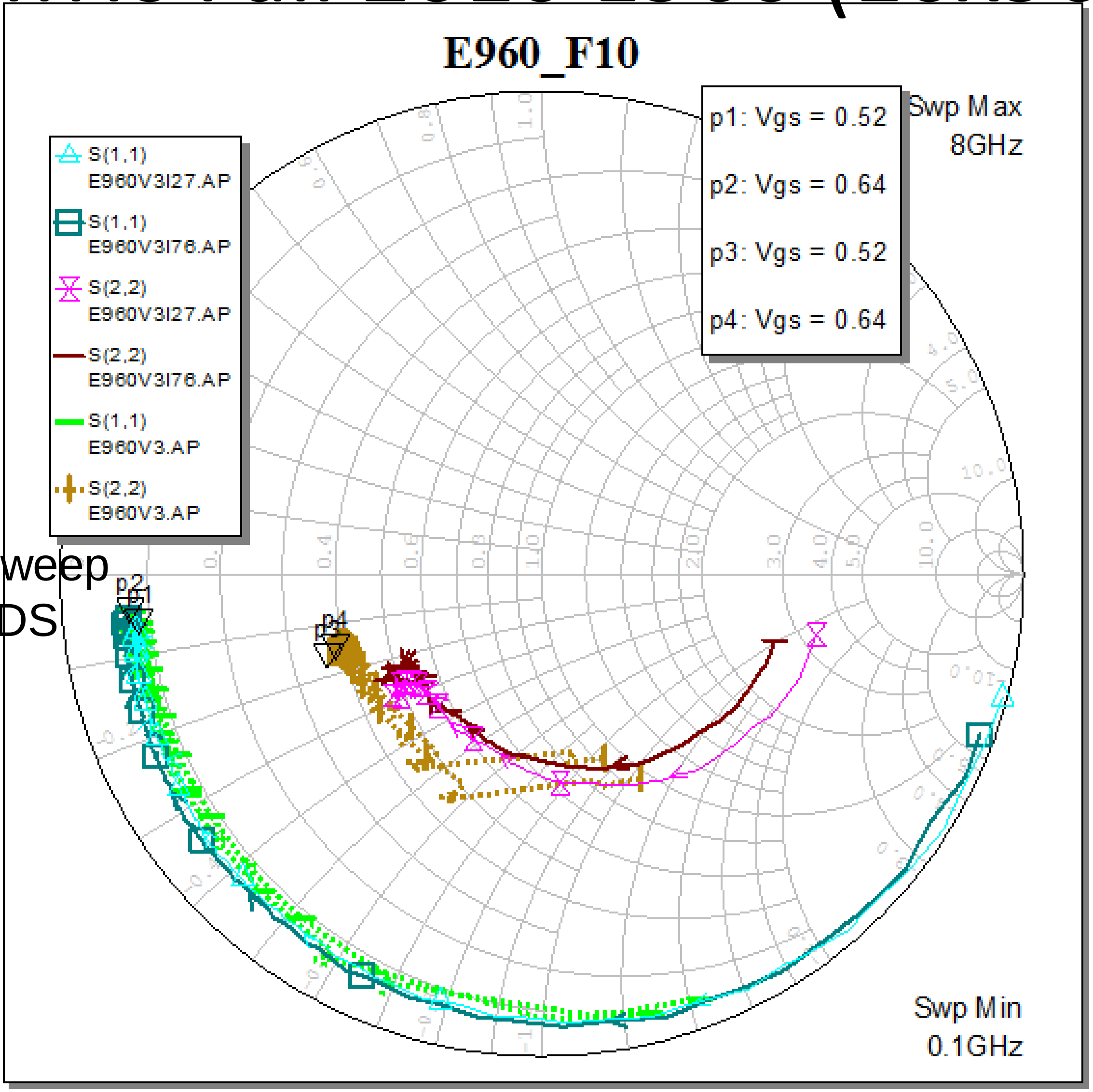
Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E960 (10x96um)



Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results

Test PHEMTs Fall 2010 E960 (10x96um)



+0.52, 0.64V Vgs Sweep
3V ~ 27, 76 mA IDS

Uses Sonnet Simulation of GSG Launch for Comparison to Measured Results