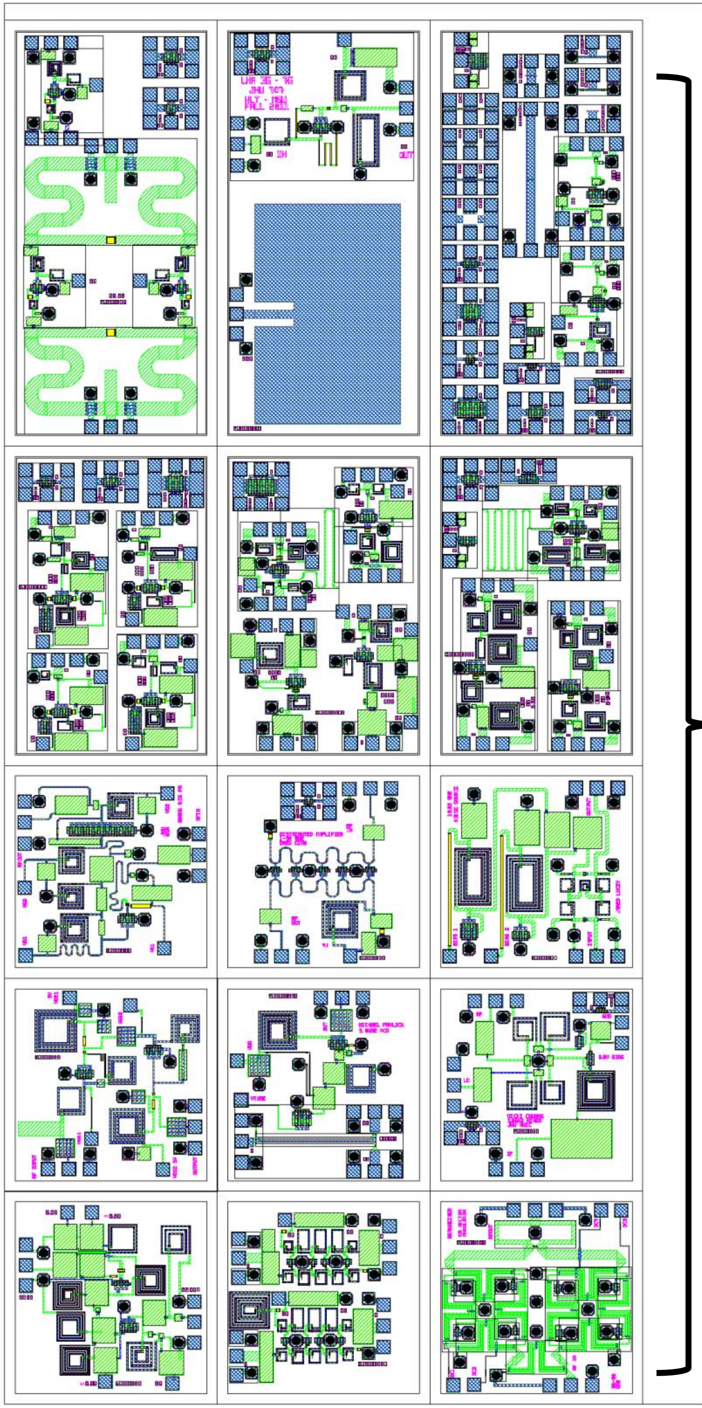


Johns Hopkins University
MMIC Class Fall 2011
Measured Results (Summer 2012)
John E. Penn & Dr. Willie Thompson

5x10mm Tile

9-60x60mil

3-60x90mil

3-60x120mil

PROJECTS F11

X-band Noise Diode –Jared Lucey	jhu11jl
Distributed Amplifier –Drew King	jhu11dk
Broad-band Low Noise Amp (LNA) –Avi Sharma	jhu11as
C-band Power Amplifier (PA)–Muhammed Usman	jhu11mu
Ka-band Vector Modulator – Mark Berkheimer	jhu11mb
C-band Mixer–Vicki Chuang	jhu11vc
X-band Power Amplifier (PA)–Wayne Miller	jhu11wm
Voltage Controlled Oscillator (VCO)—Mike Pavlick	jhu11mp

MMIC Class Fall 2011
Measured Results (Summer 2012)

<u>A quick summary of the projects:</u>

Noise Diode--Applying a large reverse bias voltage to the diode resulted in a significant noise increase. Very interesting because the models did not simulate in this region of bias!

Distributed Amp--This student project worked very well! Lots of bandwidth.

Broad Band Low Noise Amp--This design worked but had lower gain than expected. Possibly the interstage return loss was poor as part of the design tradeoff and was thus more sensitive to process/modeling variation. Still, it worked reasonably well.

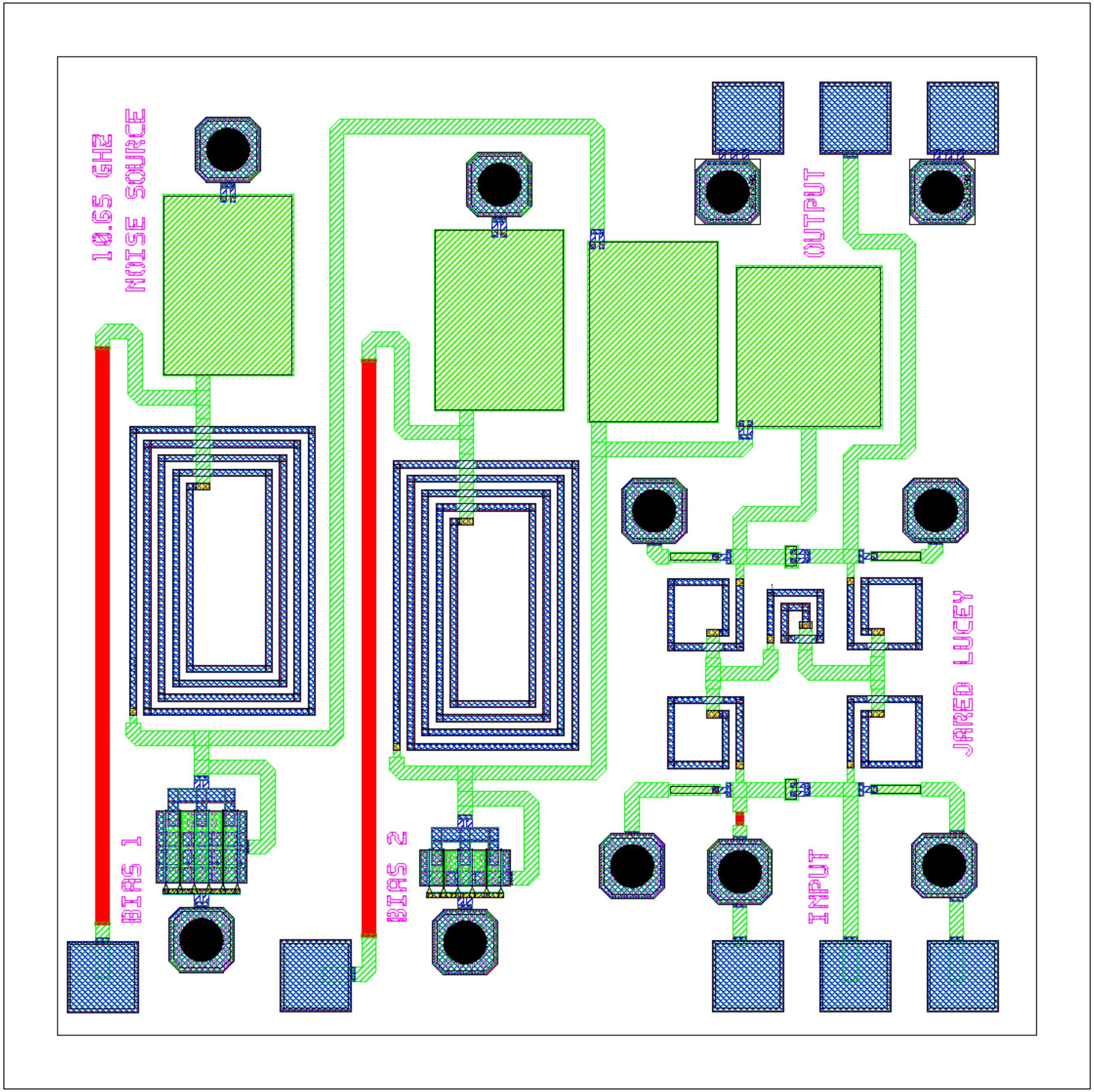
C-Band Power Amp--It was difficult to test the two stage amp which was supposed to be biased below Class C for one stage. But, we got high gain and some measurements in spite of the low freq. problems. More than 100 mW of RF power and very good efficiency in the 2nd stage amp.

Ka-Band Vector Mod--This worked as a vector mod, though ideally it would be good to take lots of measurements over a range of DC biases for the 4 DC inputs and then create a lookup table to optimize the amplitude/phase control. Very, very compact design for Ka-Band operation! 34-40 GHz or so.

C-Band Mixer--Diode mixer worked very well at C-band. Interesting that the 0.13 um PHEMTs as diodes work best with some forward bias (~0.8V) but not so well with no bias (0V) as compared to previous year's diode mixers using the different 0.5 um TQPED PHEMT process.

X-Band Power Amp--Again low frequency oscillation problems, particularly in the NWA measurements, but the amplifier did output >100 mW of RF power at 9.5 GHz. Gain was a little lower than expected but this is another one that could benefit from 100 pF caps on the DC bias supplies close to the MMIC.

VCO--Very nice C-Band voltage controlled oscillator. Just to get the VCO to work is quite a challenge, but to actually be so close to the design frequency with good tuning range was pretty amazing.

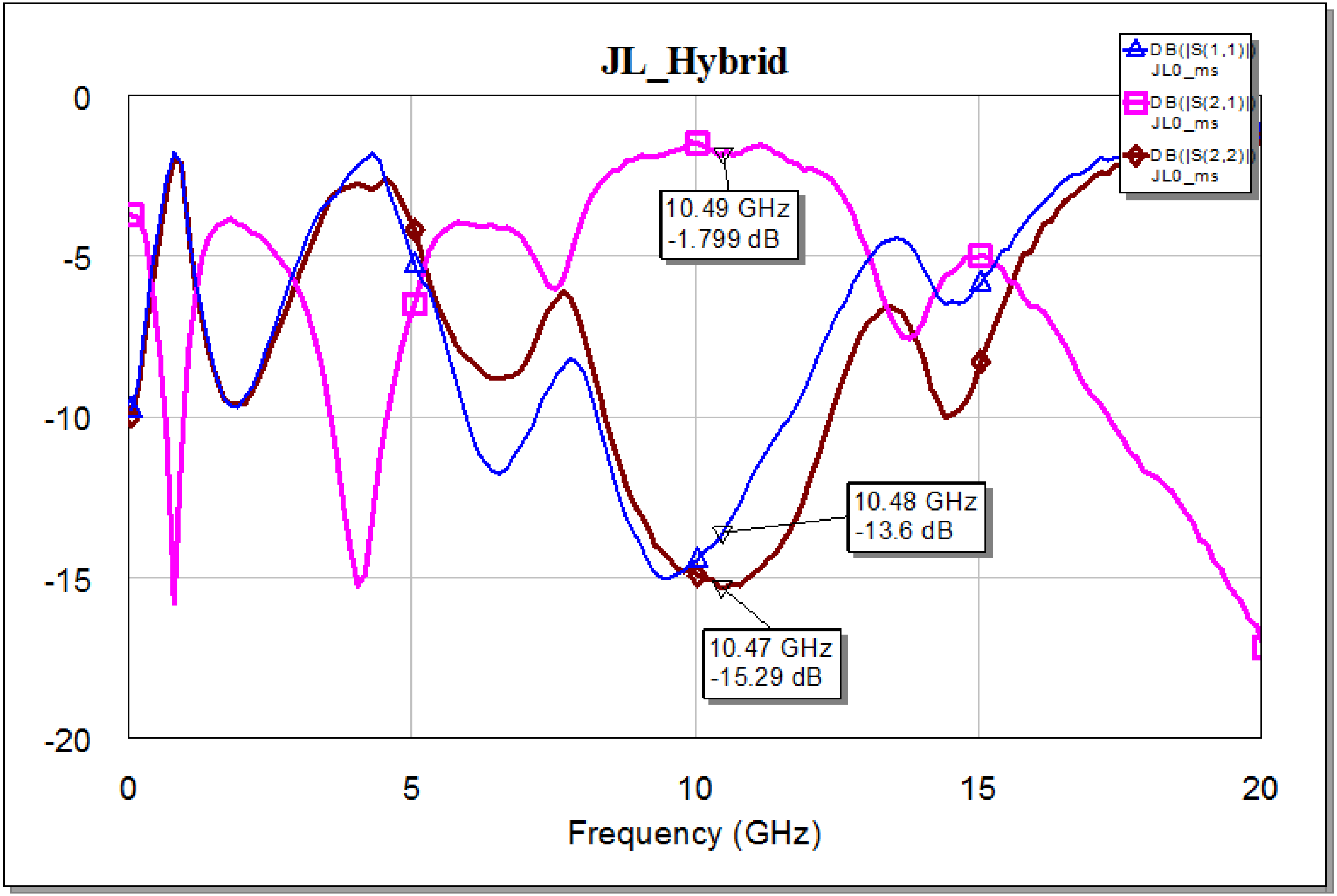


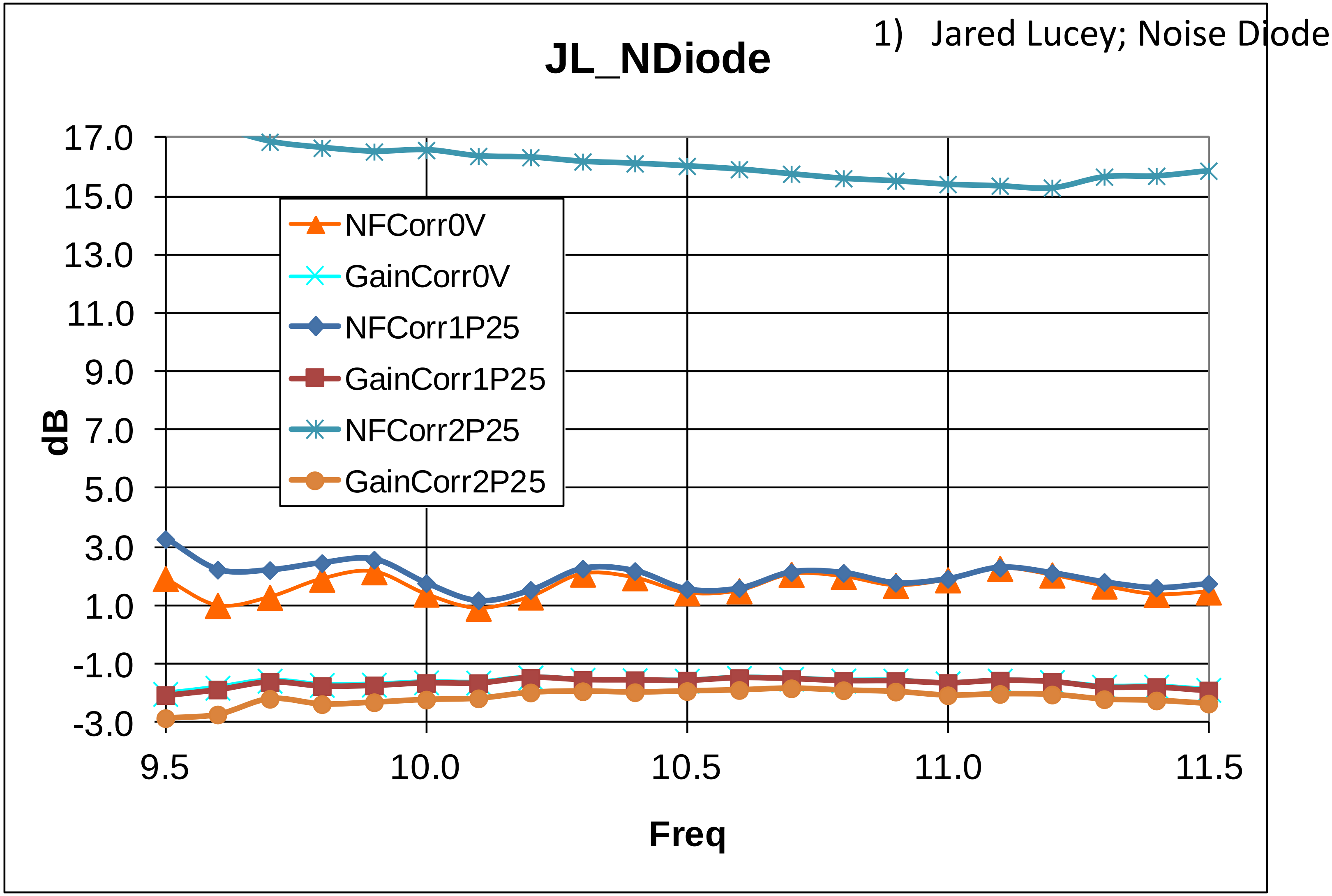
1) Jared Lucey
   Noise Diode

Worked Well!

Reverse bias beyond breakdown did create additional noise, particularly in one of the two diodes. This was not something that could be modeled with the current design kit. Resistors limited the current when 25V was applied to ~7mA.

1) Jared Lucey
Noise Diode





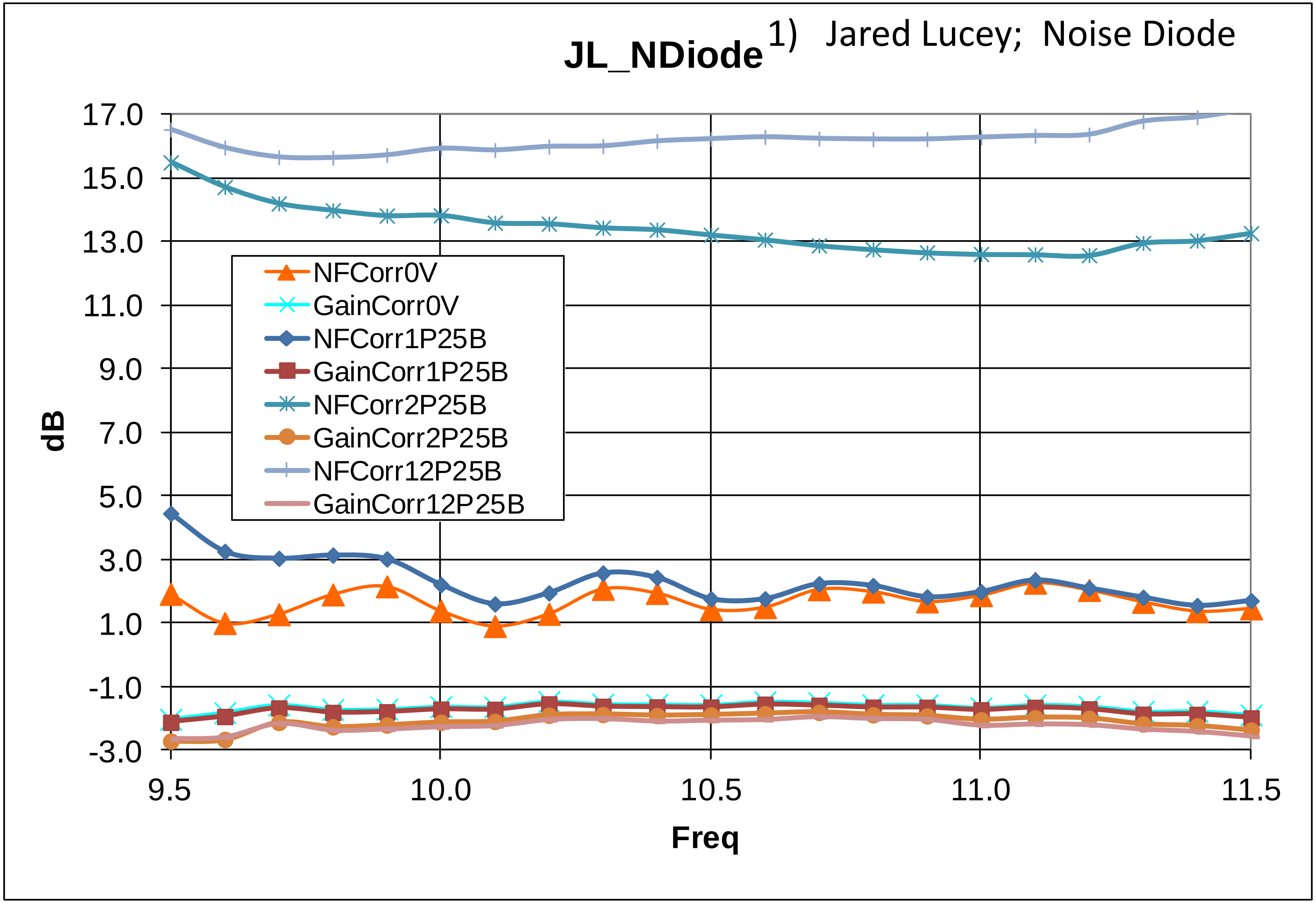
0V, is reference for Die #1 with Diodes UnBiased

1P25 is Reverse Bias of Diode 1; 25V, 7mA (Some Noise Increase)

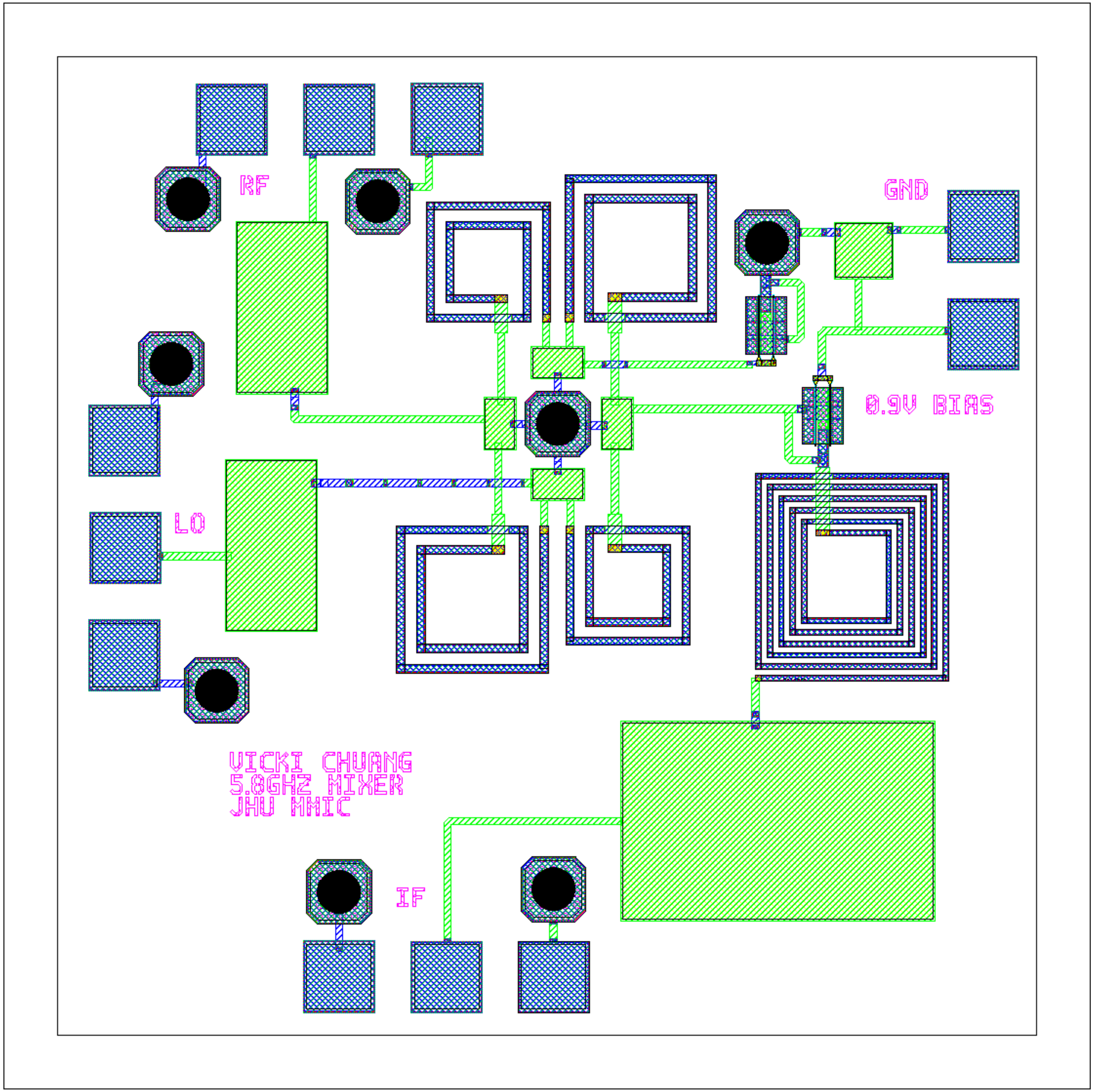
2P25 is Reverse Bias of Diode 2; 25V, 7mA (Note Large Noise Increase!)

Gain Should be approx 1.7 dB loss of hybrid, note it is slightly higher when Diode2 is ON

1) Jared Lucey; Noise Diode

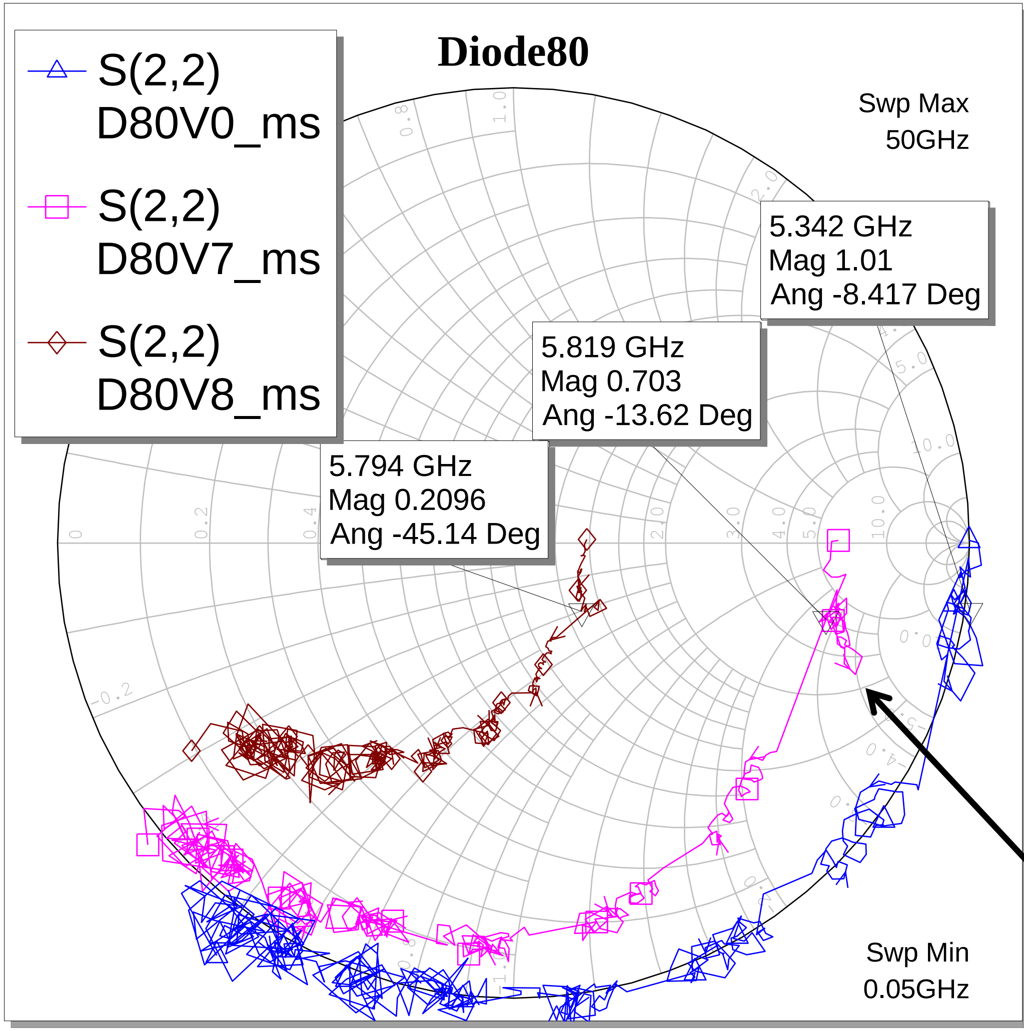


0V, is reference for Die #1 with Diodes UnBiased, but following is Die #2 Measurements
1P25B is Reverse Bias of Diode 1; 25V, 7mA (Some Noise Increase)
2P25B is Reverse Bias of Diode 2; 25V, 7mA (Note Large Noise Increase!)
12P25B is Reverse Bias of Diode 1 & 2; 25V, 13mA (Note Larger Noise Increase!)



2) Vicki Chuang
   Diode Mixer

- Mixer worked great, but definitely wanted a forward bias. Test diodes were measured and showed that the match of the 80um PHEMT/Diode was good with about 0.8V of forward bias but looked like a capacitor—reflecting all signals with no DC bias.

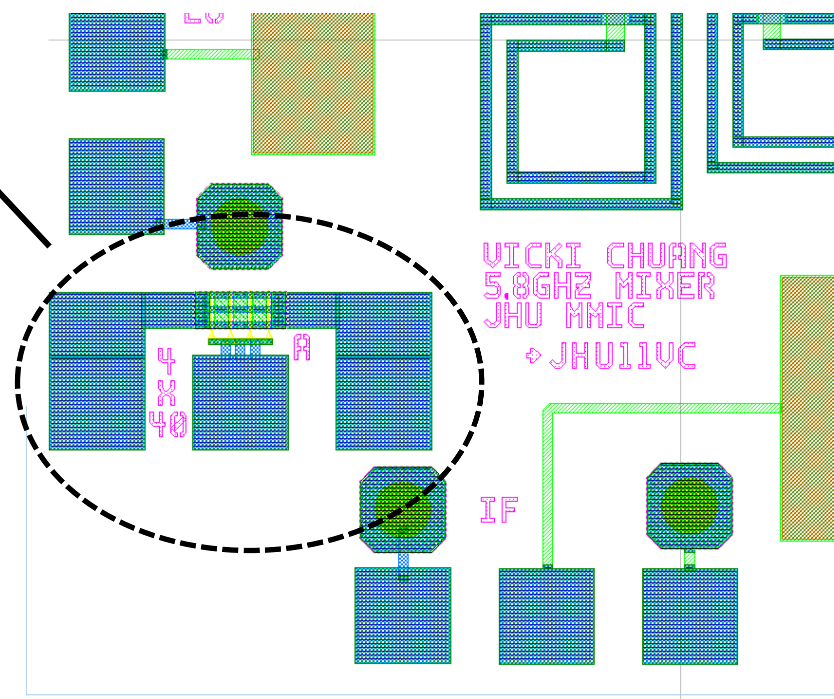


2) Vicki Chuang
Diode Mixer

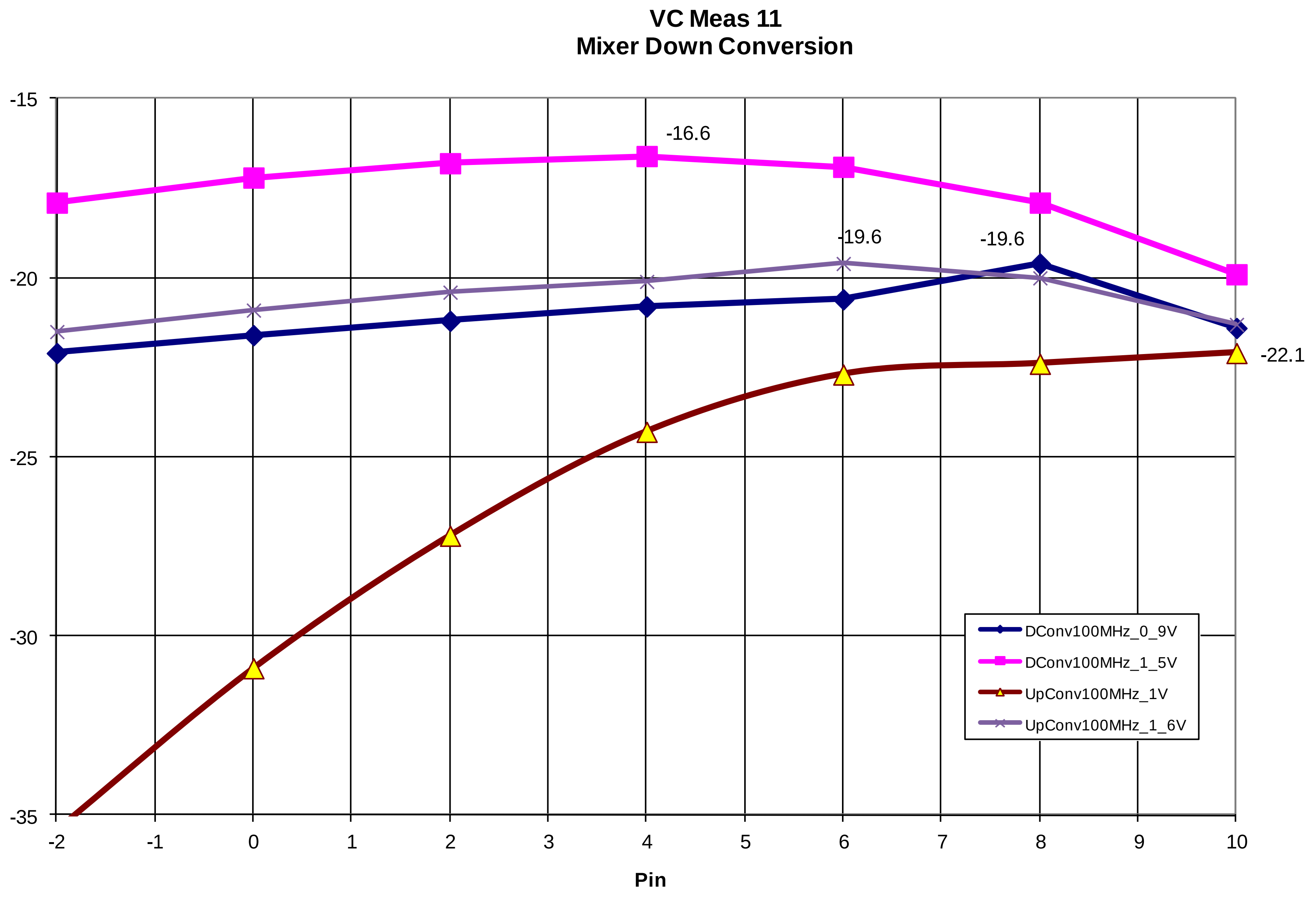
Test Diode 4x40 (0, 0.7, 0.8V):

Match Best at 0.8V forward bias.

Poor w/o Bias (0V)



Vicki Chuang Diode Mixer Best Conversion at 1.5-1.6V, Better Down Conv, but Up Conv OK



Vicki Chuang Diode Mixer Best Conversion at 1.5-1.6V, Better Down Conv, but Up Conv OK

Down Conversion			IF=100 MH	Vb=1.0V	IF=100 MHz	Vb=1.5V	IF=100 MH	Vb=1.6V
LO 5.8G	**LO (corr)**	**IF (meas)**	**RF (corr)**	**Loss (gain)**	**IF (meas)**	**Loss (gain**	**IF (meas)**	**Loss (gain**
0	-4	-39.2	-11.6	**-27.1**	-30.6	**-18.5**	-30.0	**-17.9**
2	-2	-37.7	-11.6	**-25.6**	-29.8	**-17.7**	-29.3	**-17.2**
4	0	-35.6	-11.6	**-23.5**	-29.2	**-17.1**	-28.8	**-16.7**
6	2	-33.1	-11.6	**-21.0**	-28.8	**-16.7**	-28.5	**-16.4**
8	4	-31.2	-11.6	**-19.1**	-28.6	**-16.5**	-28.3	**-16.2**
10	6	-30.6	-11.6	**-18.5**	-28.9	**-16.8**	-28.7	**-16.6**
12	8	-31.4	-11.6	**-19.3**	-30.0	**-17.9**	-29.7	**-17.6**
14	10	-33.6	-11.6	**-21.5**	-32.3	**-20.2**	-32.0	**-19.9**

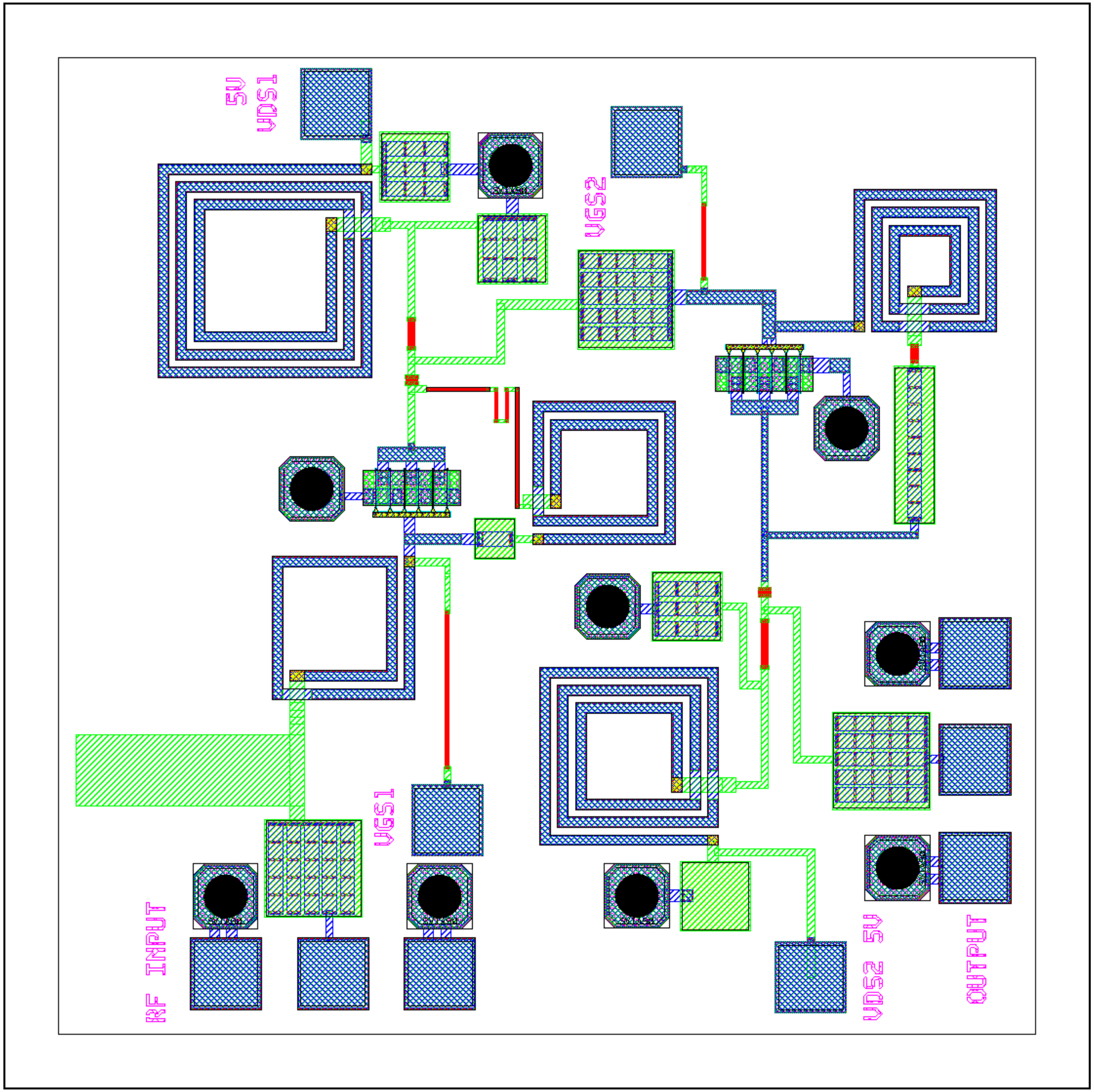
Up Conversion			RF=5.9 GI	Vb=1.0V	RF=5.9 GHz	Vb=1.6V
LO 5.8G	**LO (corr)**	**RF (meas**	**RF (corr)**	**Loss (gain)**	**RF (meas)**	**Loss (gain**
0	-4	-52.0	-10.5	**-39.9**	-34.3	**-22.2**
2	-2	-47.5	-10.5	**-35.4**	-33.6	**-21.5**
4	0	-43.0	-10.5	**-30.9**	-33.0	**-20.9**
6	2	-39.3	-10.5	**-27.2**	-32.5	**-20.4**
8	4	-36.4	-10.5	**-24.3**	-32.2	**-20.1**
10	6	-34.8	-10.5	**-22.7**	-31.7	**-19.6**
12	8	-34.5	-10.5	**-22.4**	-32.1	**-20.0**
14	10	-34.2	-10.5	**-22.1**	-33.4	**-21.3**

RF 5.9 GHz and IF 100 MHz -10 dBm setting		
~4dB loss to LO		
~0.5 dB loss to IF		

Notes:

meas--measured

corr—corrected



3) Avi Sharma

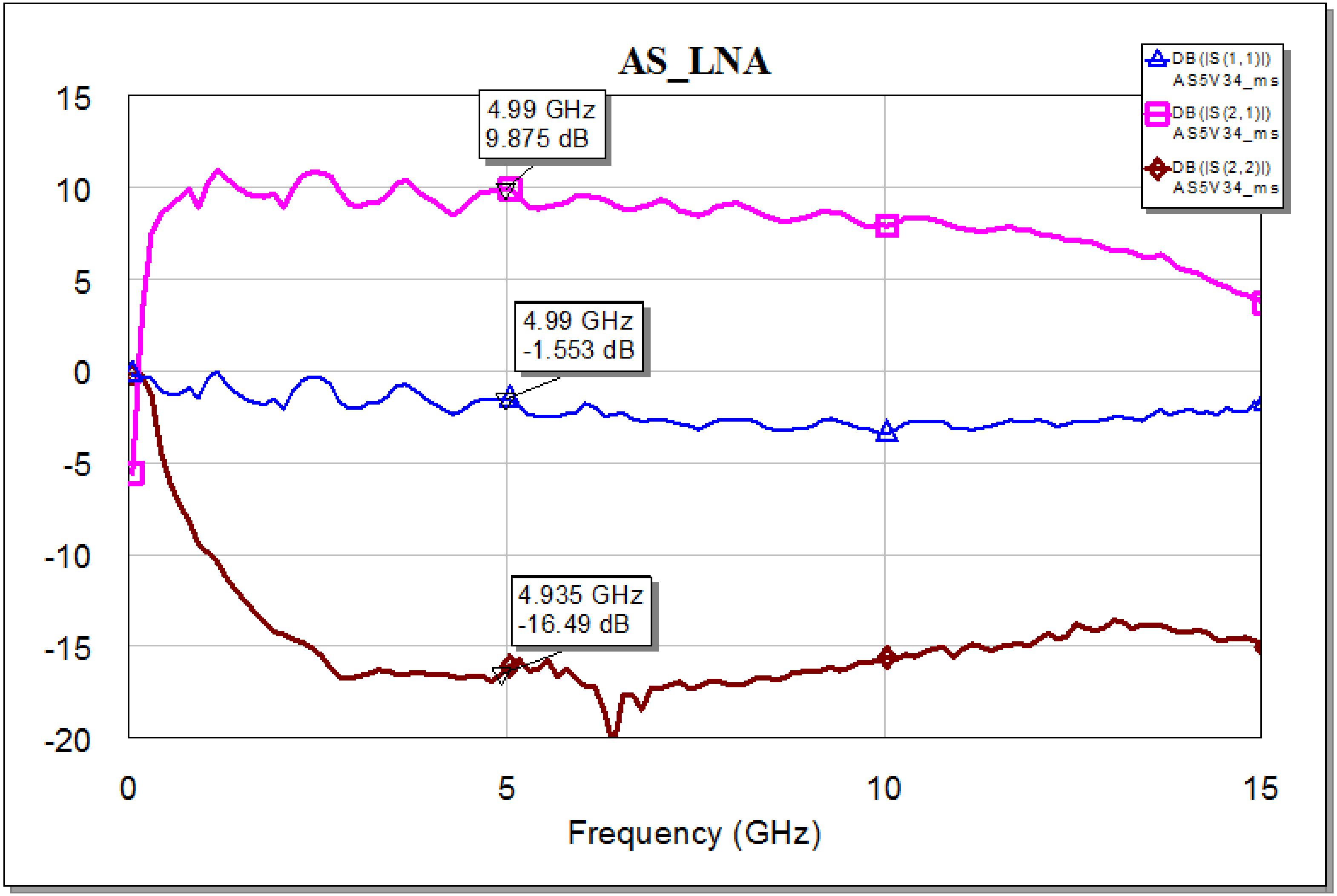
Broad Band LNA

Measured at 5V ~34mA.

Gain Low, but then Input return loss is also poor. Output return loss is very good and gain is broadband. Noise figure is a little higher than expected but follows shape of simulations.

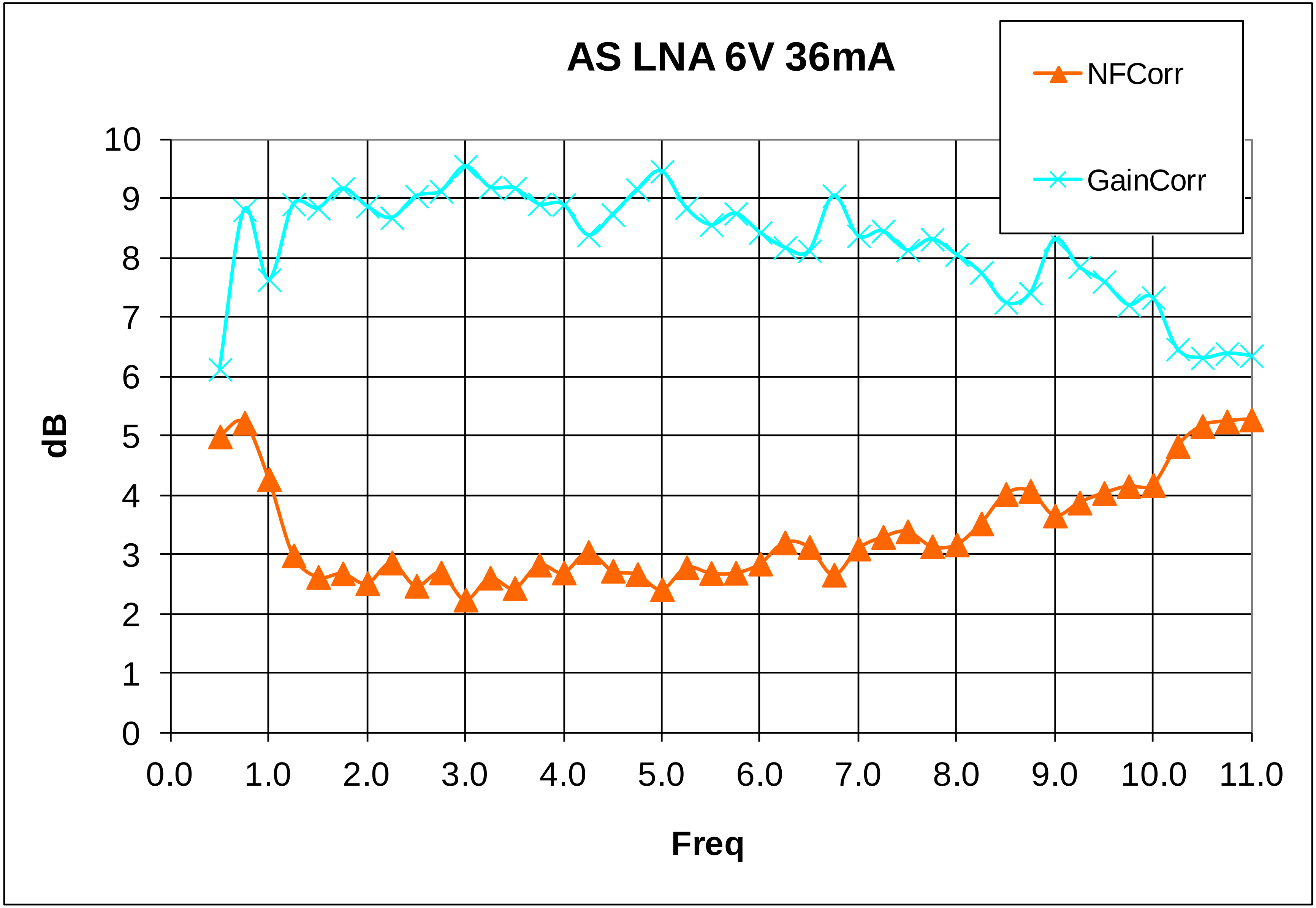
3) Avi Sharma Broad Band LNA

Measured at 5V ~34mA. Gain Low but broadband. Input return loss is poor. Output return loss is very good and broadband.



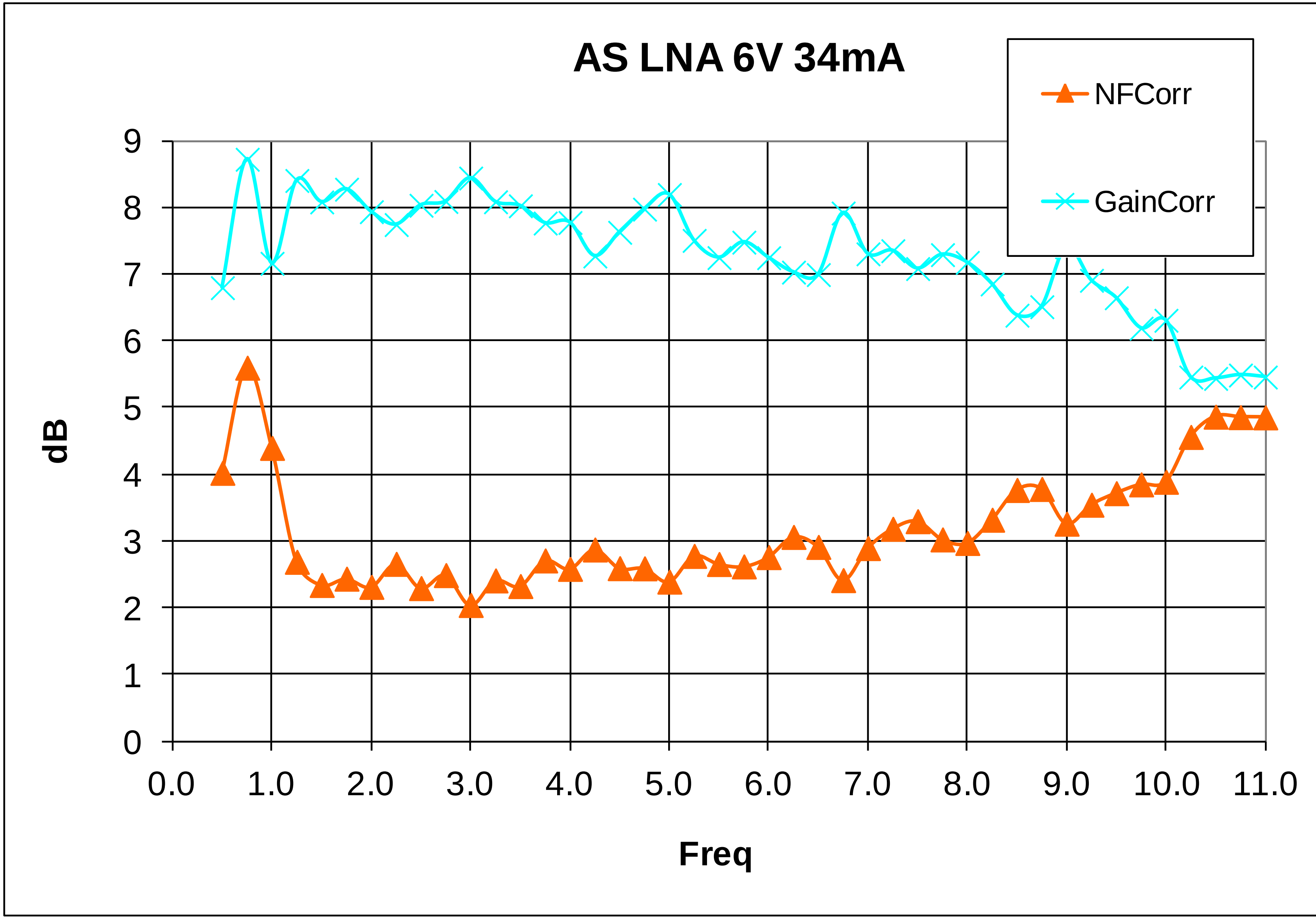
3) Avi Sharma Broad Band LNA

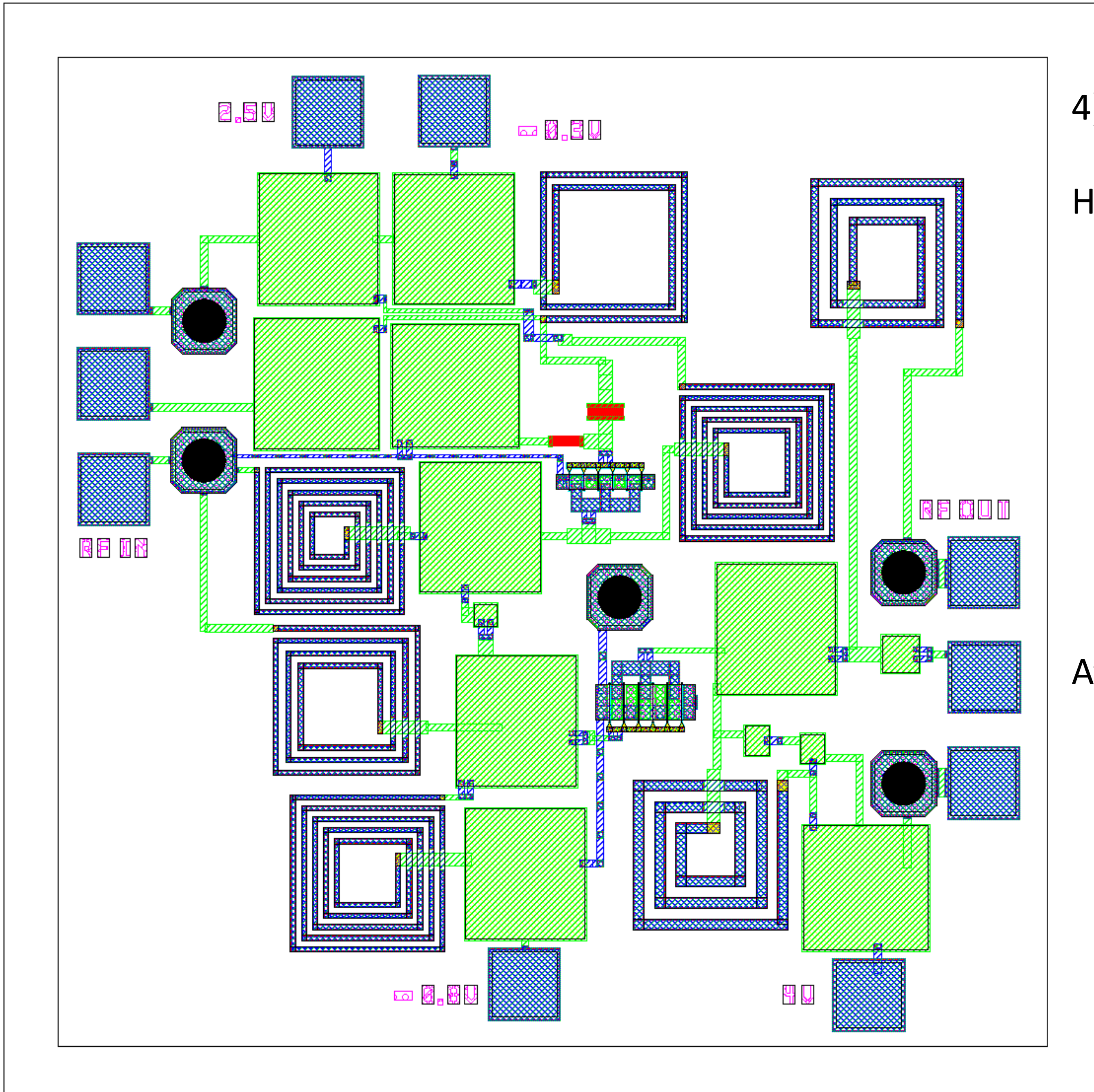
Measured at 6V ~36mA. Comparable Gain with good Noise Figure.



3) Avi Sharma Broad Band LNA

Measured at 6V ~34mA, Die #2. Comparable Gain with good Noise Figure.





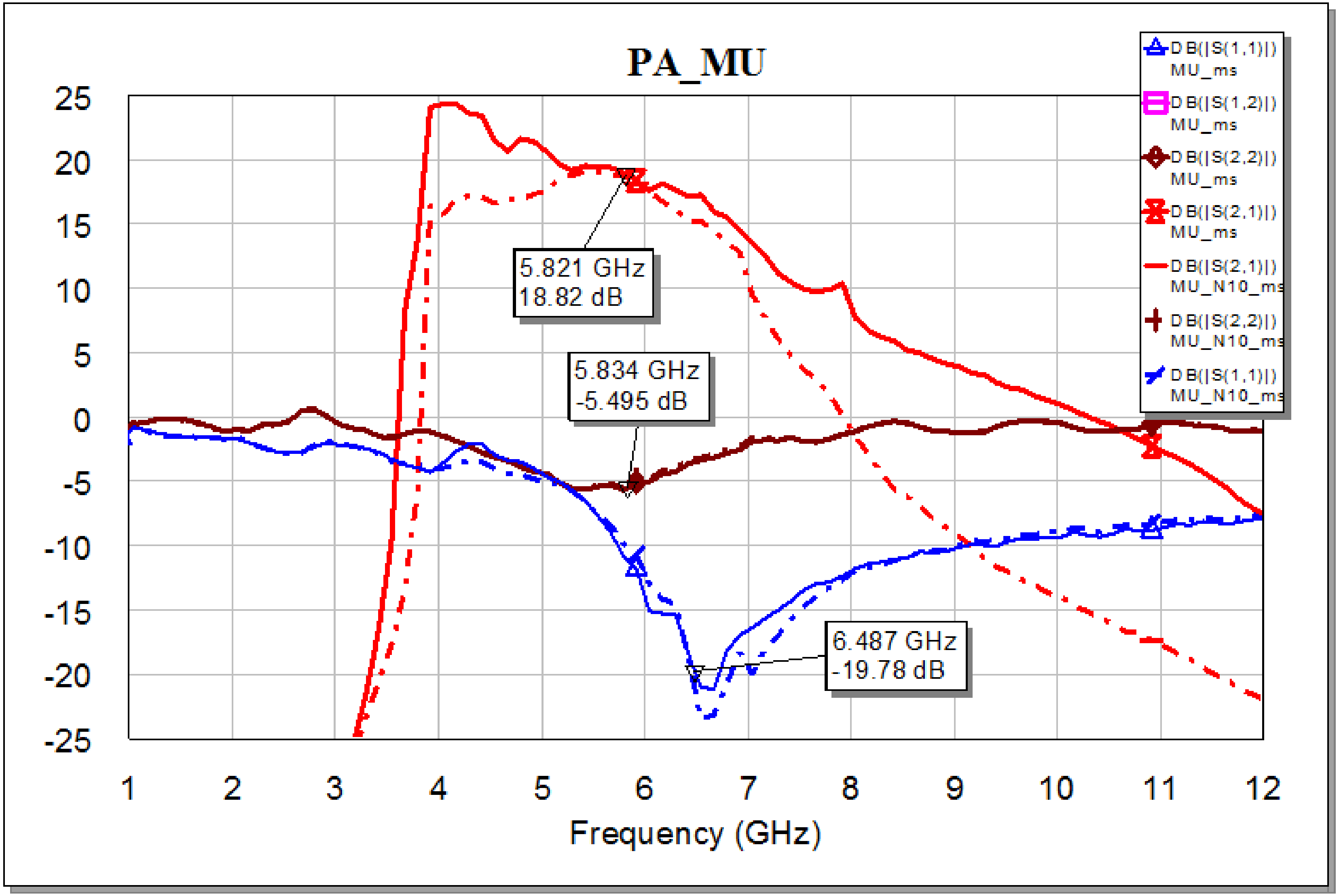
4) Muhammed Usman
C Band PA

Had difficulty with low frequency oscillations during testing, and also with getting the desired bias. One stage was intended to be strongly Class C bias. Definitely had gain as shown in the following measurements.

Attaching 100pF caps to the DC bias inputs and retesting would probably quell the ~30-40MHz oscillations.

4) Muhammed Usman Measured C Band PA

Low freq. oscillations? Approx. Bias vg1=-0.5V, vd1=4V; vg2=0v, vd2=2.0V; Plots with -2dBm and -10dBm Power (8510)



4) Muhammed Usman Performance Measurements C Band PA 5.6/5.8 GHz

Low freq. oscillations died out at higher input levels; Bold is “clean” looking spectrum on analyzer.

Approx. Bias vg1=-0.5V, vd1=4V; vg2=0v, vd2=2.5V first stage is Class A DC bias, second stage is Class B…

Measured 7/31/12				Loss 3.6-3.7 dB for thru		Low Frequency Oscillations; Vg~0V		
5.8 GHz	Die#1	**5.8 GHz Fall11 TQP13**			Vg2=-0.5V	4V ; 9 mA	1st stage: 2.5V ; ~42 m	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC2(mw)**	**Pout(mw)**	**Drn Eff2?**
-10.0	1.00	-11.85	2.85	14.70	9	36.0	1.93	5.4
-8.0	3.92	-9.85	5.77	15.62	11	44.0	3.78	8.6
-6.0	7.27	-7.85	9.12	16.97	13	52.0	8.17	15.7
-4.0	10.06	-5.85	11.91	17.76	17	68.0	15.52	22.8
-2.0	12.02	-3.85	13.87	17.72	20	80.0	24.38	30.5
0.0	13.90	-1.85	15.75	17.60	24	96.0	37.58	39.1
2.0	**15.25**	**0.15**	**17.10**	**16.95**	**28**	**112.0**	**51.29**	**45.8**
3.0	**15.59**	**1.15**	**17.44**	**16.29**	**30**	**120.0**	**55.46**	**46.2**
4.0	**15.80**	**2.15**	**17.65**	**15.50**	**31**	**124.0**	**58.21**	**46.9**
			No Oscillations at Higher Drive--Bold!					

5.6 GHz	Die#1	**5.8 GHz Fall11 TQP13**			Vg2=-0.5V	4V ; 9 mA	1st stage: 2.5V ; ~42	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC2(mw**	**Pout(mw)**	**Drn Eff2?**
-10.0	3.03	-11.80	4.83	16.63	10	40.0	3.04	7.6
-8.0	6.45	-9.80	8.25	18.05	13	52.0	6.68	12.9
-6.0	10.12	-7.80	11.92	19.72	18	72.0	15.56	21.6
-4.0	12.67	-5.80	14.47	20.27	22	88.0	27.99	31.8
-2.0	**14.84**	**-3.80**	**16.64**	**20.44**	**27**	**108.0**	**46.13**	**42.7**
0.0	**15.72**	**-1.80**	**17.52**	**19.32**	**31**	**124.0**	**56.49**	**45.6**
2.0	**16.37**	**0.20**	**18.17**	**17.97**	**34**	**136.0**	**65.61**	**48.2**
3.0	**16.51**	**1.20**	**18.31**	**17.11**	**35**	**140.0**	**67.76**	**48.4**
			No Oscillations at Higher Drive--Bold!					

Notes:

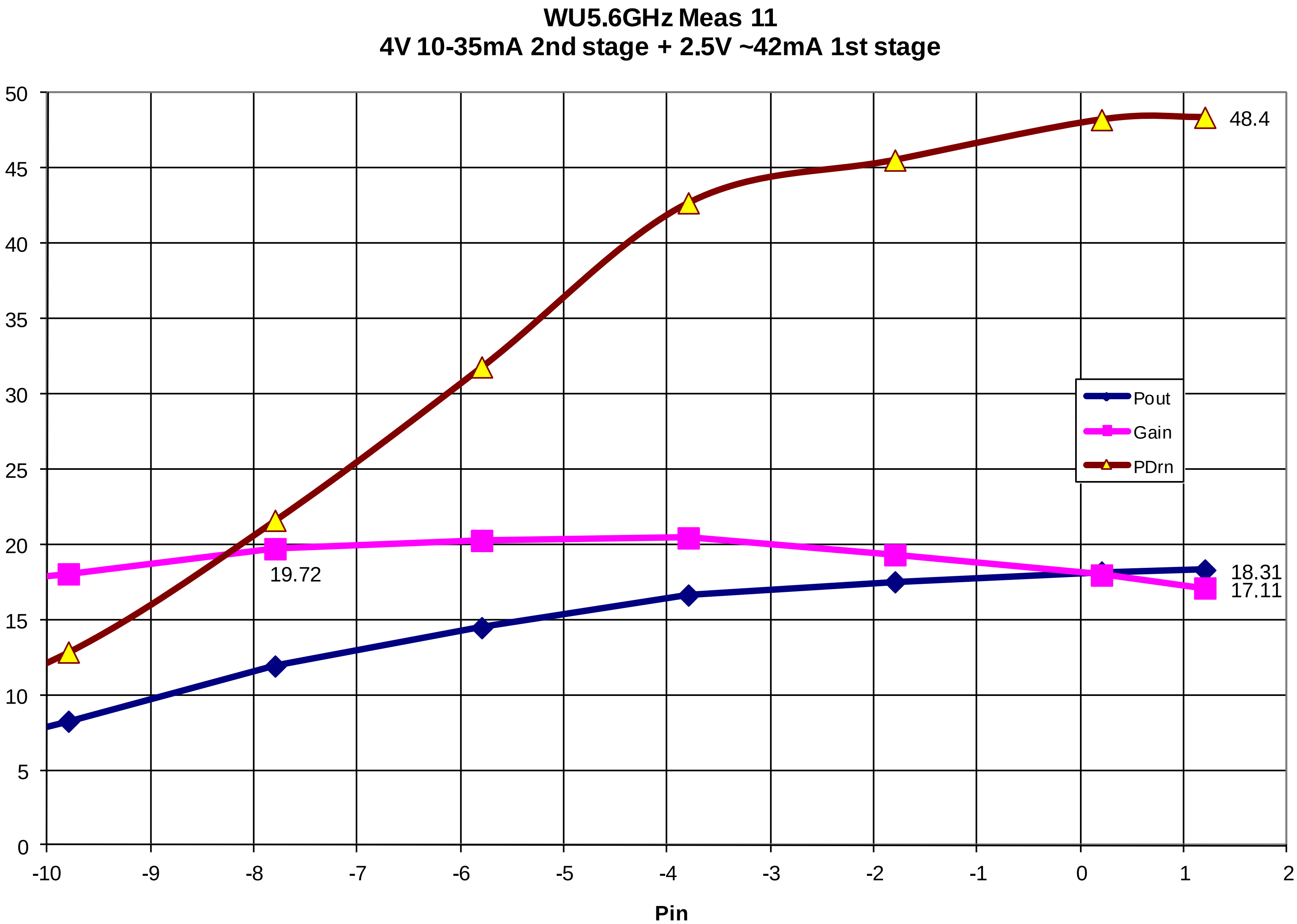
corr—corrected

SG—Signal Generator

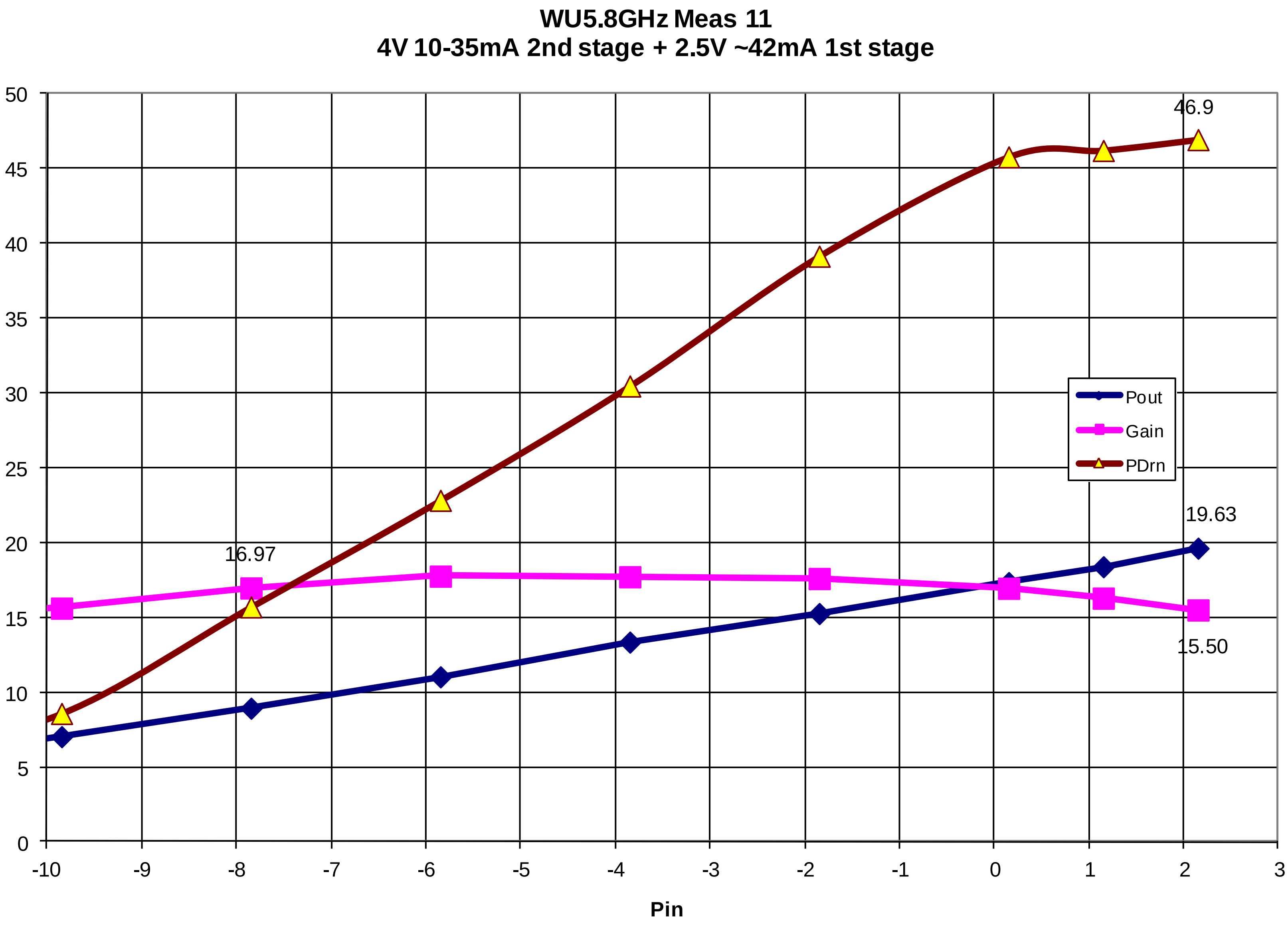
SA—Spectrum Analyzer

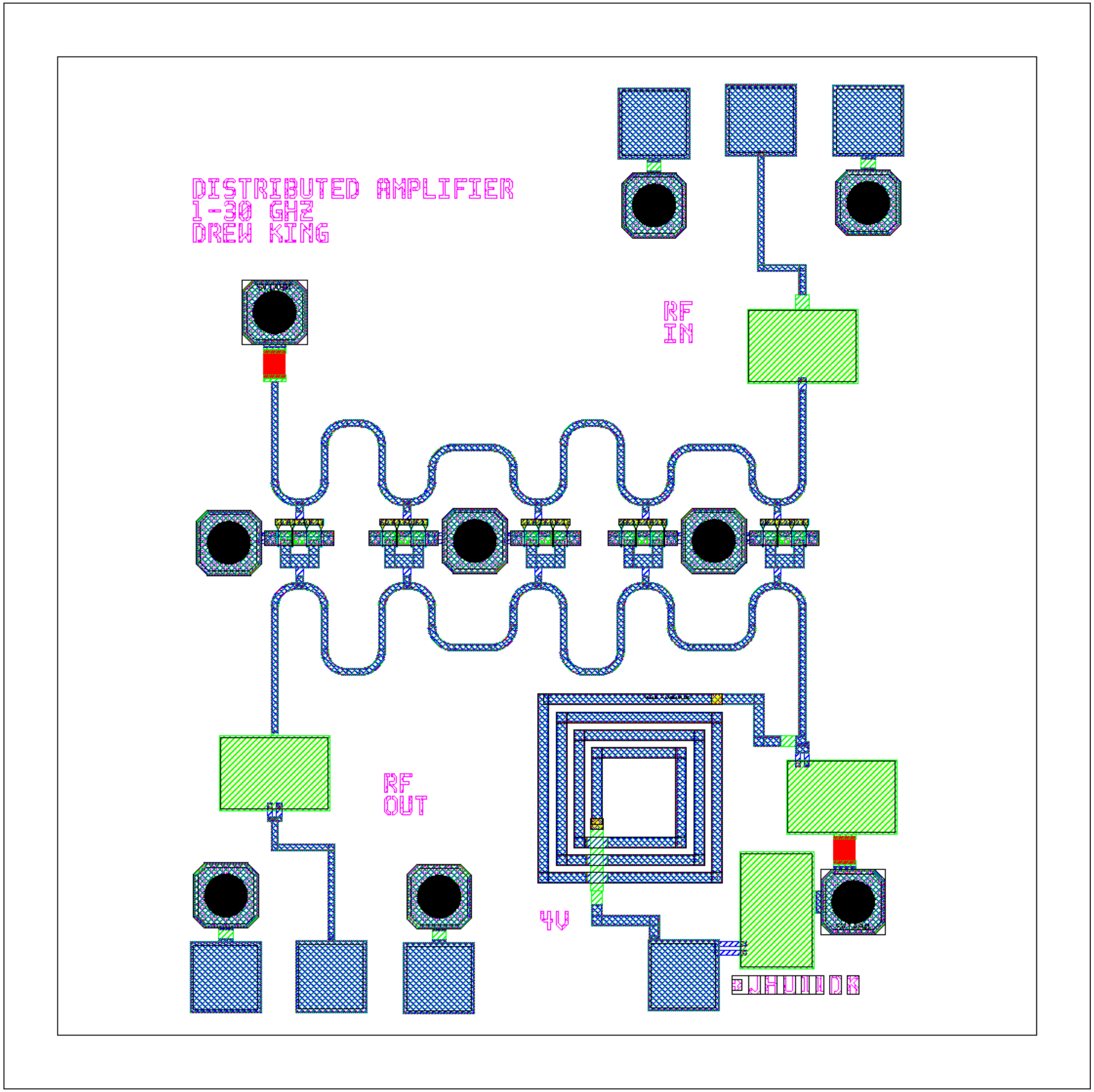
4) Muhammed Usman Performance Measurements C Band PA 5.6 GHz

Pout, Gain, Pdrn (Drain Efficiency of Stage 2 only) vs. Pin



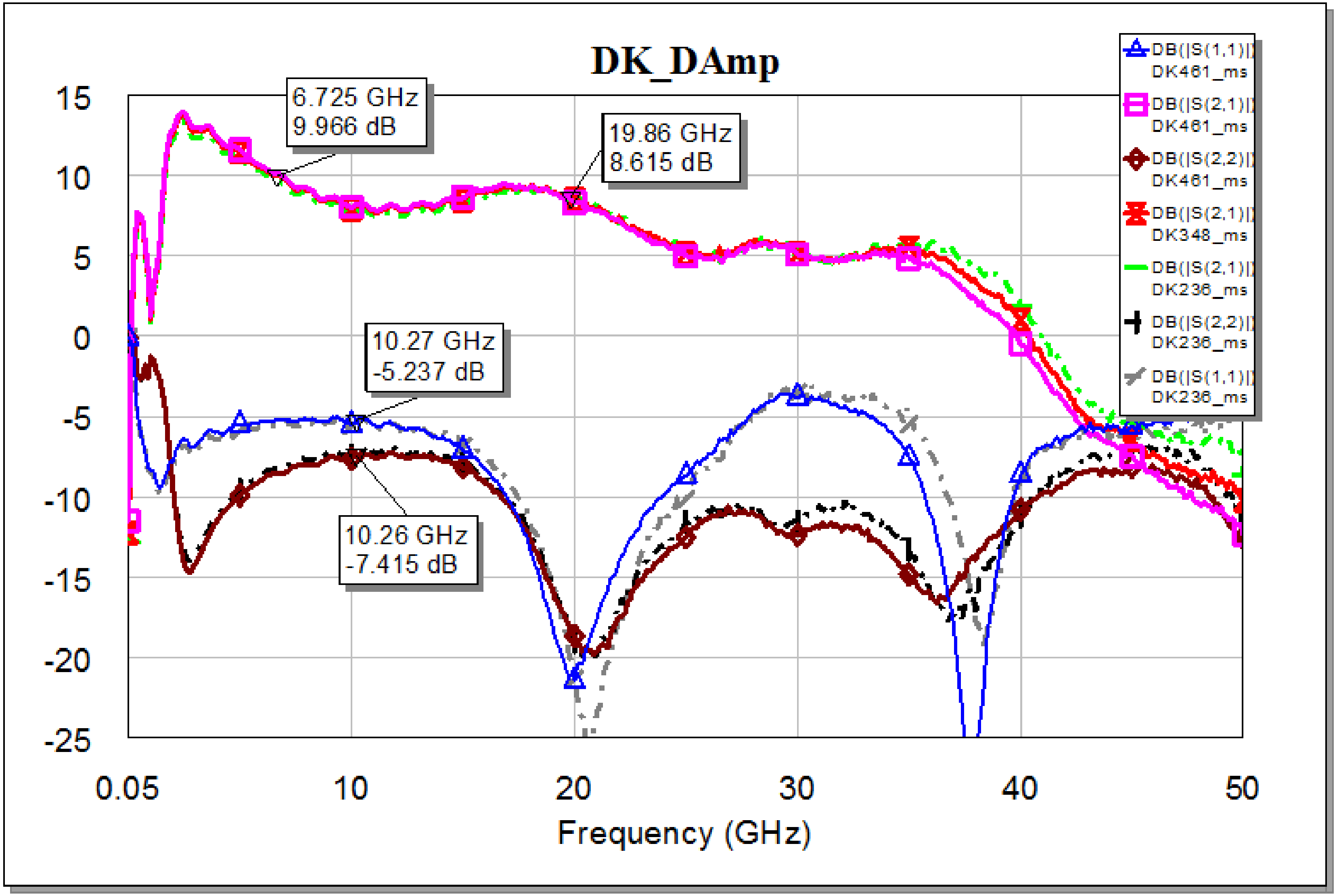
4) Muhammed Usman Performance Measurements C Band PA 5.8 GHz Pout, Gain, Pdrn (Drain Efficiency of Stage 2 only) vs. Pin



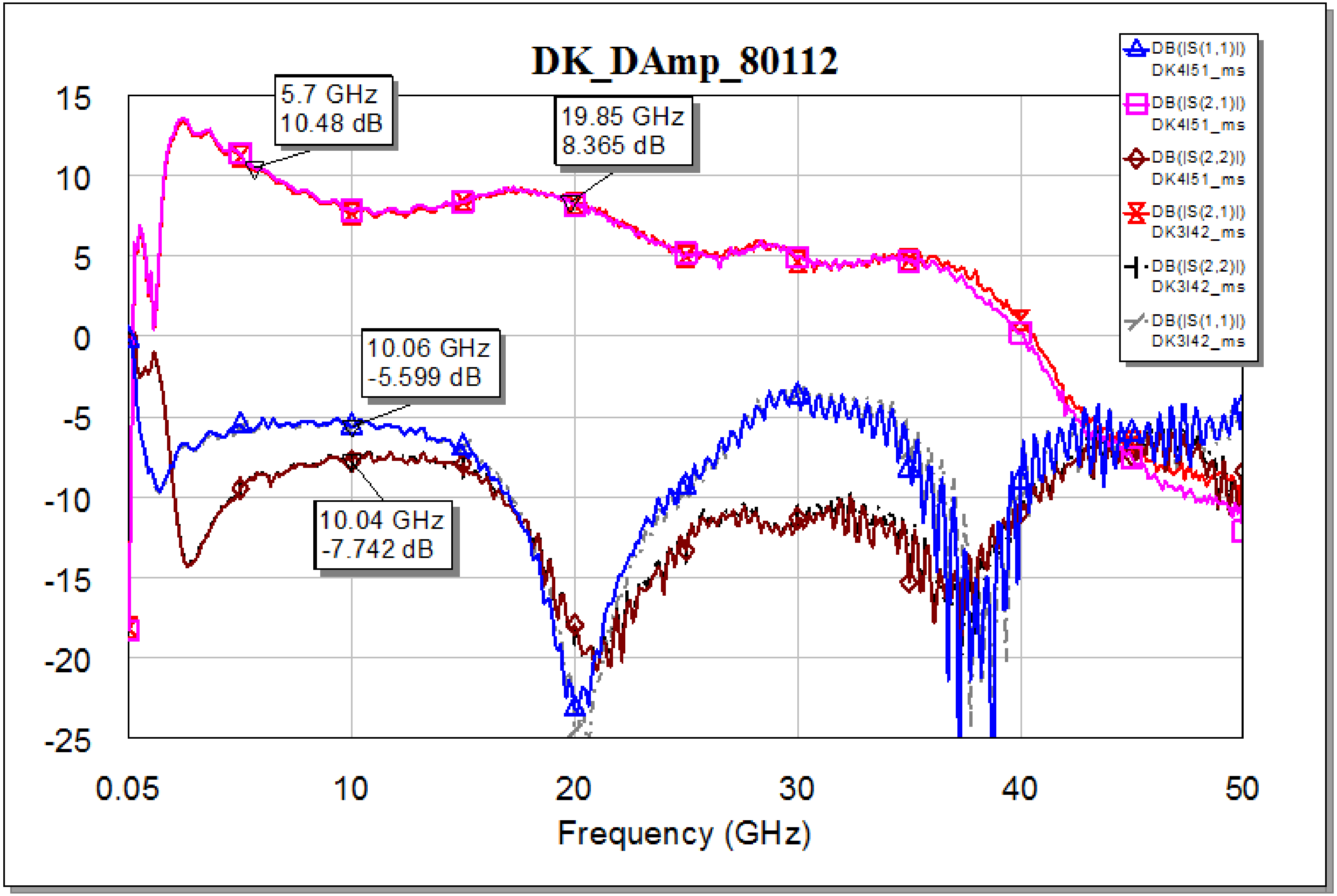


5) Drew King
1-30 GHz Dist Amp
Worked Great! DC bias was as expected at about 4V 51mA.

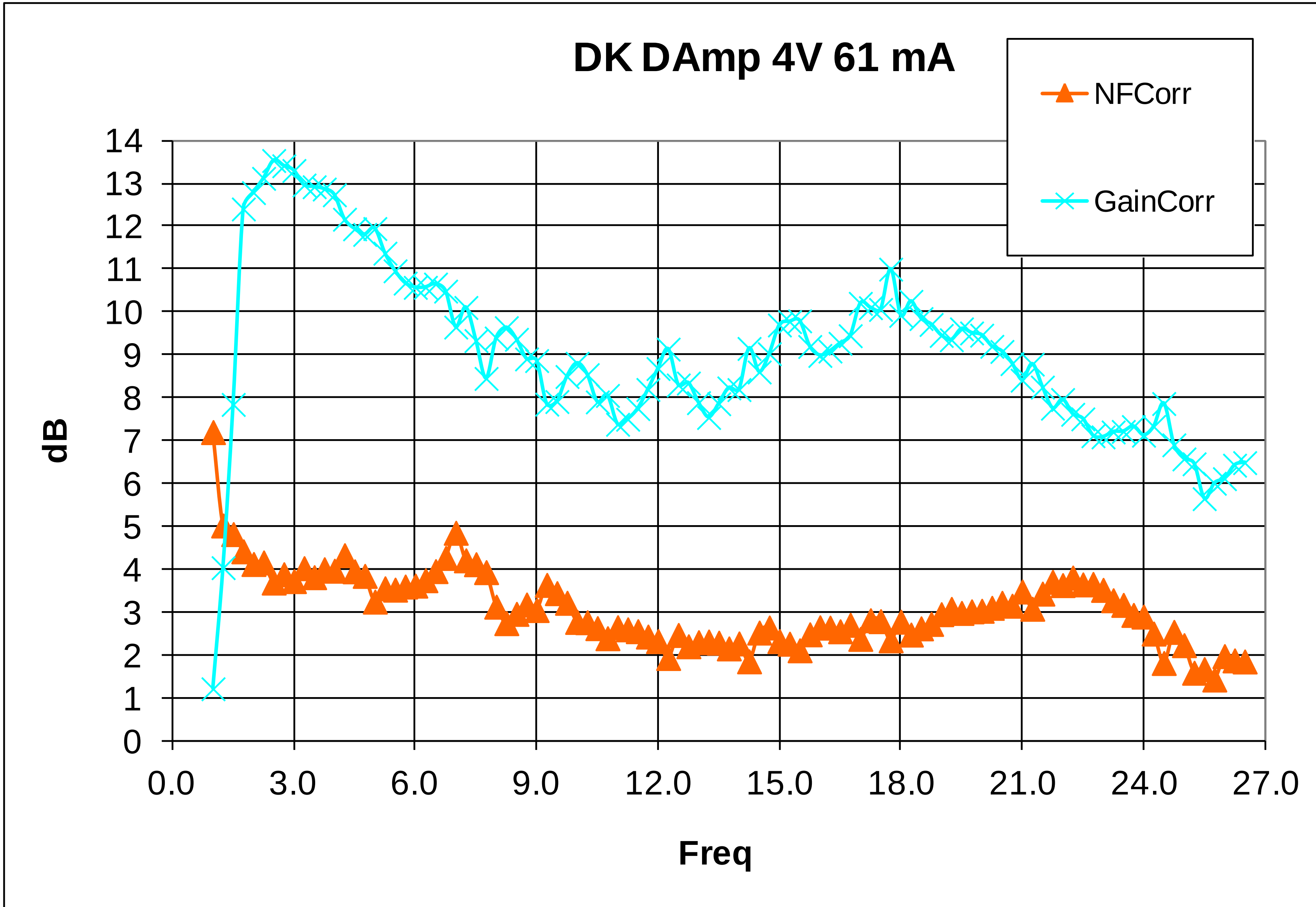
5) Drew King 4V 61 mA
1-30 GHz Dist Amp

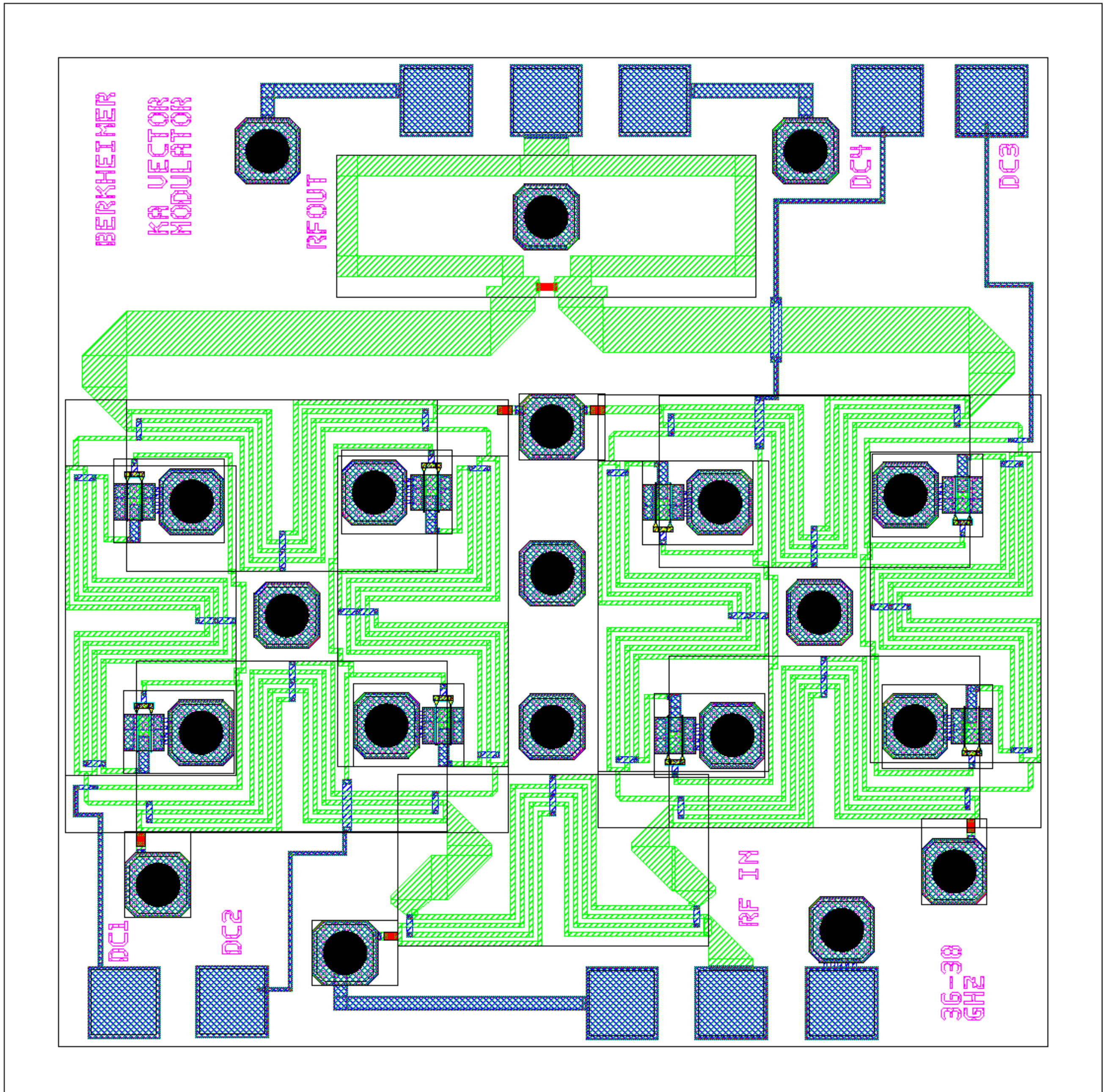


5) Drew King 4V 51 mA
1-30 GHz Dist Amp Re-Measured 8/1/12



5) Drew King 4V 61 mA
1-30 GHz Dist Amp NF Measured 7/12/12; Noisy Cal (esp. ~7 GHz)



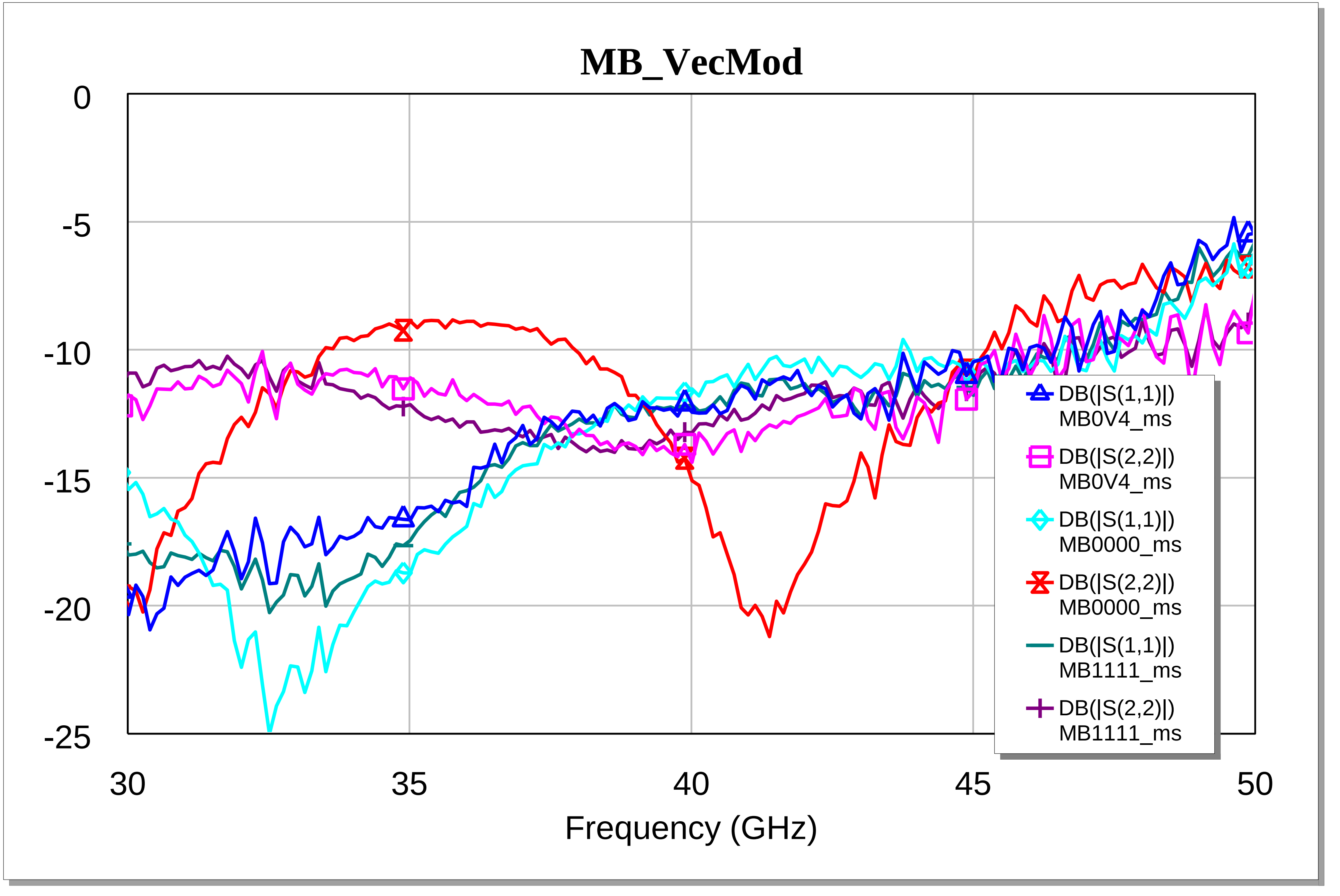


6) Mark Berheimer Vector Modulator

Vector Modulator tested at various DC inputs. Not sure what the ideal levels should be but automated measurements and a lookup table could be used to control the amplitude and phase over a range of frequencies around 34-40 GHz.

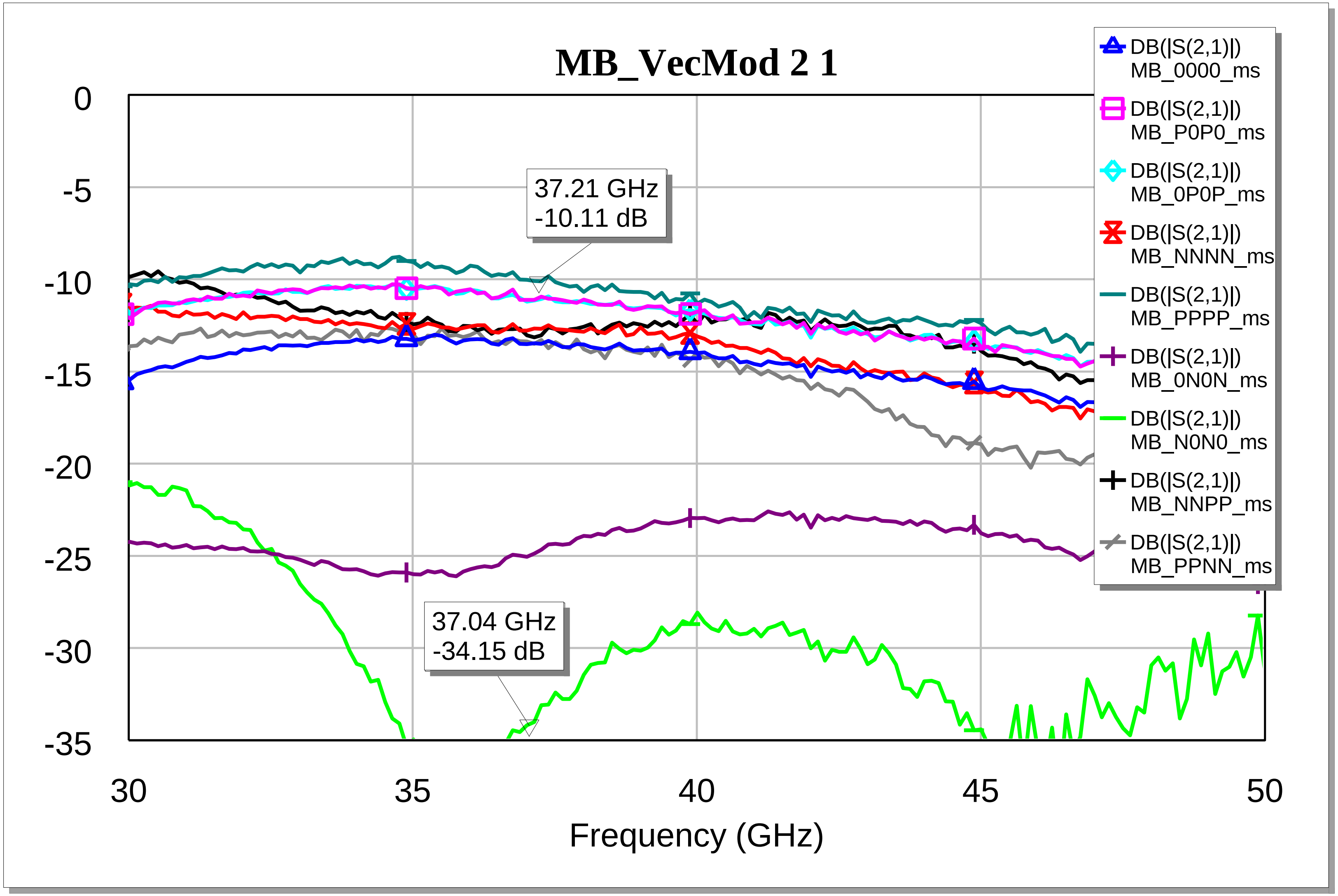
6) Mark Berheimer Vector Modulator

(Plot Showing Return Loss at Various DC Biases)



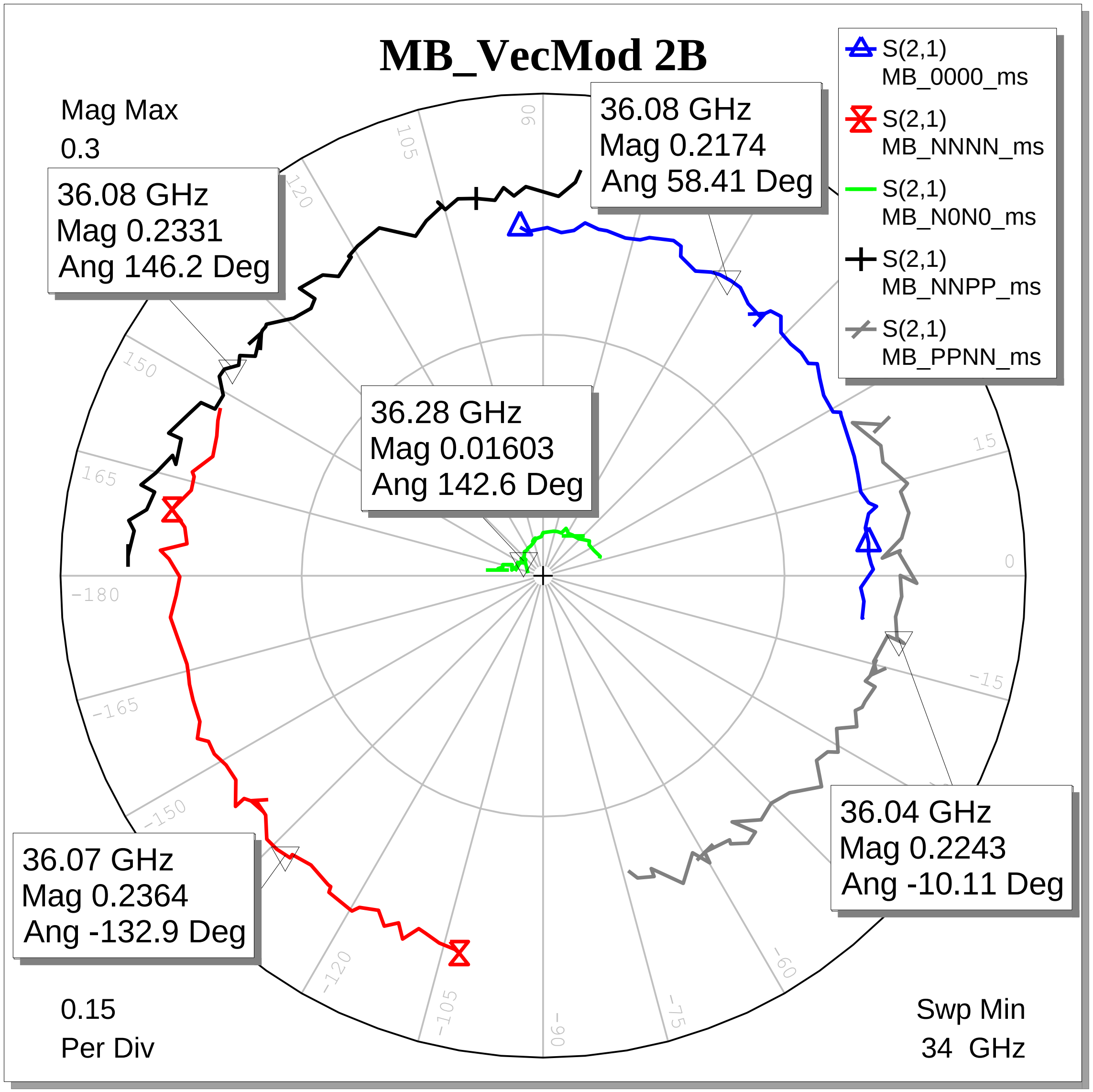
6) Mark Berheimer Vector Modulator

(Plot Showing Range of Insertion Loss S21 at Various DC Biases)



6) Mark Berheimer Vector Modulator

(Plot Showing ~QPSK and min. Points 34-40 GHz)



JHU11MB Re-Measured 7/31/12

Tried for “max" swing using +0.5V(P), -0.5V(N), & 0V

Max. swing seemed to be when "Both" diodes were full ON! So NNNN, PPPP, NNPP, PPNN are DC1,2,3,4

NNNN all -0.5V

PPPP all +0.5V

NNPP

PPNN

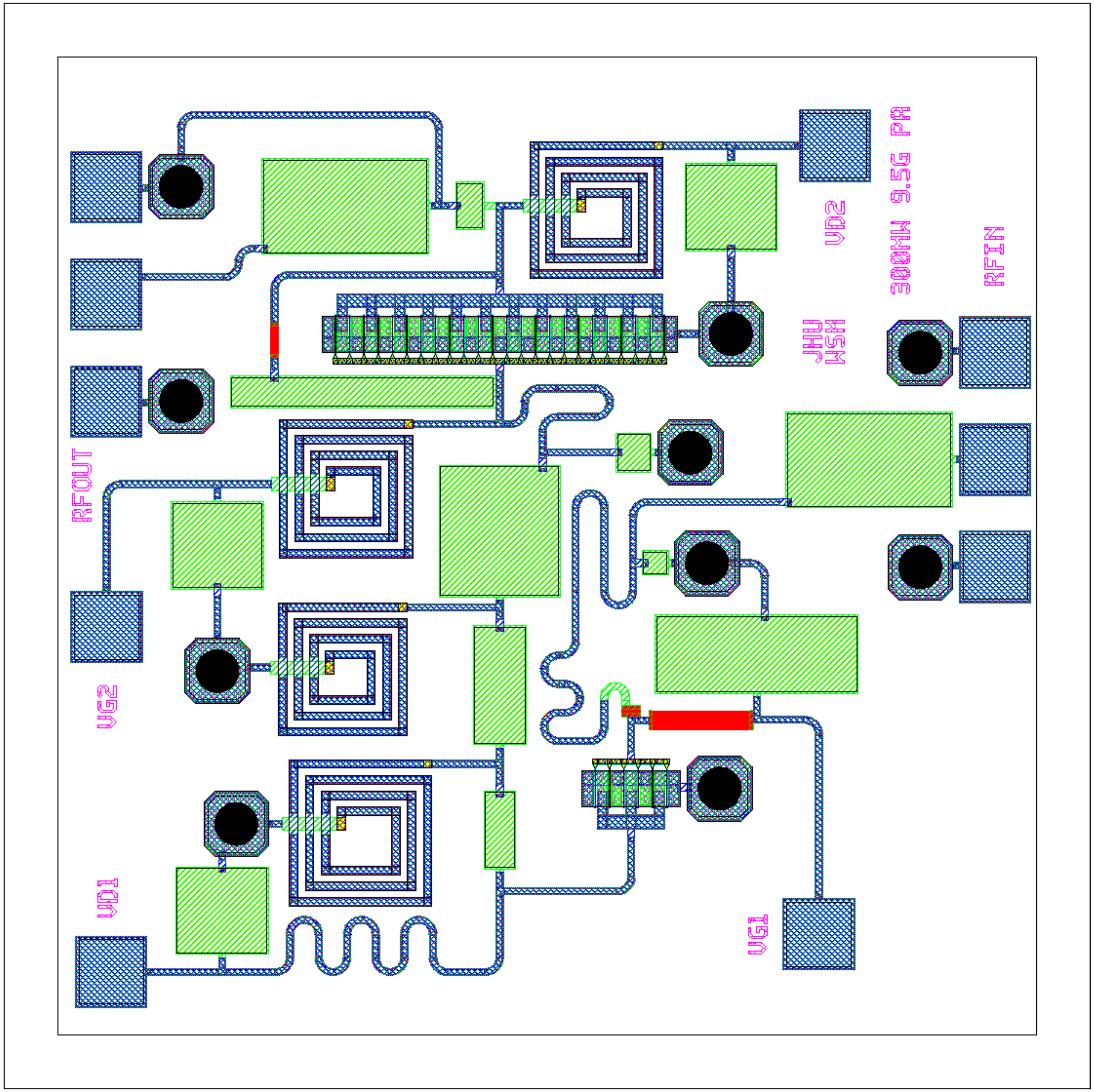
0000 all 0V

0N0N alternating 0, -0.5V

N0N0 alternating -0.5V, 0V

0P0P alternating 0, +0.5V

P0P0 alternating +0.5V, 0V

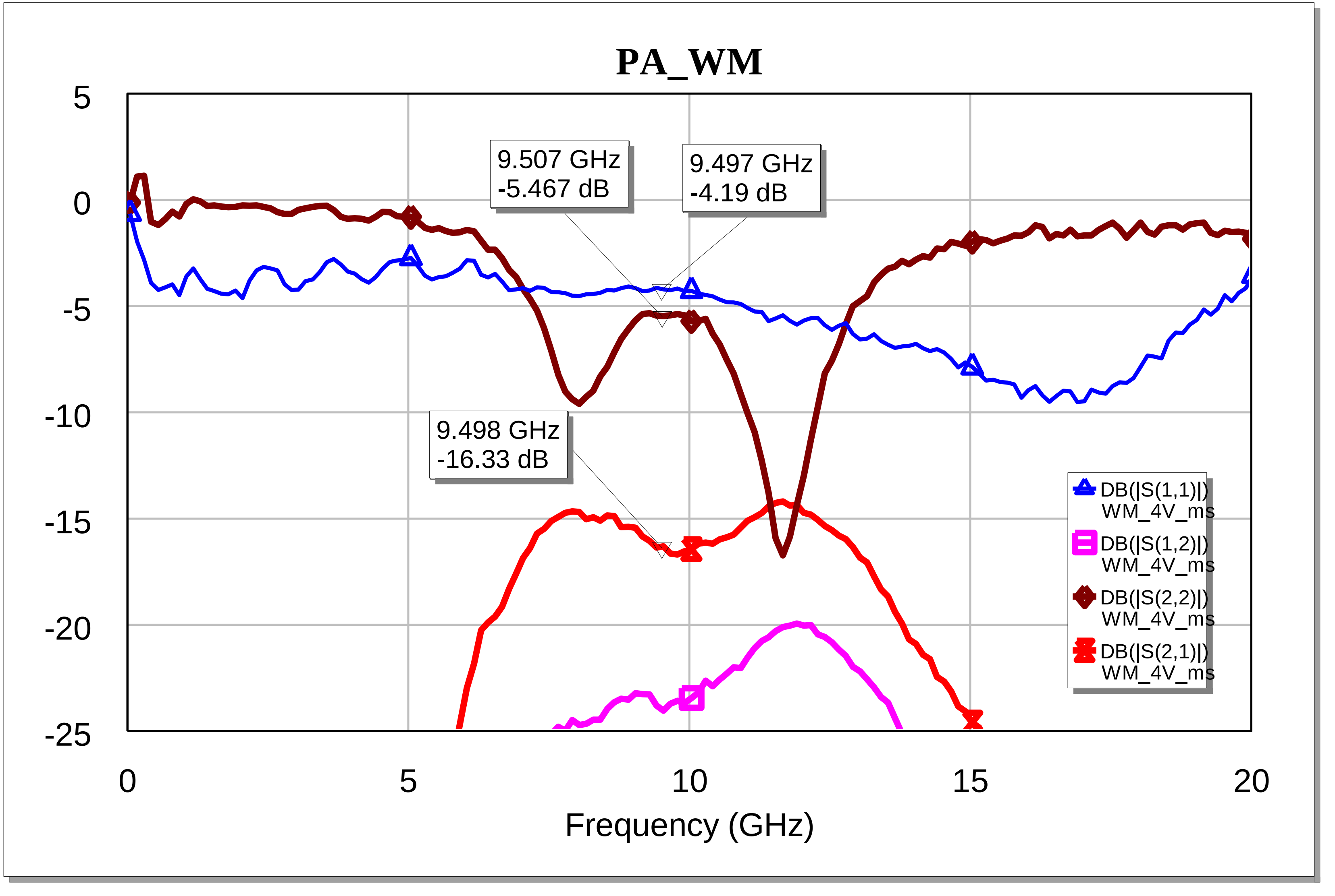


7) Wayne Miller
X Band PA

Another two stage amplifier with 4 DC bias inputs which created difficulty due to low frequency oscillations. Definitely had gain as shown in the following measurements. Achieved > 100 mW of output power at 9.5 GHz.

Attaching 100pF caps to the DC bias inputs and retesting would probably quell the ~30-40MHz oscillations.

7) Wayne Miller X Band PA S-parameters (Low Gain due to LF Oscillations?)



7) Wayne Miller
X Band PA

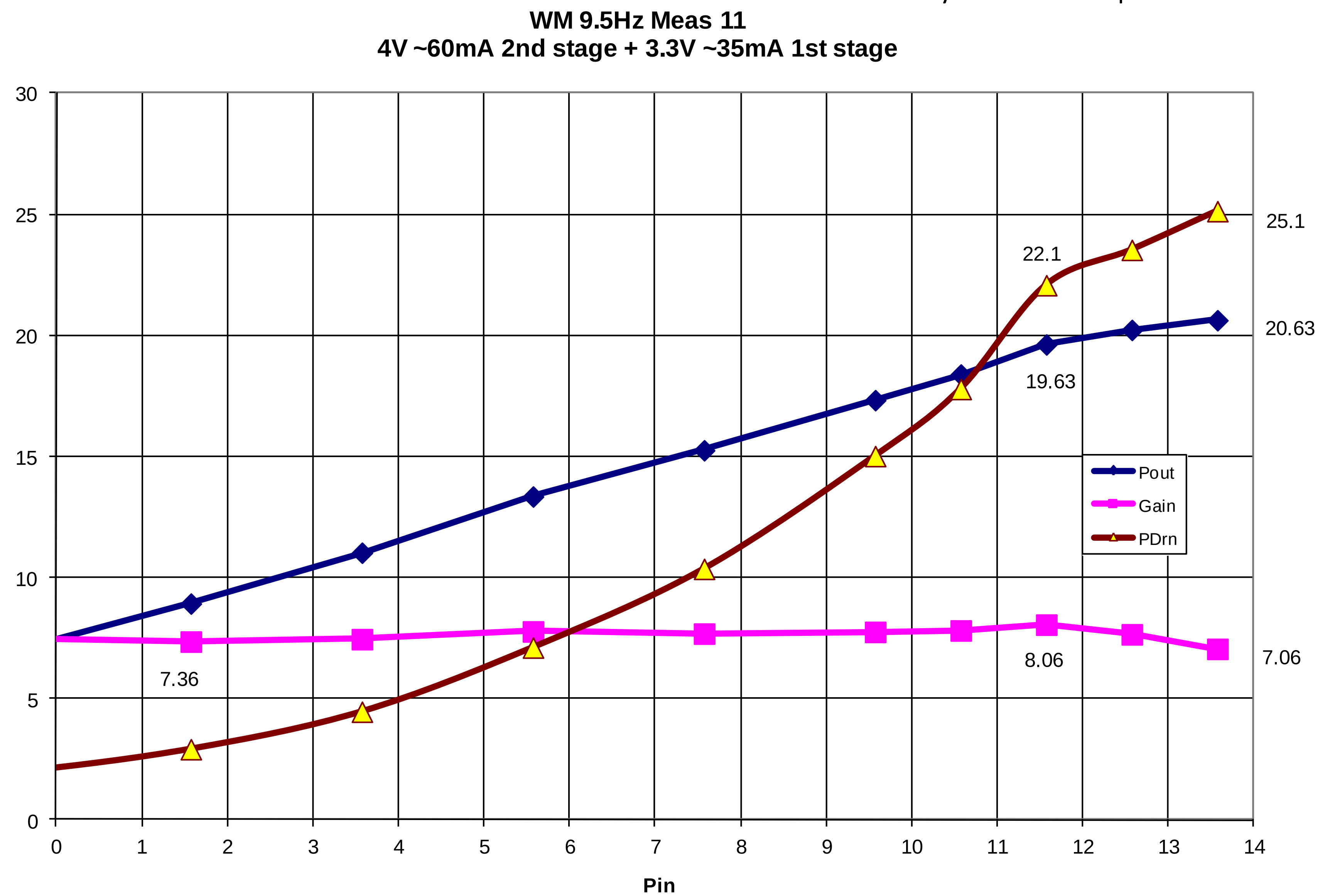
- Difficulty with Low Freq. Oscillations in Test
- Gain seems Low for 2 stage, output match looked OK, input match? Need to record current on 2nd stage for PAE measurement. >100 mW ouput!

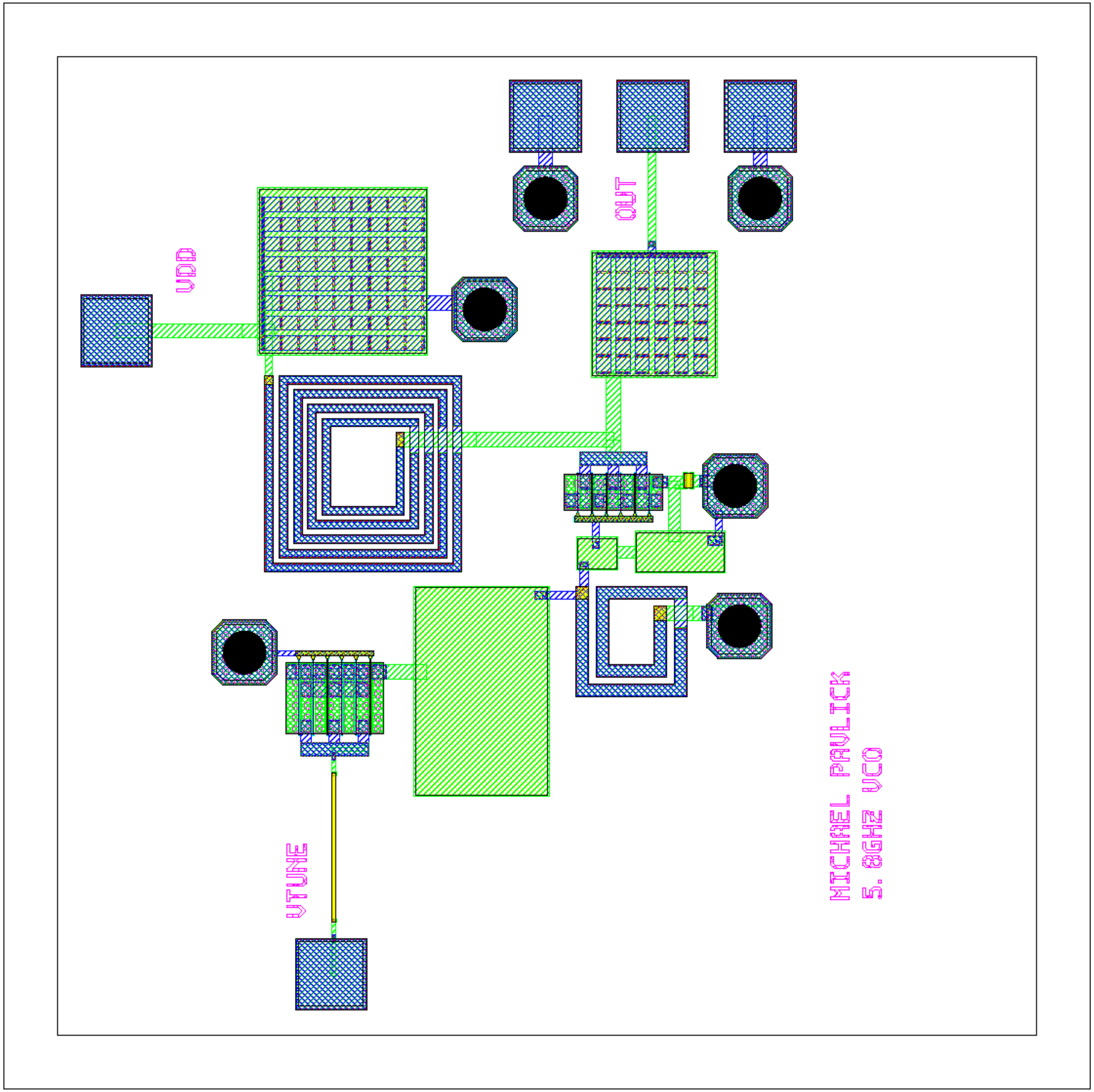
Wayne Miller PA at 9.5 GHz									
Measured at 9.5 GHz 7/26/12				Loss 4.85 dB for thru					
9.5 GHz	Die#1	**28 GHz Fall11 TQP13**				4V ; 60 mA	1st stage: 3.3V ; ~35 mA?		
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC2(mw)**	**Pout(mw)**	**Drn Eff2?**	**PAE2?**
0.0	2.80	-2.43	5.23	7.66	60	240.0	3.33	1.4	1.2
2.0	4.60	-0.43	7.03	7.46	64	256.0	5.05	2.0	1.6
4.0	6.50	1.57	8.93	7.36	67	268.0	7.82	2.9	2.4
6.0	8.60	3.57	11.03	7.46	71	284.0	12.68	4.5	3.7
8.0	10.92	5.57	13.35	7.78	76	304.0	21.63	7.1	5.9
10.0	12.83	7.57	15.26	7.69	81	324.0	33.57	10.4	8.6
12.0	14.90	9.57	17.33	7.76	90	360.0	54.08	15.0	12.5
13.0	15.96	10.57	18.39	7.82	97	388.0	69.02	17.8	14.9
14.0	17.20	11.57	19.63	8.06	104	416.0	91.83	22.1	18.6
15.0	17.80	12.57	20.23	7.66	112	448.0	105.44	23.5	19.5
16.0	18.20	13.57	20.63	**7.06**	115	460.0	115.61	**25.1**	**20.2**

Notes:
corr—corrected
SG—Signal Generator
SA—Spectrum Analyzer

7) Wayne Miller
X Band PA

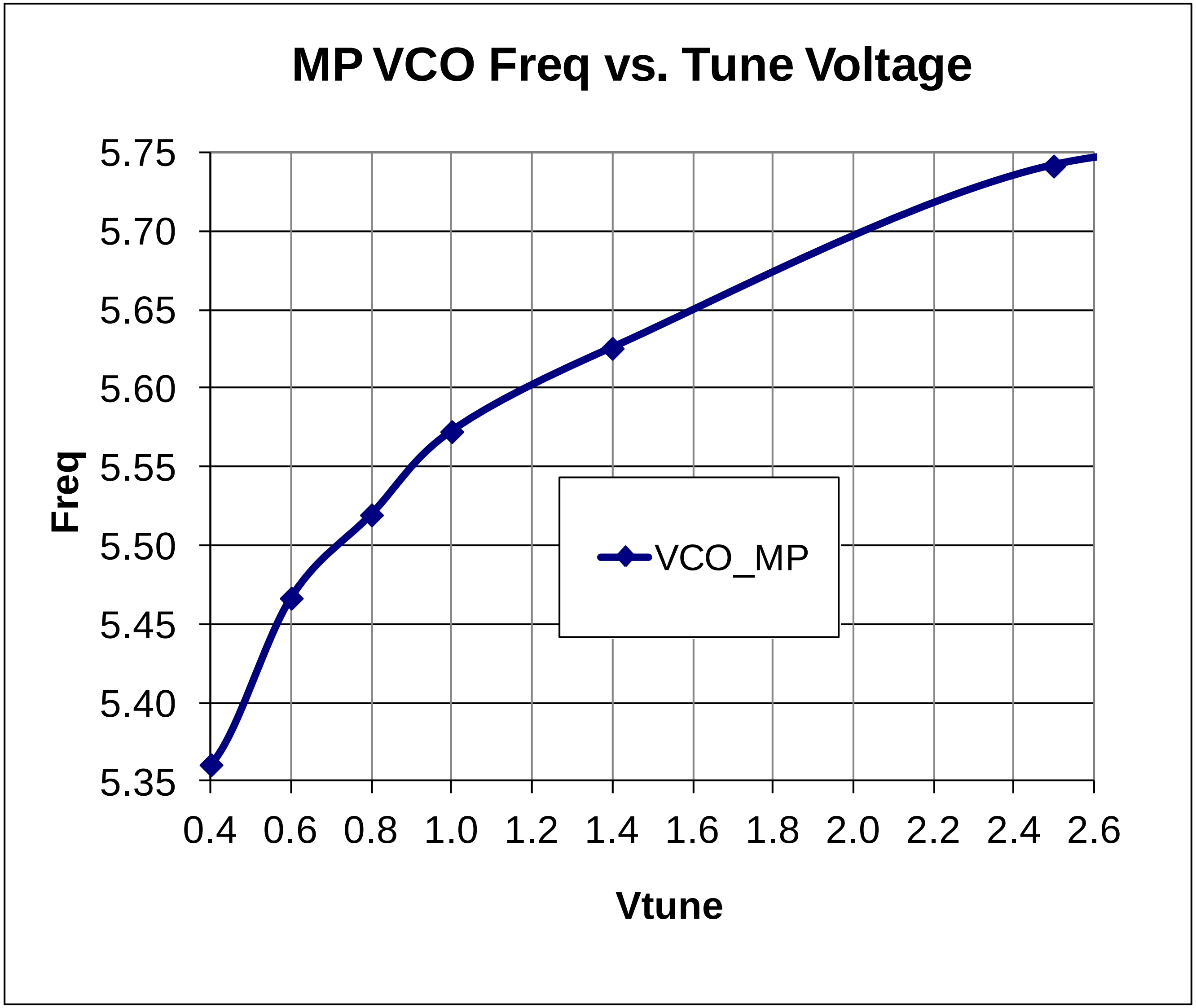
* Difficulty with Low Freq. Oscillations in Test





8) Mike Pavlick
VCO

VCO worked great!
Very close to expected frequency with a decent tuning range.

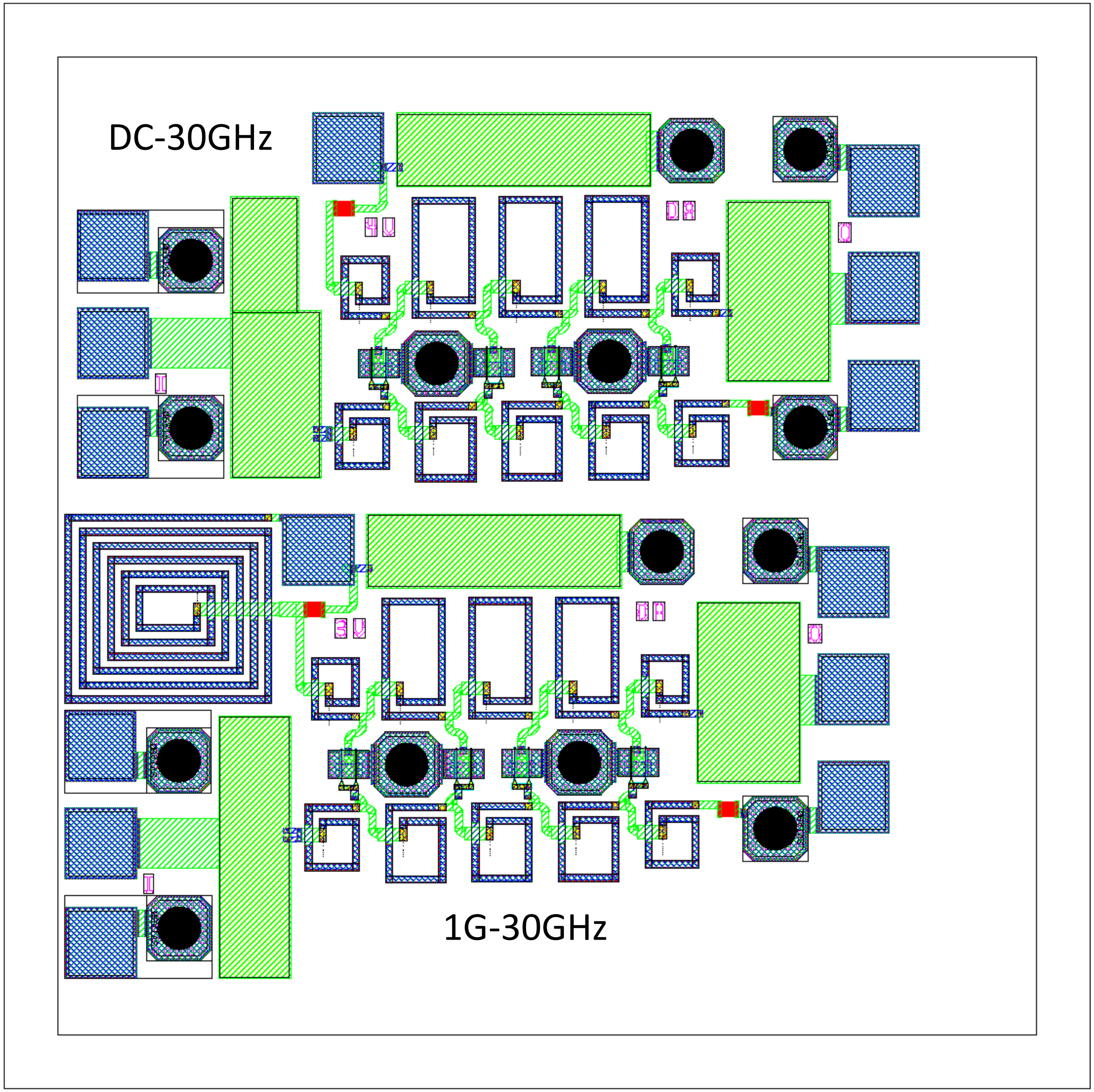


8) Mike Pavlick
VCO

VCO	3.3V at 10mA		Die #2
VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)
0.2	*5.361*	*-18.7*	*-16.9*
0.4	5.361	1.9	3.8
0.6	5.467	1.3	3.1
0.8	5.520	1.7	3.6
1.0	5.573	3.3	5.2
1.4	5.626	2.2	4.0
2.5	5.742	1.2	3.0
3.5	5.746	2.2	4.0

Notes:
ms—measured
corr—corrected

Measured MWO VCO 5.8 GHz Fall 11			
Michael Pavlick			
7/17/2012			
Oscillated at Higher Biases, but not low Bias voltages			



9) JEP

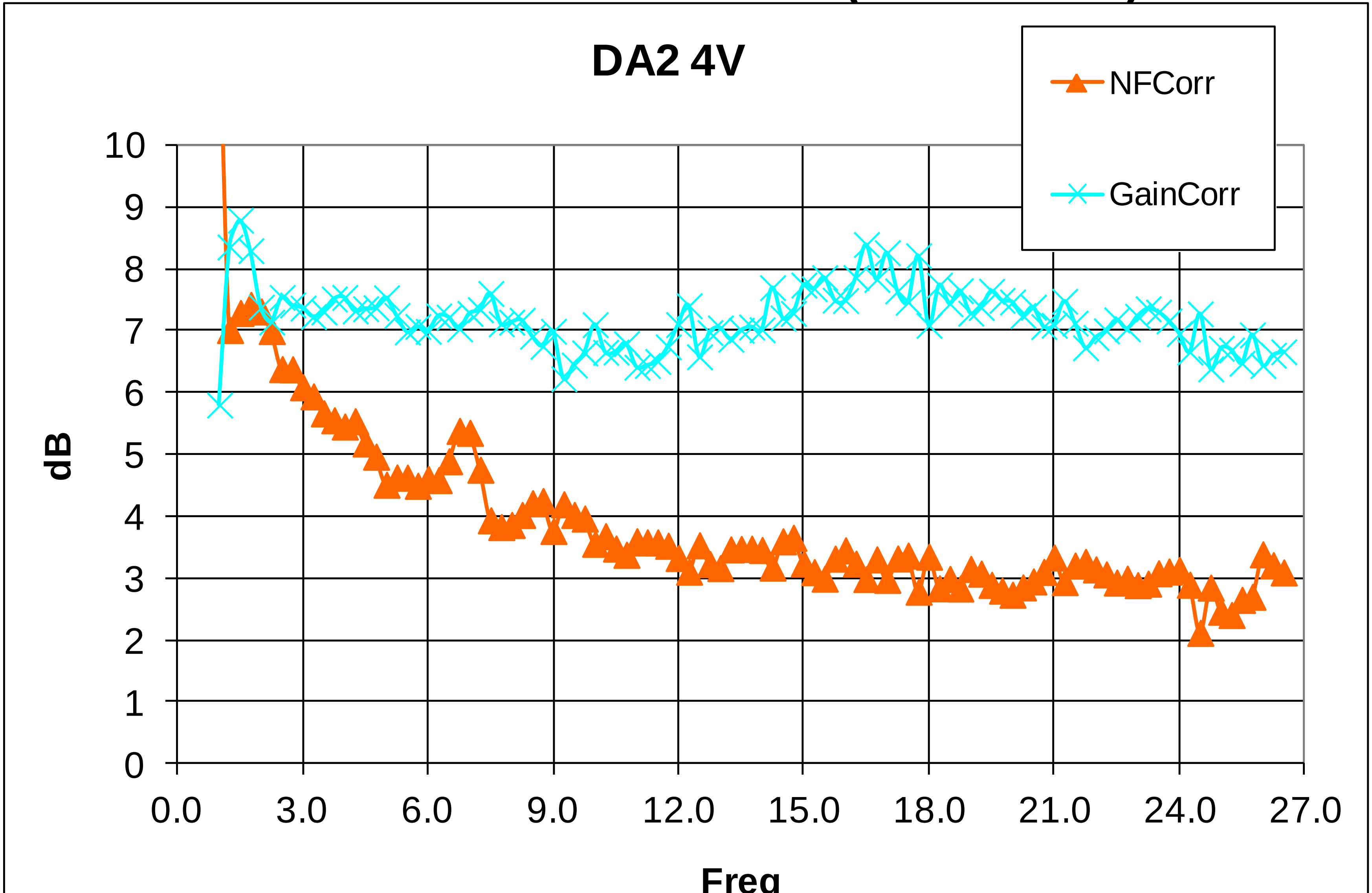
Distributed Amp(s)

4V 30 mA (1 DC, 2RF)

3V 30 mA (1 DC, 2RF)

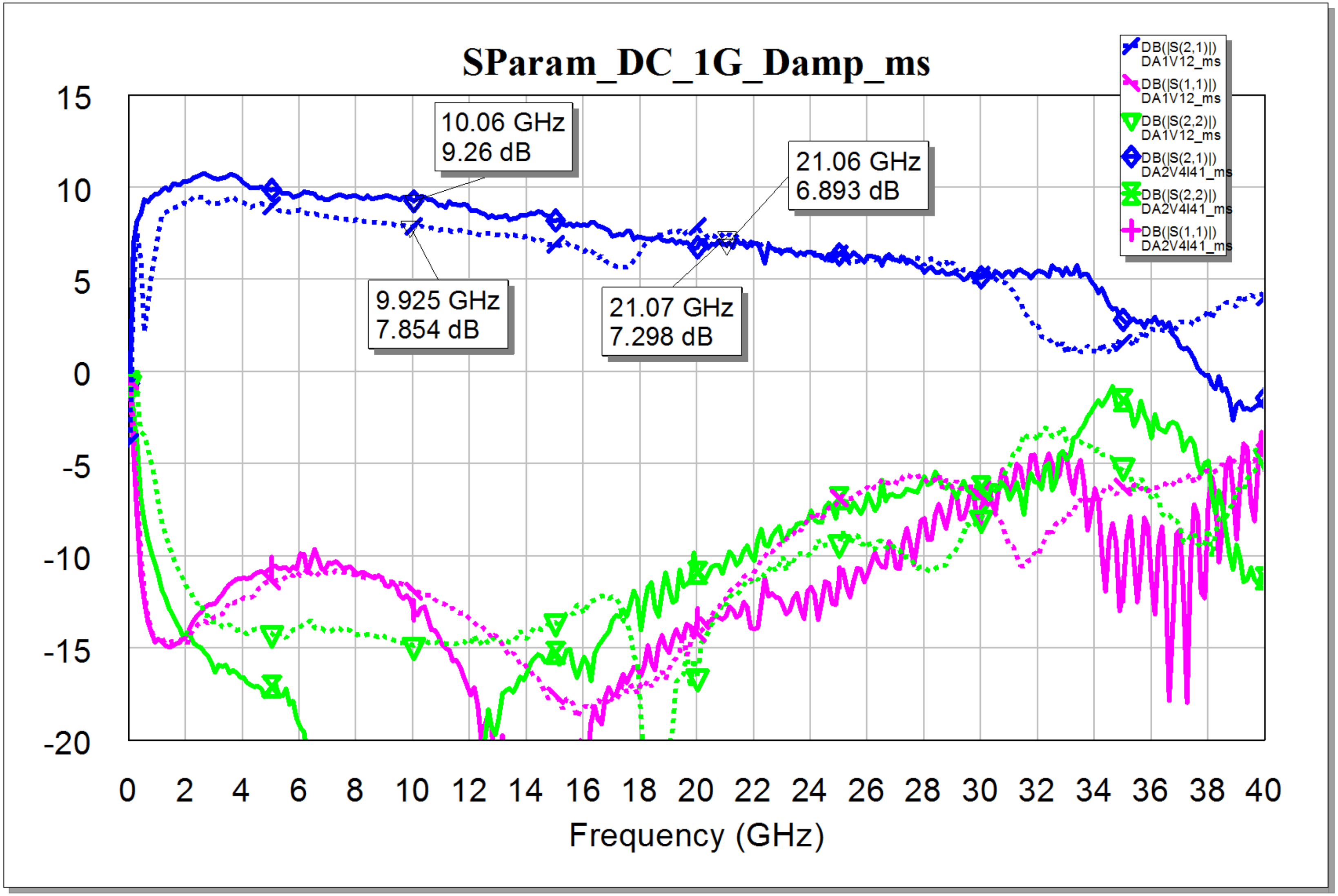
Initial simulations of Distributed Amplifier using Sonnet EM hinted at possible oscillation problems around 30 GHz. Resistors were supposed to have been added to the drains of the PHEMTs to reduce this possible problem, but inadvertently the original design was fabbed instead of the "fixed" version. The result in both similar designs is marginal stability problems around 45 GHz at some DC biases. Not clear if the 'fixed' version would have helped with this higher freq. issue or not.

Measured Results (DC-30G)



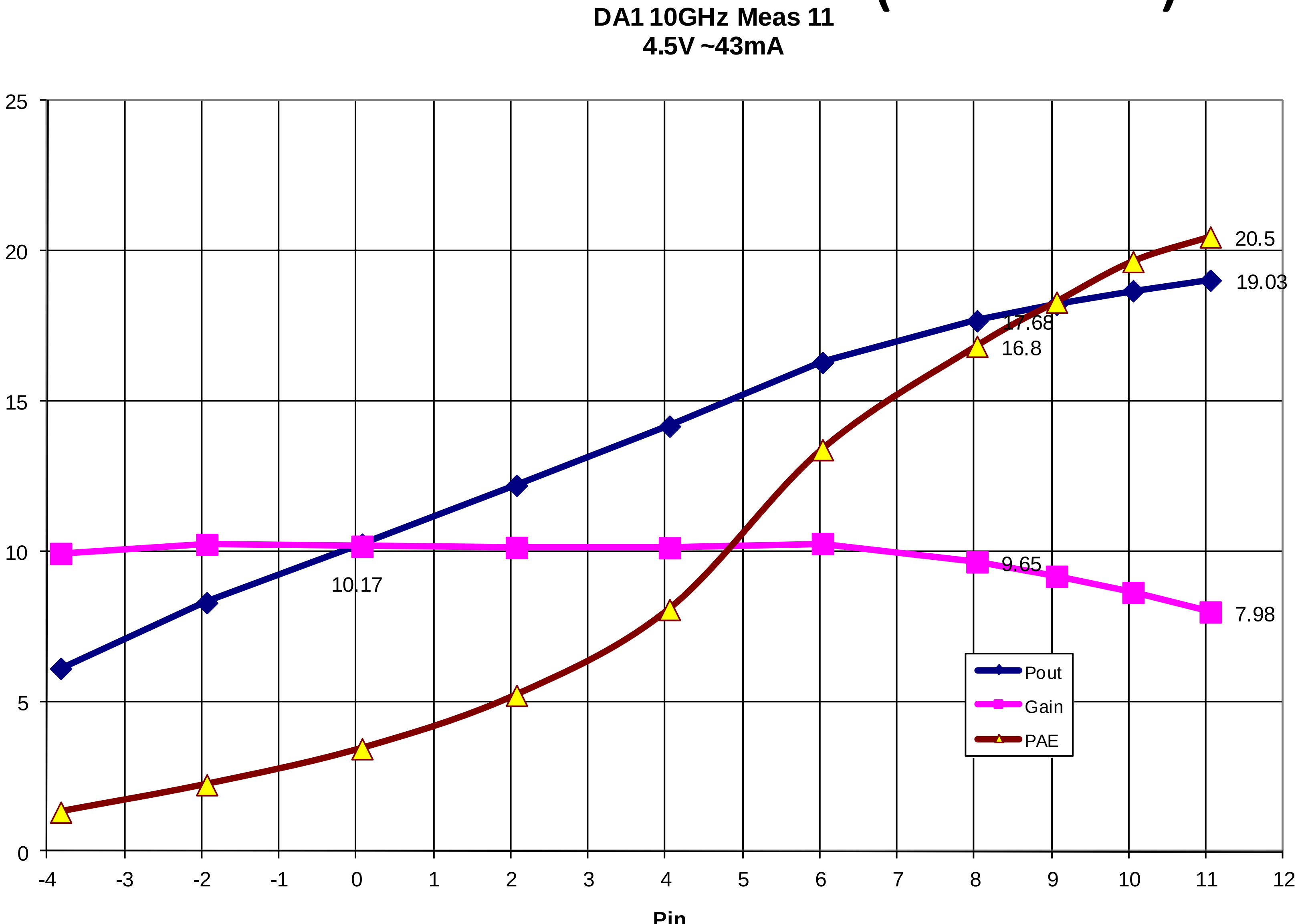
4V Measured Noise Figure; Gain

Measured Results (Both)



1.2V 1G; 4V DC; Similar Designs Except Bias

Measured Results (1G-30G)



No Oscillations at 4.5V DC; 1G-30GHz Dist. Amp at 10 GHz

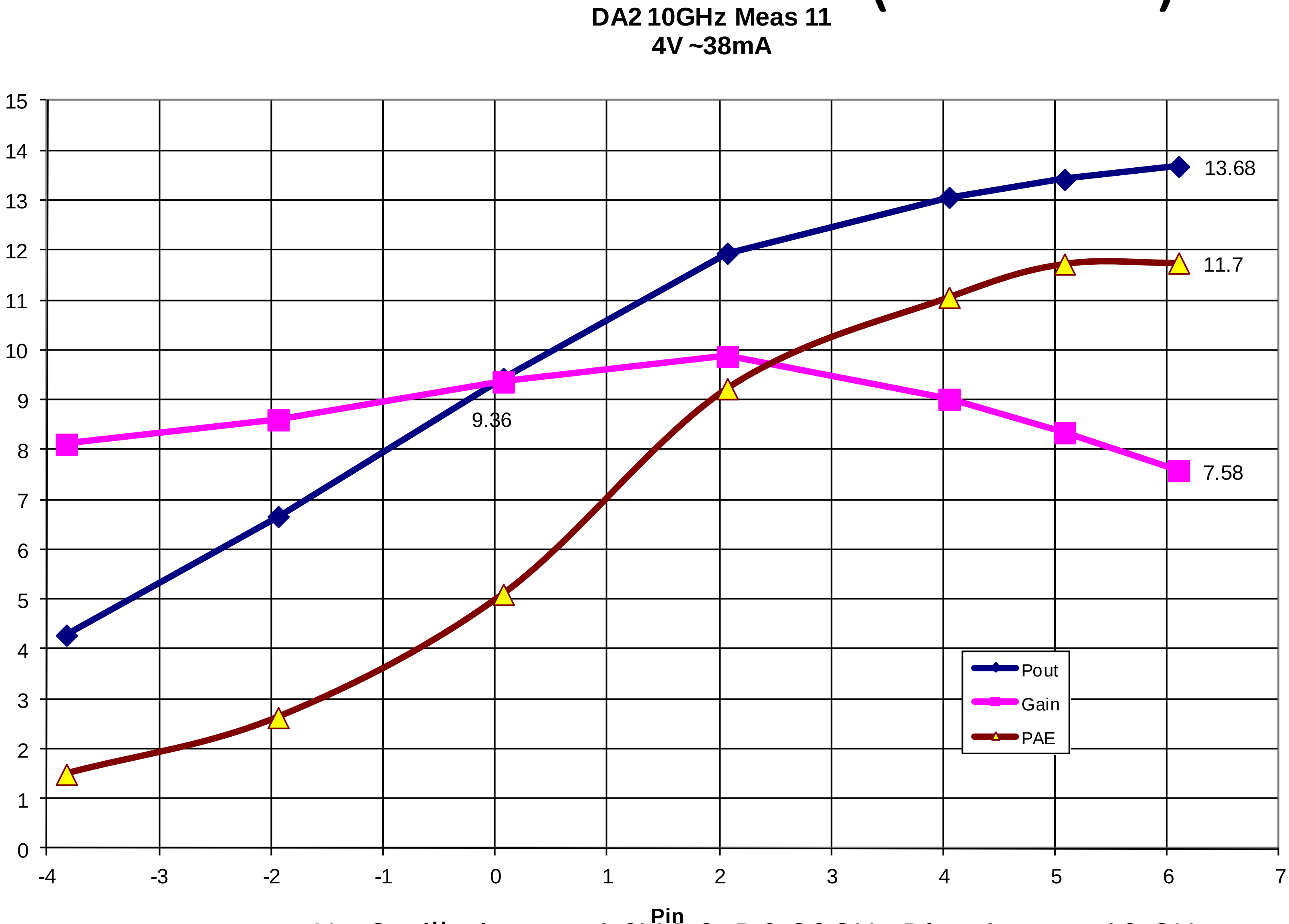
Measured Results (1G-30G)

		Higher DC bias, no oscillations!					
10 GHz	Die#1	**DA1 4.5V 10 GHz Fall11 TQP13**				4.5V ; 61 mA	
Pin(corr)	**Pout(corr)**	**Gain**	**I1(4.5V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-3.83	6.10	9.93	62	279.0	4.07	1.5	1.3
-1.94	8.29	10.23	61	274.5	6.75	2.5	2.2
0.07	10.24	10.17	62	279.0	10.57	3.8	3.4
2.07	12.20	10.13	64	288.0	16.60	5.8	5.2
4.05	14.17	10.12	65	292.5	26.12	8.9	8.1
6.03	16.29	10.26	64	288.0	42.56	14.8	13.4
8.03	17.68	9.65	69	310.5	58.61	18.9	16.8
9.06	18.23	9.17	71	319.5	66.53	20.8	18.3
10.05	18.68	**8.63**	72	324.0	73.79	**22.8**	**19.7**
11.05	19.03	**7.98**	73	328.5	79.98	**24.3**	**20.5**

Notes:
corr—corrected

No Oscillations at 4.5V DC; 1G-30GHz Dist. Amp at 10 GHz

Measured Results (DC-30G)



No Oscillations at 4.0V DC; DC-30GHz Dist. Amp at 10 GHz

Measured Results (DC-30G)

DA1 DC-30GHz 3V Bot		Re-Measured 8/10/12					
DA2 1-30GHz 4V Top		ARL		Loss 3.1 dB for thru			
10 GHz	Die#1	**DA2 4V 10 GHz Fall11 TQP13**				4V ; 43 mA	
Pin(corr)	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-3.83	4.28	8.11	38	152.0	2.68	1.8	1.5
-1.94	6.66	8.60	38	152.0	4.63	3.0	2.6
0.07	9.43	9.36	38	152.0	8.77	5.8	5.1
2.07	11.94	9.87	38	152.0	15.63	10.3	9.2
4.05	13.06	9.01	40	160.0	20.23	12.6	11.1
5.08	13.42	8.34	40	160.0	21.98	13.7	11.7
6.10	13.68	7.58	41	164.0	23.33	14.2	11.7

Notes:
corr—corrected

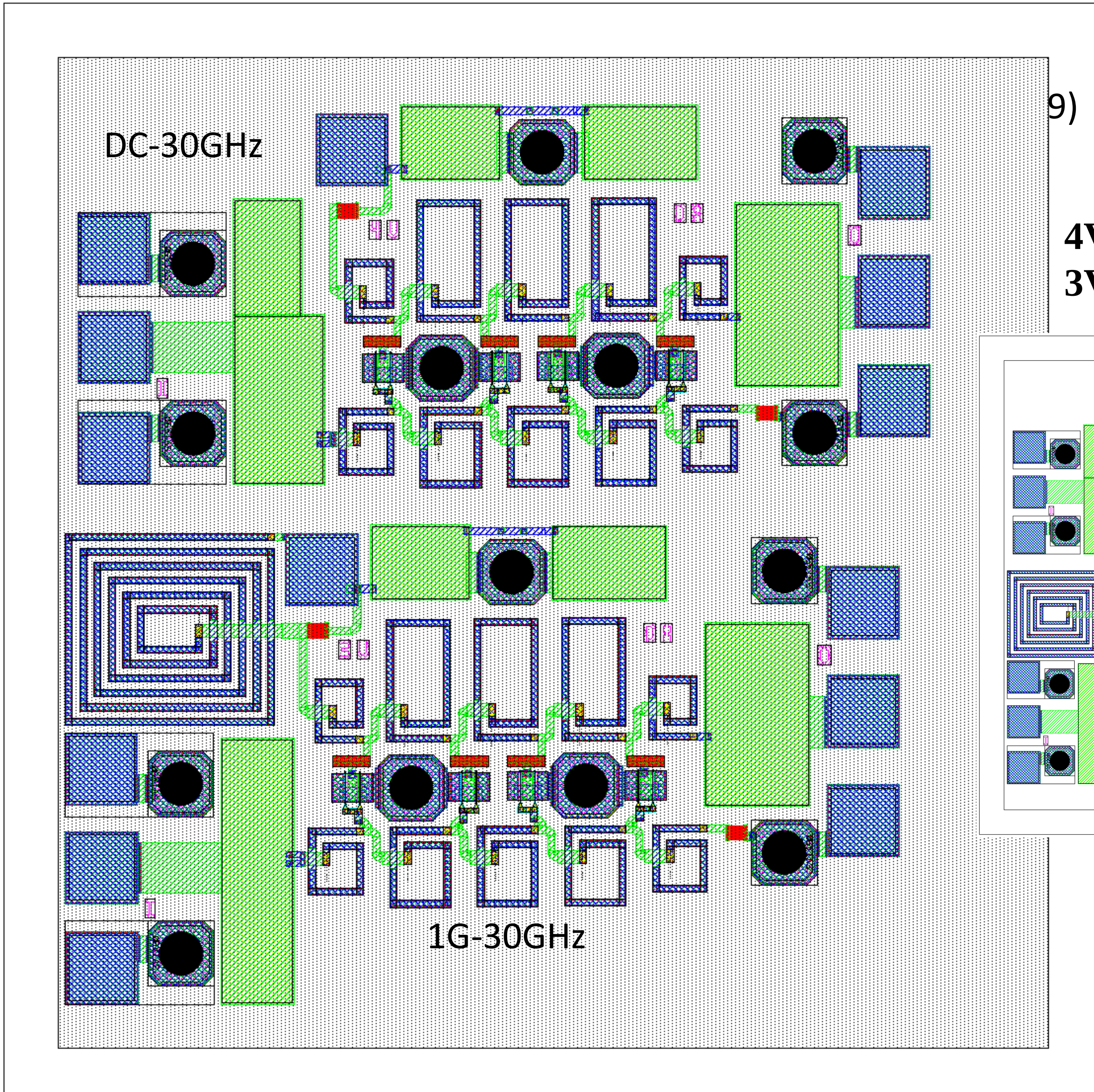
No Oscillations at 4.0V DC; DC-30GHz Dist. Amp at 10 GHz

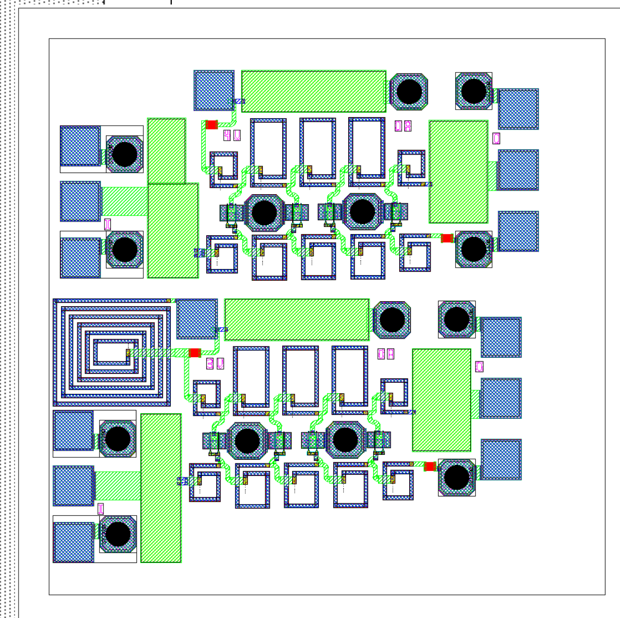
9) JEP *Should have fabbed this one!

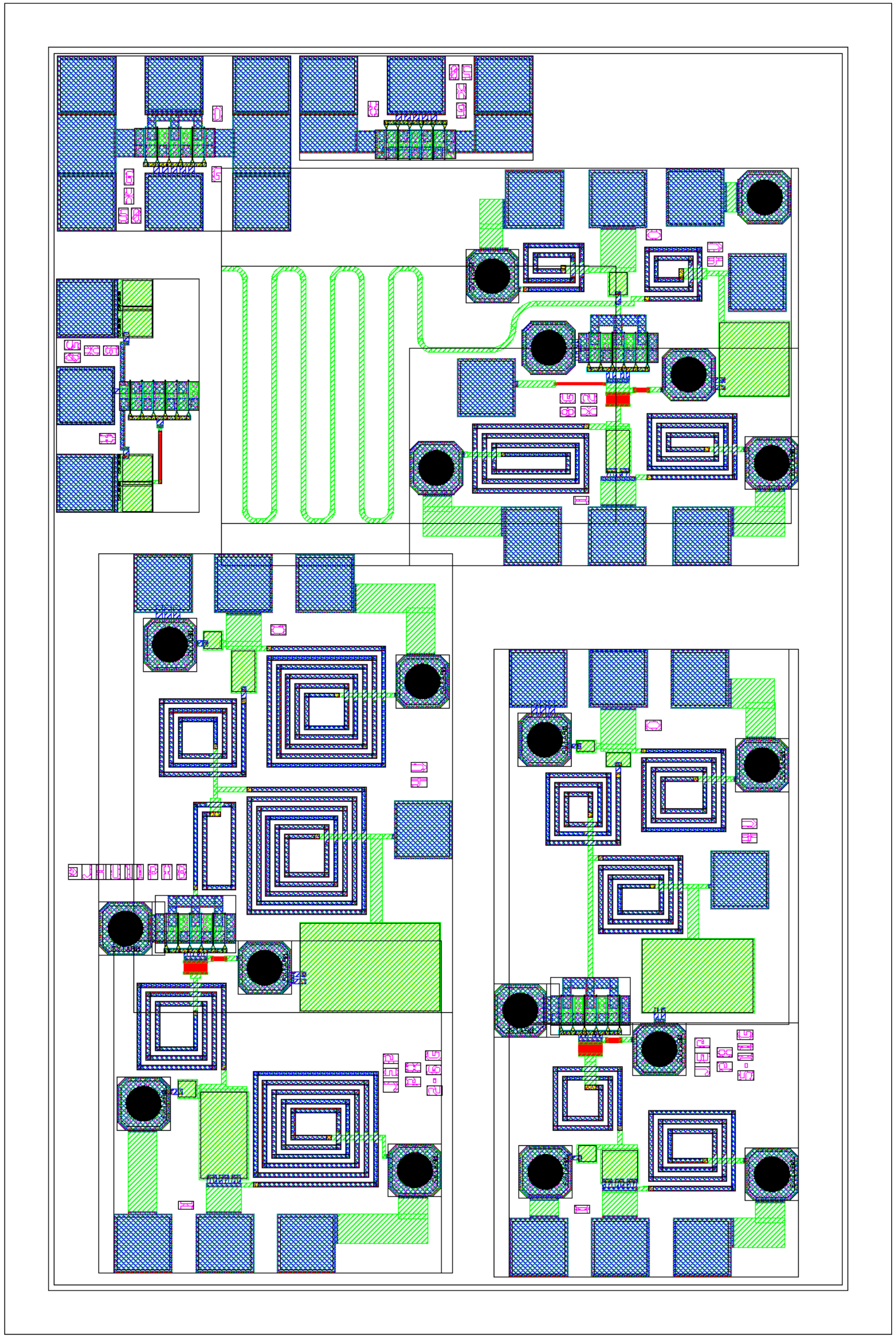
Distributed Amp(s) V2

4V 30 mA (1 DC, 2RF)

3V 30 mA (1 DC, 2RF)







10) JHU11PAB -- JEP

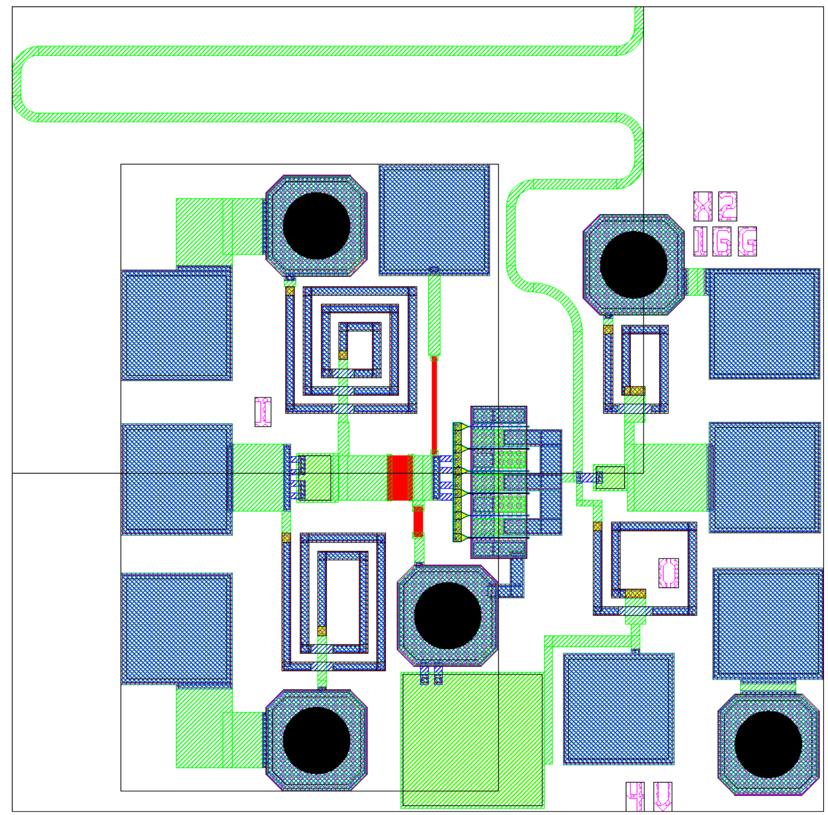
BB 2-6, 5-11 GHz PA

X2 8 GHz

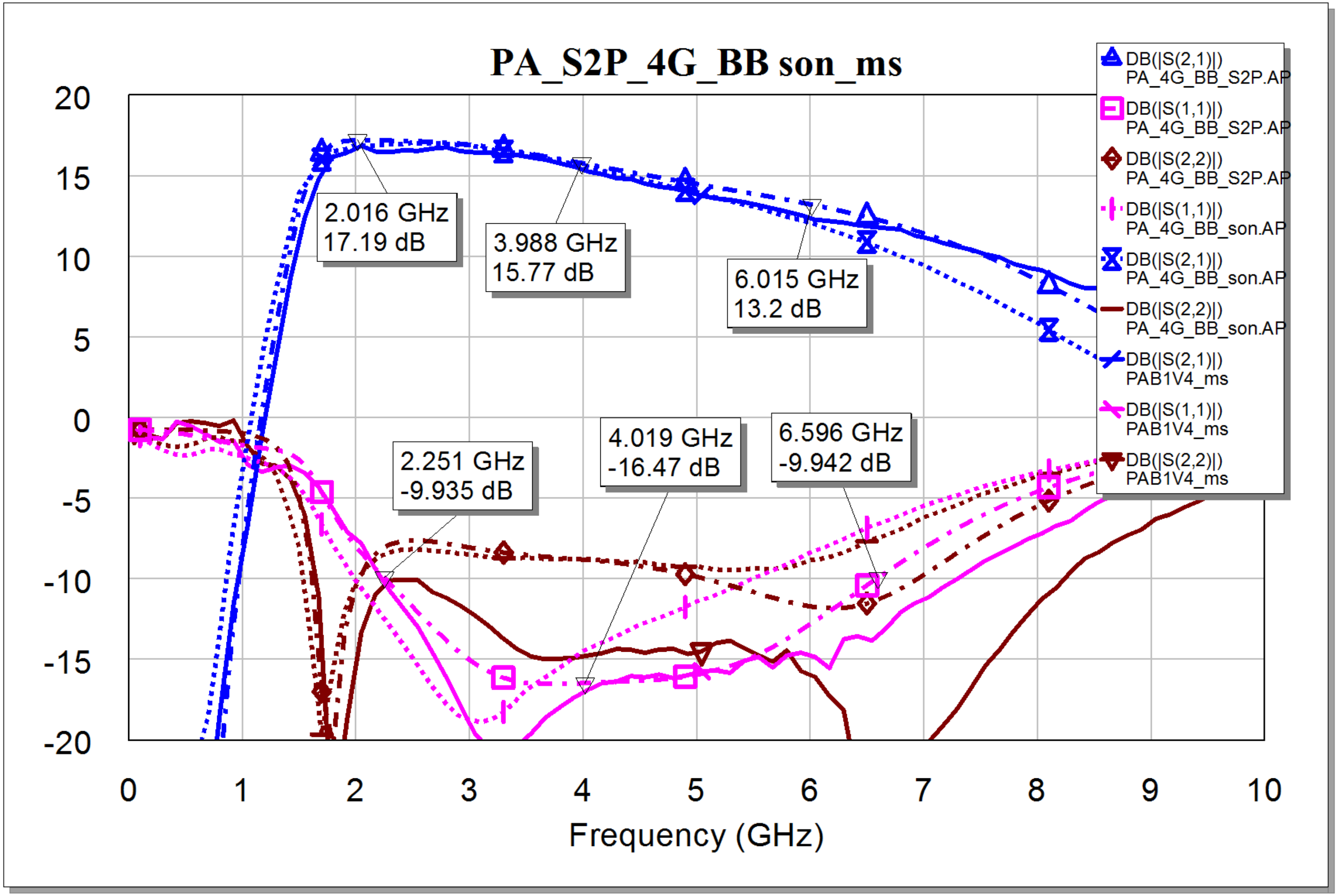
4V 35-55 mA (1 DC, 2RF)

4V 35-55 mA (1 DC, 2RF)

4V 35-55 mA (1 DC, 2RF)

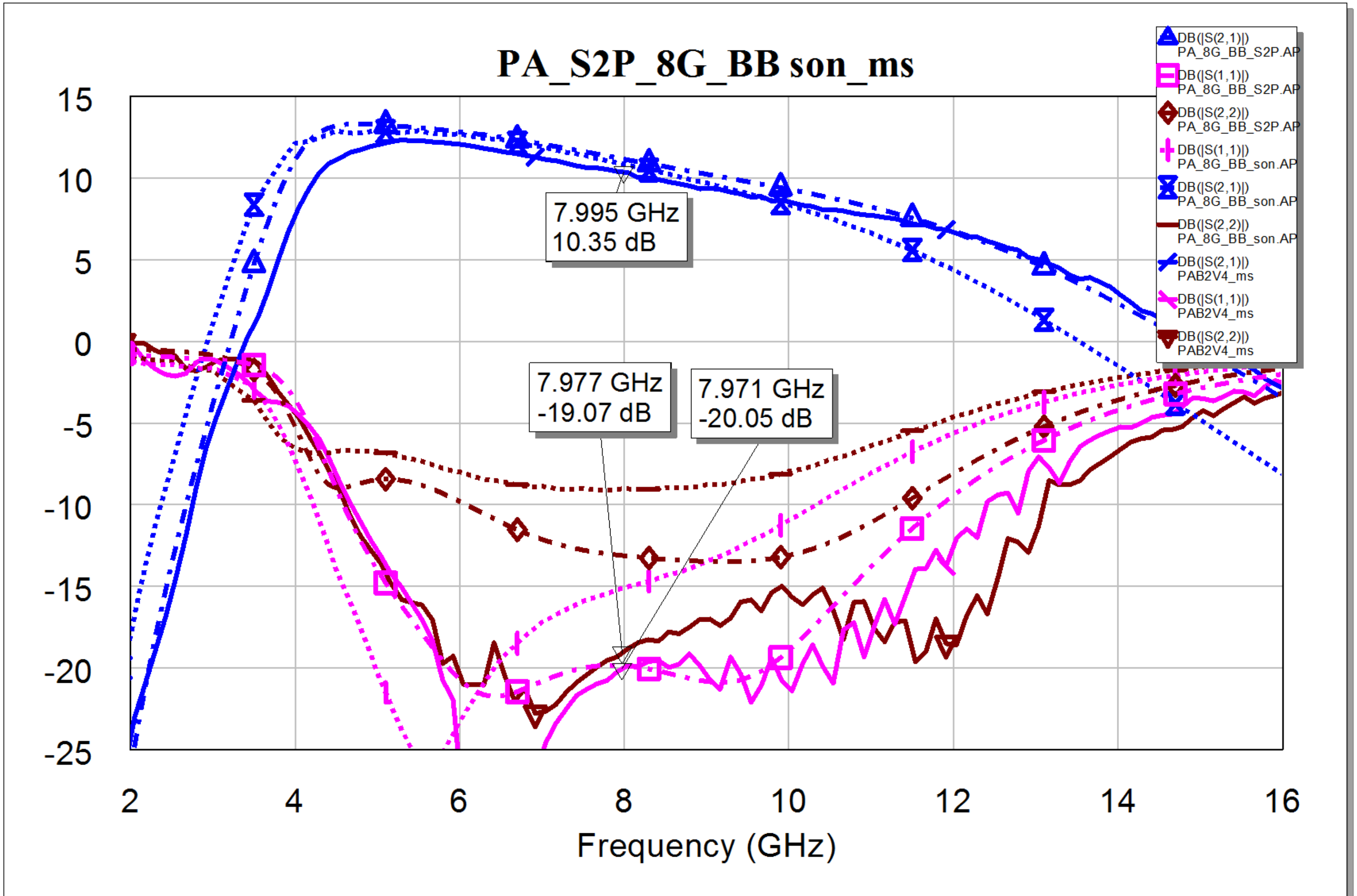


Broadband PA 2-6GHz—Measured vs. Sonnet, AWR



Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

Broadband PA 5-11GHz—Measured vs. Sonnet, AWR



Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

Frequency Doubler 8 to 16 GHz

Measured 7.5, 8, 8.5 Ghz Input

7/11/2012			4.6 dB loss thru			
Doubler 8G		**4V at 47mA, vg=0v**		**Die #1**		
SG	**Pin(corr)**	**Pout8G(m**	**Pout16G(ms)**	**Pout(corr)**	**Pout2X(corr)**	**Cnvloss**
6.0	**3.7**	7.2	-14.0	**9.5**	**-10.5**	14.2
8.0	**5.7**	9.0	-10.1	**11.3**	**-6.6**	12.3
10.0	**7.7**	10.6	-6.2	**12.9**	**-2.7**	10.4
12.0	**9.7**	11.9	-3.3	**14.2**	**0.3**	9.5
14.0	**11.7**	12.9	-1.0	**15.2**	**2.5**	9.2
16.0	**13.7**	13.6	1.2	**15.9**	**4.7**	9.0

Doubler 8G		**4V at 40mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout8G(m**	**Pout16G(ms**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	6.5	-12.7	**8.8**	**-9.2**	12.9
8.0	**5.7**	8.3	-8.4	**10.6**	**-4.9**	10.6
10.0	**7.7**	10.0	-4.4	**12.3**	**-0.9**	8.6
12.0	**9.7**	11.5	-1.8	**13.8**	**1.7**	8.0
14.0	**11.7**	12.7	0.0	**15.0**	**3.5**	8.2
16.0	**13.7**	13.5	1.7	**15.8**	**5.2**	8.5

Notes:

ms--measured

corr—corrected

Pout—Fundamental

Pout2X—2^{nd} Harmonic

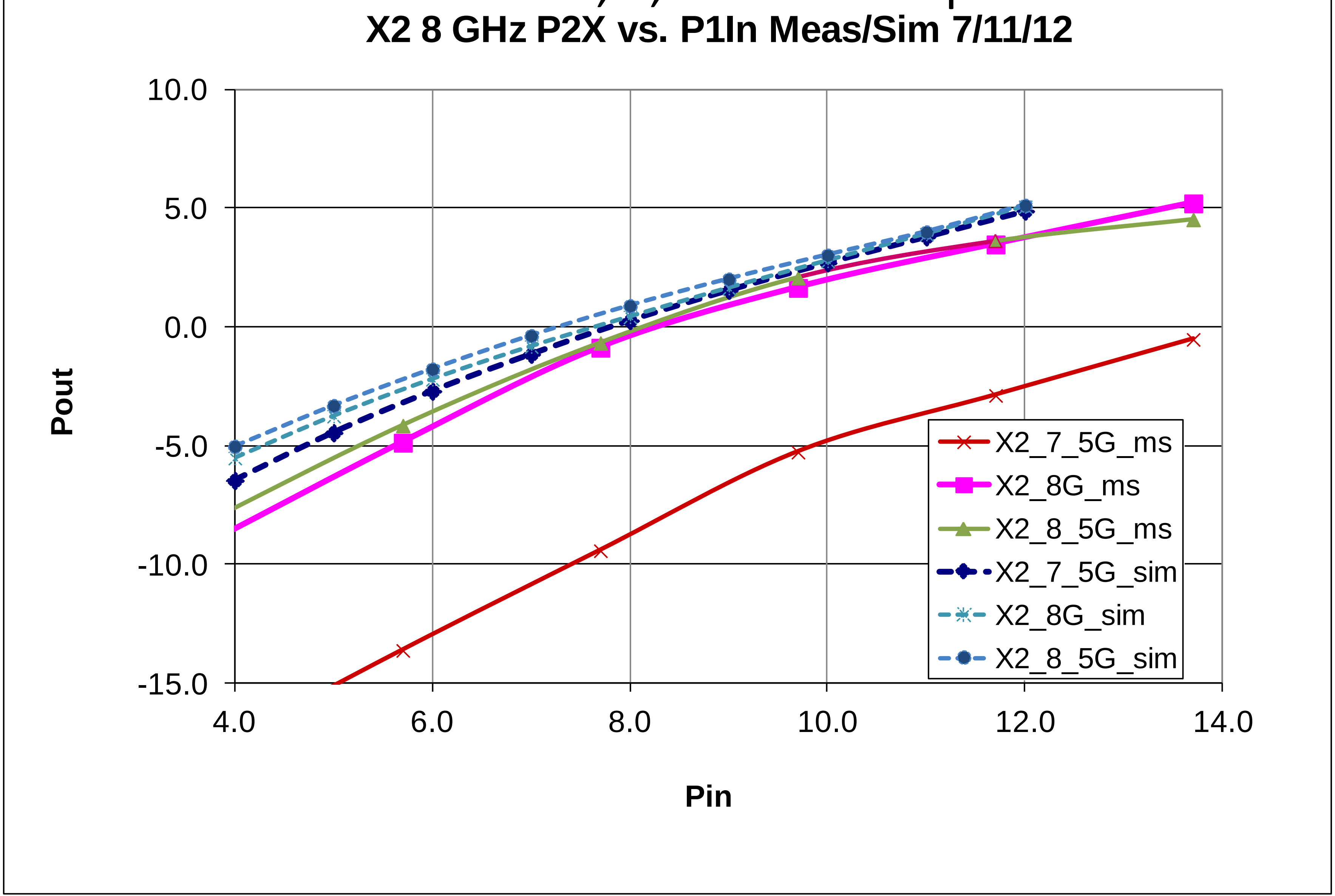
Cnvloss—2^{nd} Harm Conversion Loss

	8.5 GHz					
Doubler 8G		**4V at 40mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout8G(m**	**Pout16G(r**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	7.5	-11.8	**9.8**	**-8.3**	12.0
8.0	**5.7**	9.2	-7.6	**11.5**	**-4.1**	9.8
10.0	**7.7**	10.8	-4.2	**13.1**	**-0.7**	8.4
12.0	**9.7**	12.4	-1.4	**14.7**	**2.1**	7.6
14.0	**11.7**	13.7	0.1	**16.0**	**3.6**	8.1
16.0	**13.7**	14.7	1.1	**17.0**	**4.6**	9.2

	7.5 GHz					
Doubler 8G		**4V at 40mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout8G(m**	**Pout16G(r**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	4.9	-21.5	**7.2**	**-18.0**	21.7
8.0	**5.7**	6.9	-17.1	**9.2**	**-13.6**	19.3
10.0	**7.7**	9.0	-12.9	**11.3**	**-9.4**	17.1
12.0	**9.7**	10.9	-8.8	**13.2**	**-5.3**	15.0
14.0	**11.7**	12.4	-6.4	**14.7**	**-2.9**	14.6
16.0	**13.7**	13.4	-4.0	**15.7**	**-0.5**	14.2

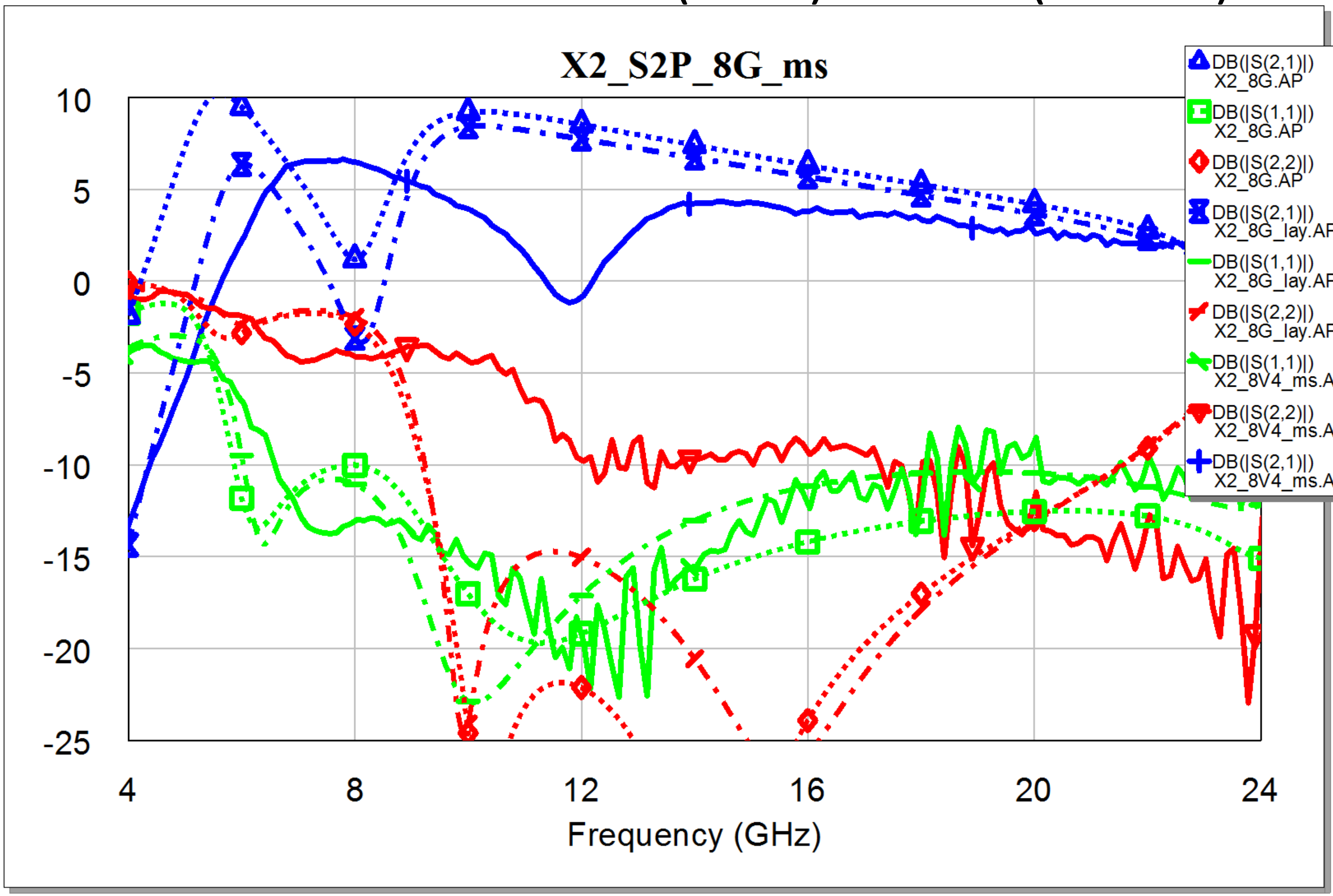
Frequency Doubler 8 to 16 GHz

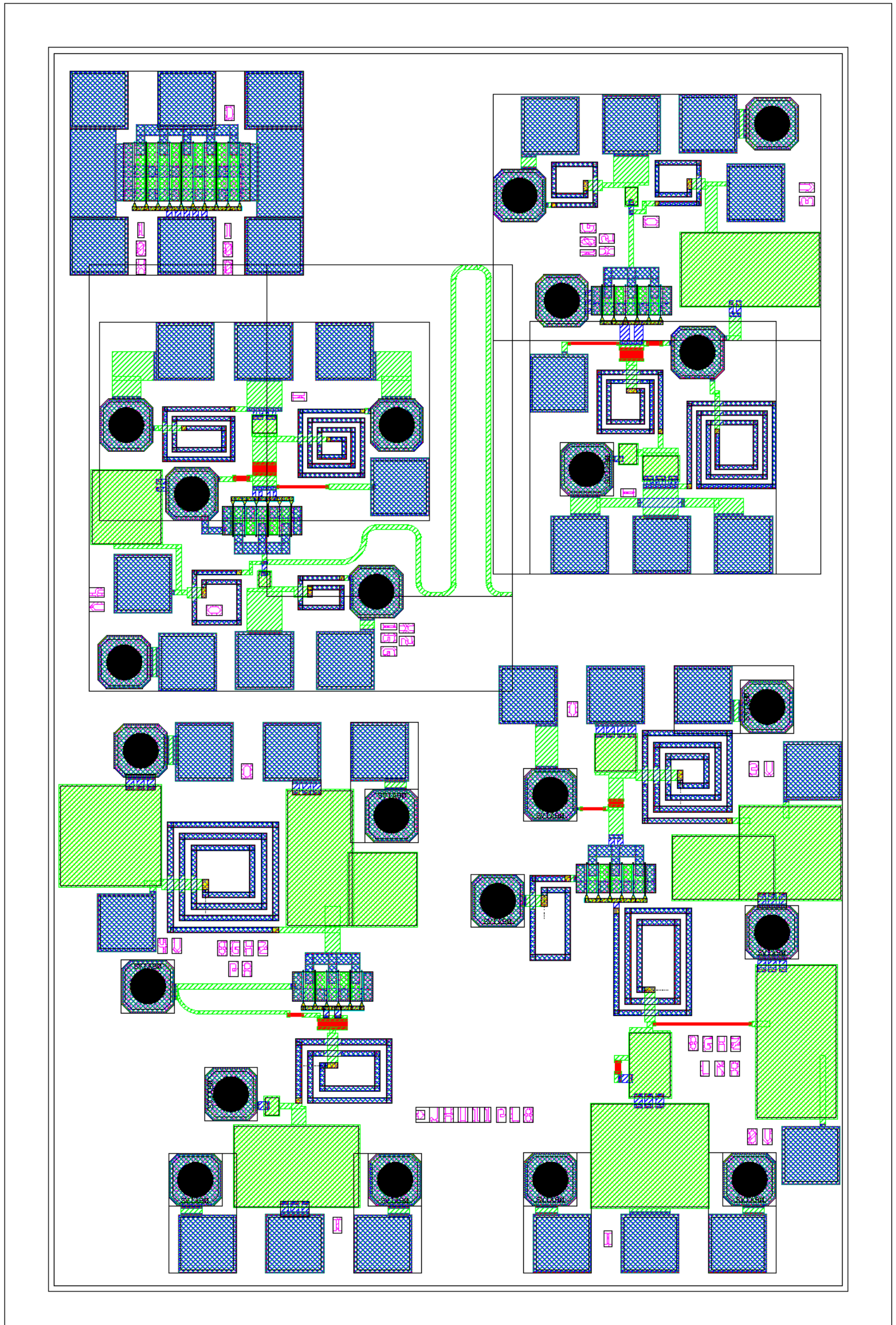
Measured 7.5, 8, & 8.5 Ghz Input



Frequency Doubler 8 to 16 GHz

Measured S-Parameters (solid) vs. Sim (dotted)





11) JHU11PL8 -- JEP

8 GHz PA, LNA

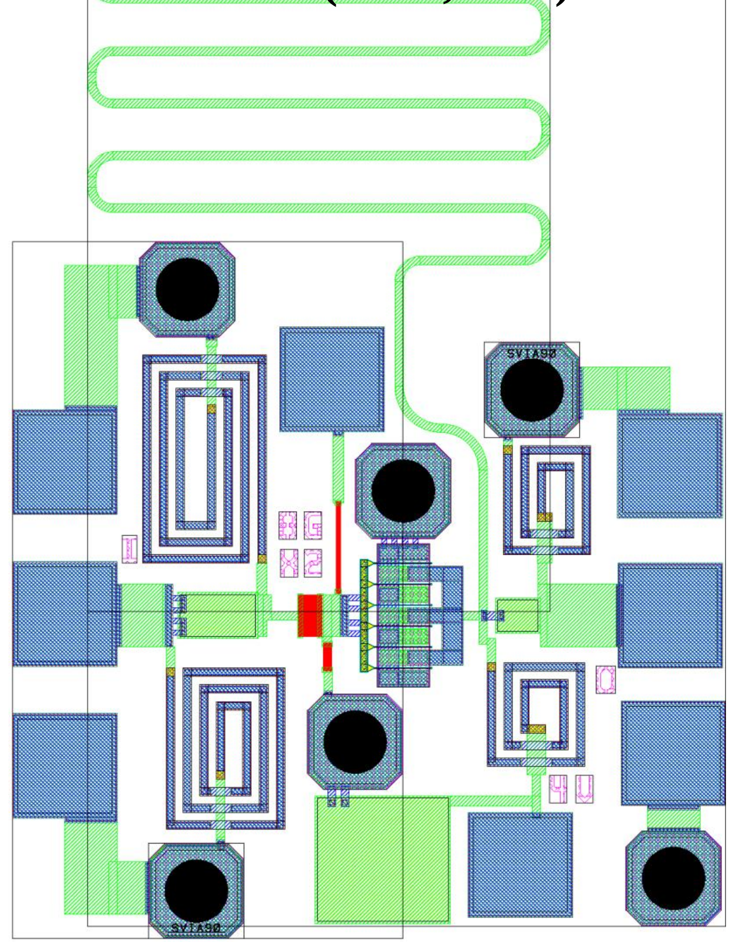
X2 10, 16 GHz

4V 35 mA (1 DC, 2RF)

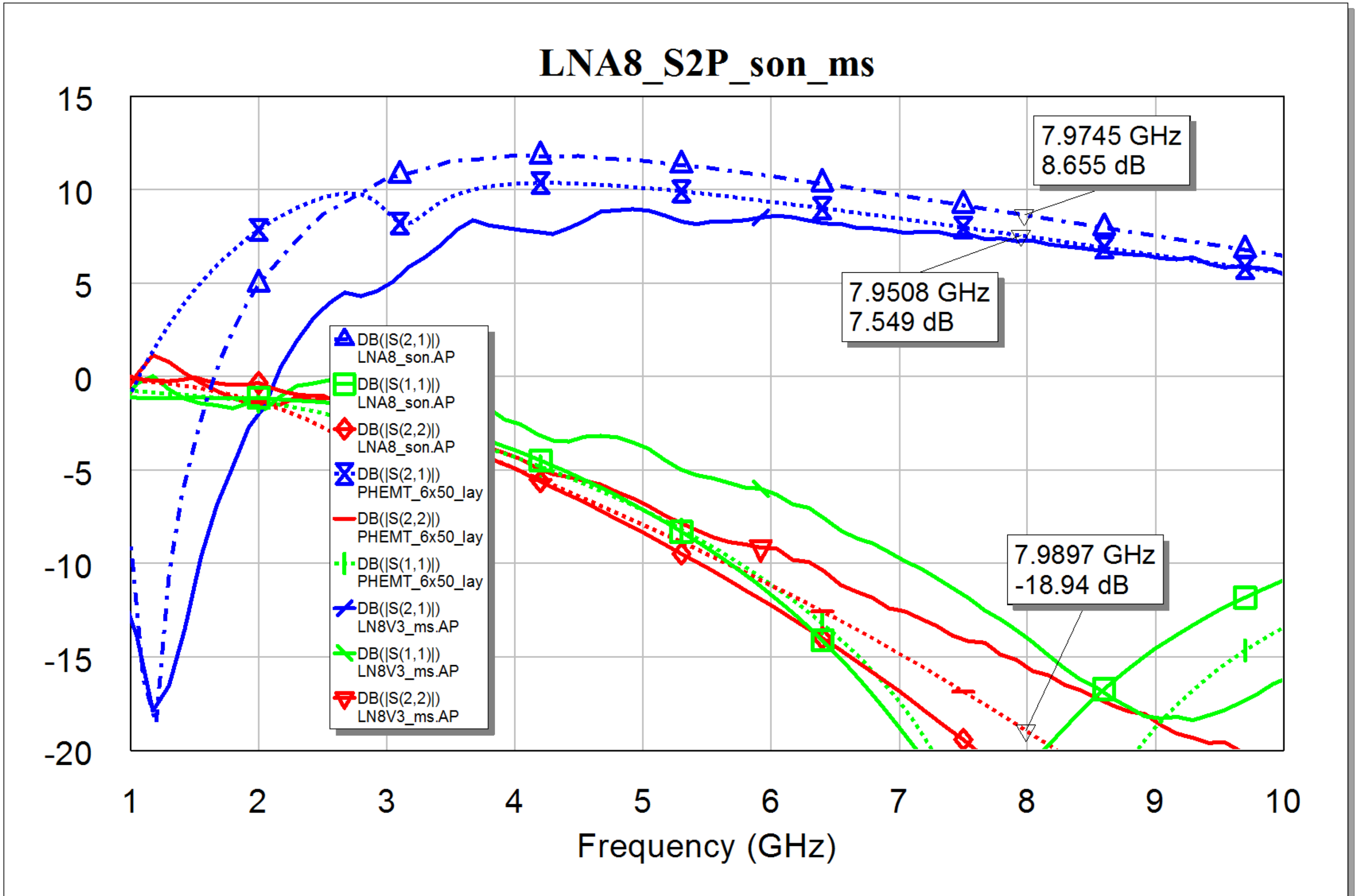
3V 27 mA (1 DC, 2RF)

4V 35-55 mA (1 DC, 2RF)

4V 35-55 mA (1 DC, 2RF)

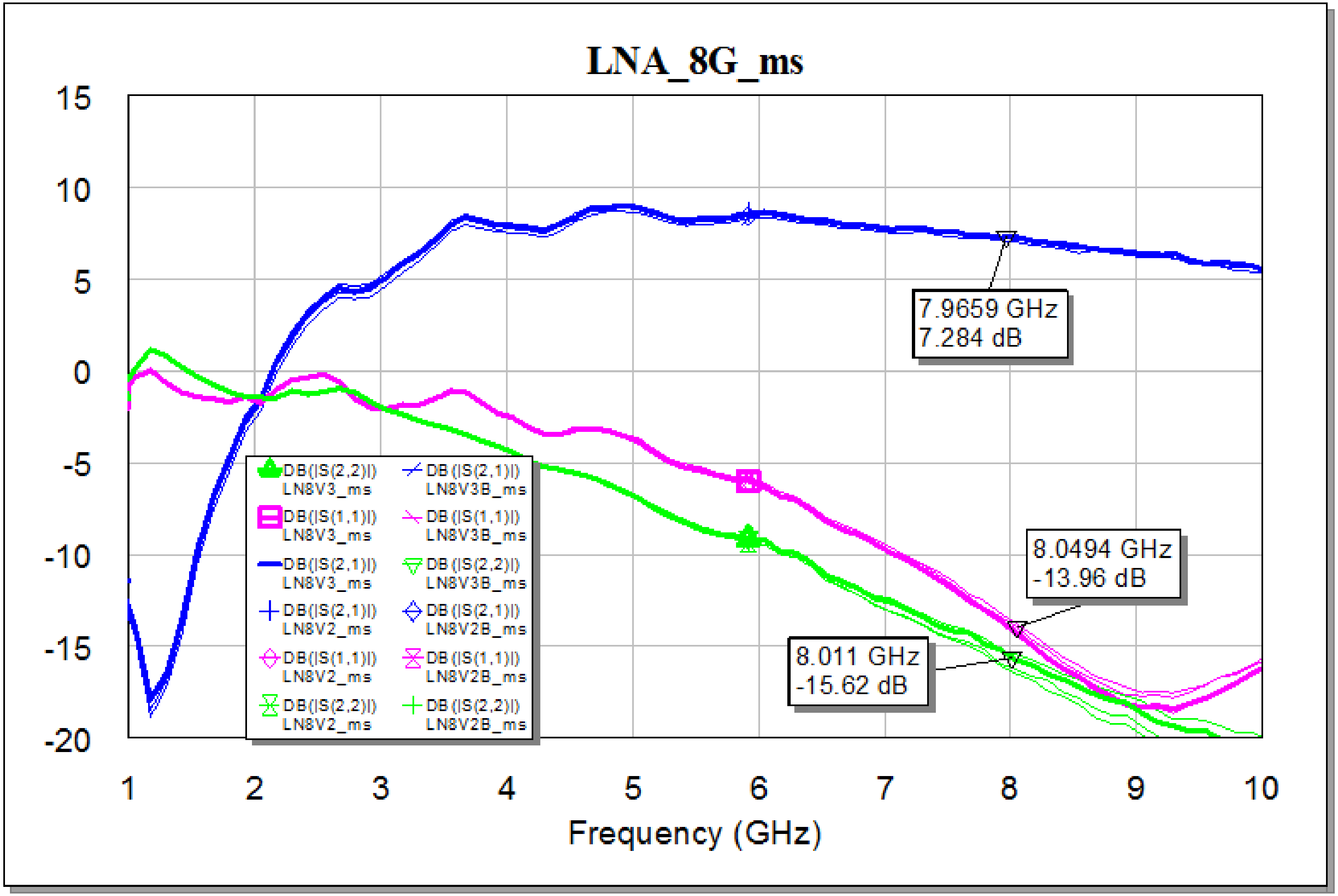


LNA 8GHz—Measured vs. Sonnet, AWR



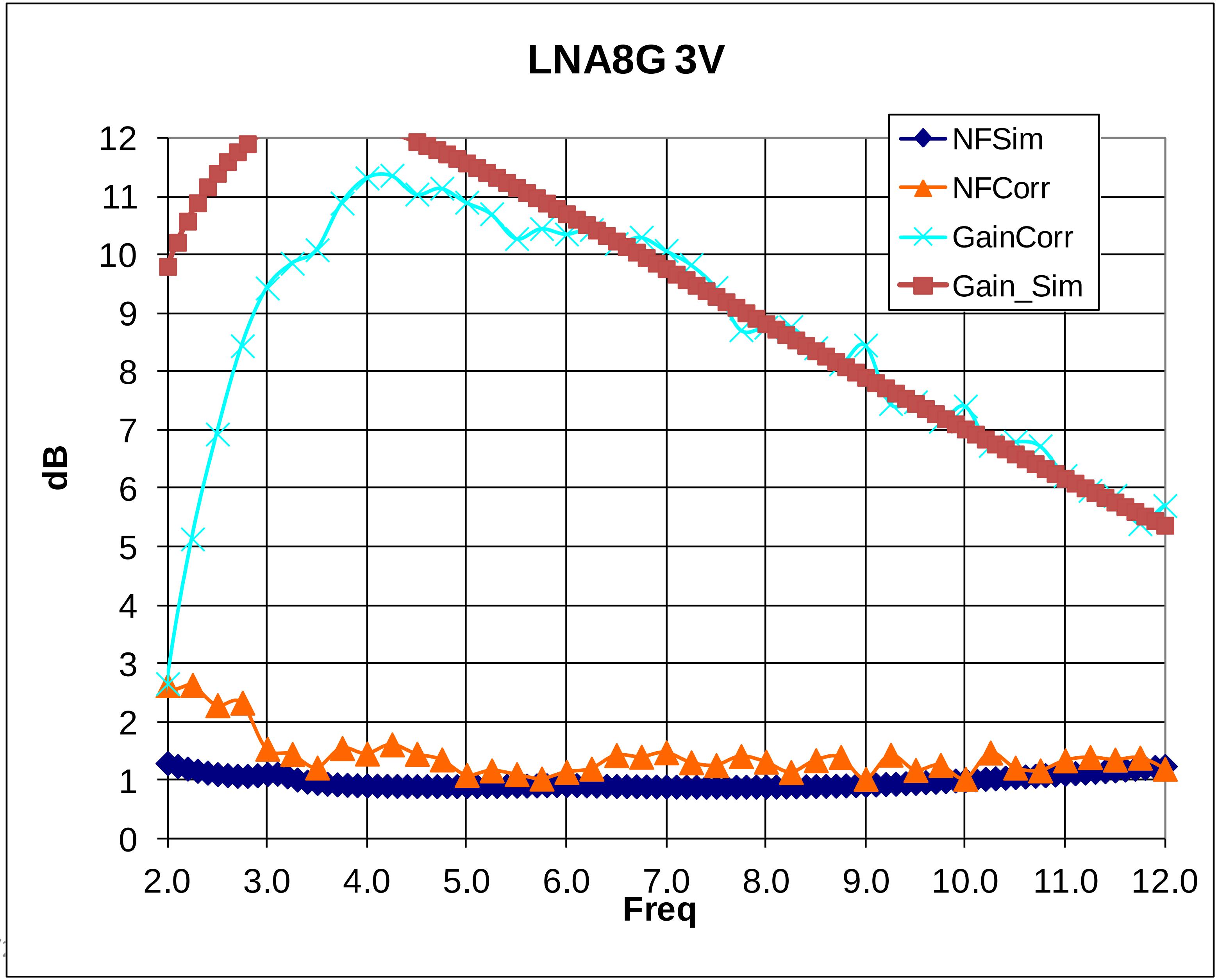
Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

LNA 8GHz—Measured 2V, 3V, and two Die

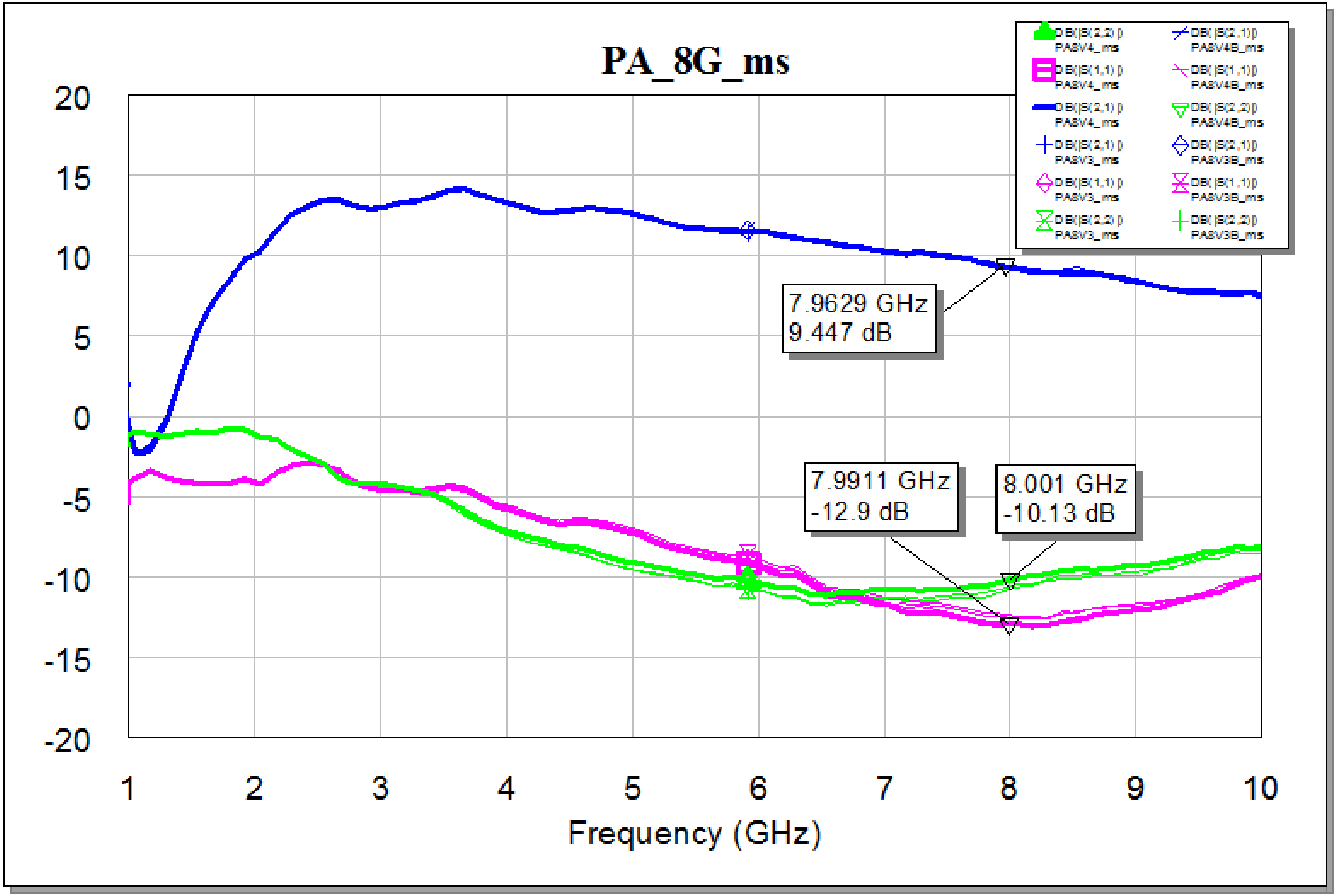


Blue-S21, Green-S22, Magenta-S11; Re-scaled

LNA 8GHz—Measured Performance

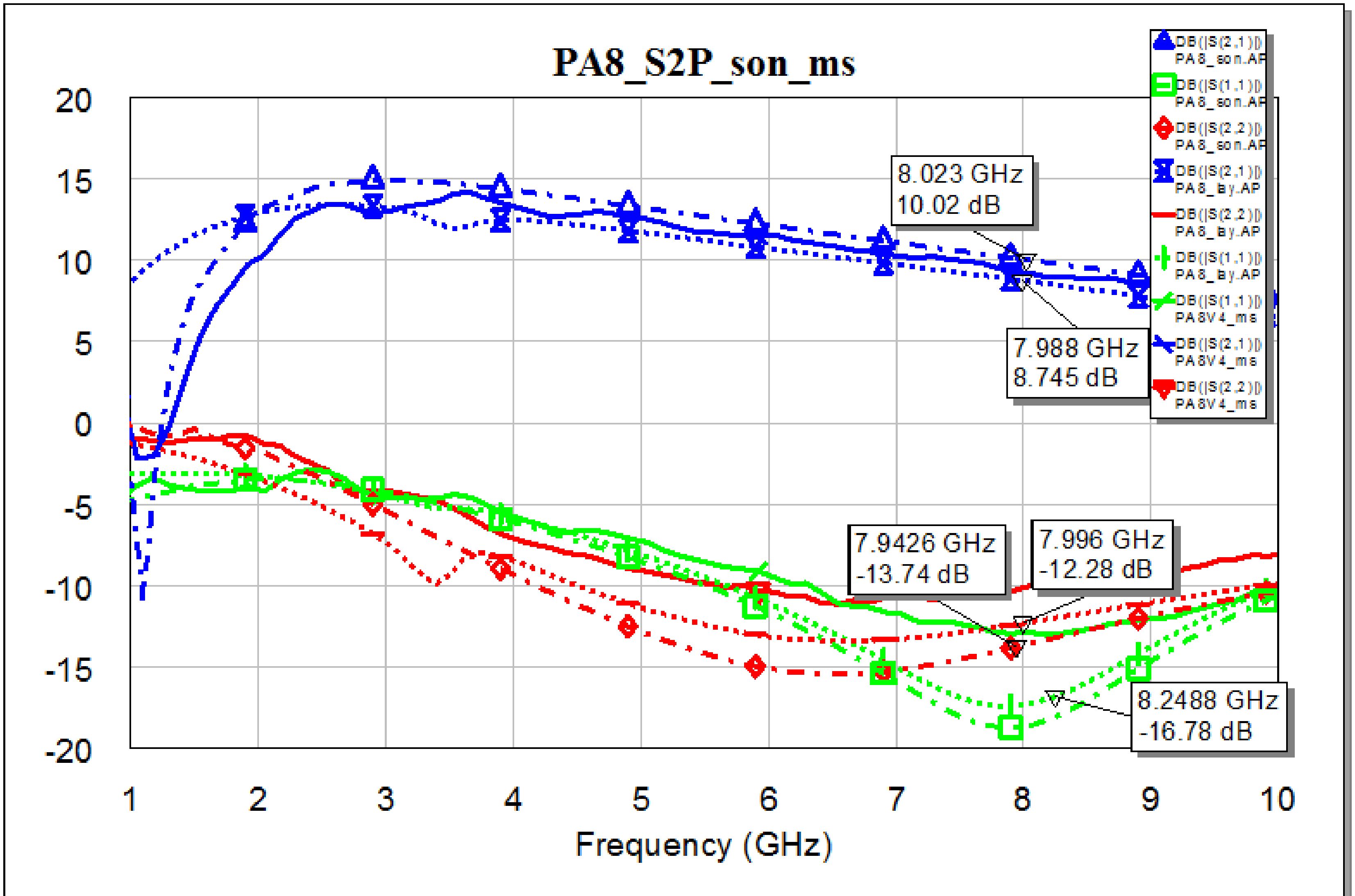


PA 8GHz—Measured 3V, 4V, and two Die



Blue-S21, Green-S22, Magenta-S11

PA 8GHz—Measured vs. Sonnet, AWR



Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

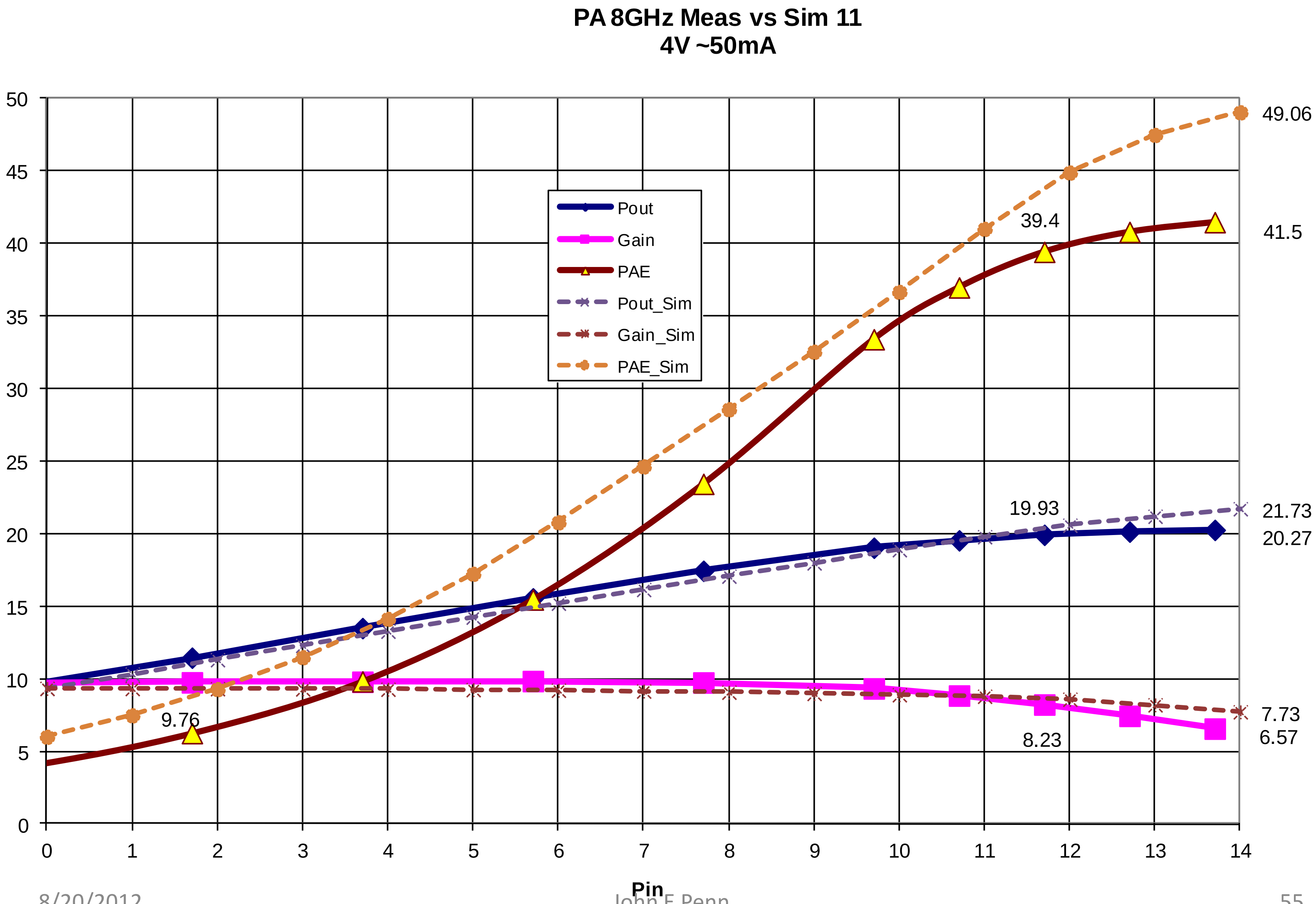
PA 8GHz—Measured Performance vs. Sim

8 GHz	Die#1	**8 GHz Fall11 TQP13**				4V ; 50 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
0.0	5.15	-2.30	7.45	9.75	50	200.0	5.56	2.8	2.5
2.0	7.14	-0.30	9.44	9.74	50	200.0	8.79	4.4	3.9
4.0	9.16	1.70	11.46	9.76	50	200.0	14.00	7.0	6.3
6.0	11.20	3.70	13.50	9.80	51	204.0	22.39	11.0	9.8
8.0	13.25	5.70	15.55	9.85	52	208.0	35.89	17.3	15.5
10.0	15.15	7.70	17.45	9.75	53	212.0	55.59	26.2	23.4
12.0	16.74	9.70	19.04	9.34	53	212.0	80.17	37.8	33.4
13.0	17.25	10.70	19.55	8.85	53	212.0	90.16	42.5	37.0
14.0	17.63	11.70	19.93	8.23	53	212.0	98.40	46.4	39.4
15.0	17.85	12.70	20.15	7.45	52	208.0	103.51	49.8	40.8
16.0	17.97	13.70	**20.27**	**6.57**	50	200.0	106.41	**53.2**	**41.5**

MWO Simulation (Layout) 4V 31mA			
Pin (dBm)	Pout (dBm)	PAE	Pgain
0	9.34	6.00	9.34
1	10.33	7.48	9.33
2	11.32	9.29	9.32
3	12.30	11.49	9.30
4	13.28	14.13	9.28
5	14.25	17.24	9.25
6	15.21	20.79	9.21
7	16.16	24.64	9.16
8	17.08	28.58	9.08
9	17.99	32.55	8.99
10	18.90	36.68	8.90
11	19.80	41.02	8.80
12	20.59	44.90	8.59
13	21.21	47.50	8.21
14	21.73	49.06	7.73

Notes:
corr—corrected
SG—Signal Generator
SA—Spectrum Analyzer

PA 8GHz—Measured Performance vs. Sim



Frequency Doubler 10 to 20 GHz

Measured 9, 10, & 11 Ghz Input

7/11/2012			4.6 dB loss thru			
Doubler 10G		**4V at 39mA, vg=0v**		**Die #1**		
SG	**Pin(corr)**	**Pout10G(r**	**Pout120G(m**	**Pout(corr)**	**Pout2X(corr)**	**Cnvloss**
6.0	**3.7**	1.9	-19.2	**4.2**	**-15.7**	19.4
8.0	**5.7**	3.9	-15.5	**6.2**	**-12.0**	17.7
10.0	**7.7**	5.4	-10.9	**7.7**	**-7.4**	15.1
12.0	**9.7**	7.0	-5.6	**9.3**	**-2.1**	11.8
14.0	**11.7**	7.8	-1.0	**10.1**	**2.5**	9.2
16.0	**13.7**	8.3	1.9	**10.6**	**5.4**	8.4

Doubler 10G		**4V at 13mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout10G(r**	**Pout120G**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	-2.8	-10.1	**-0.5**	**-6.6**	10.3
8.0	**5.7**	0.4	-7.7	**2.7**	**-4.2**	9.9
10.0	**7.7**	2.1	-5.2	**4.4**	**-1.7**	9.4
12.0	**9.7**	4.5	-2.8	**6.8**	**0.7**	9.0
14.0	**11.7**	6.6	-0.5	**8.9**	**3.1**	8.7
16.0	**13.7**	7.8	1.7	**10.1**	**5.2**	8.6

Notes:

ms--measured

corr—corrected

Pout—Fundamental

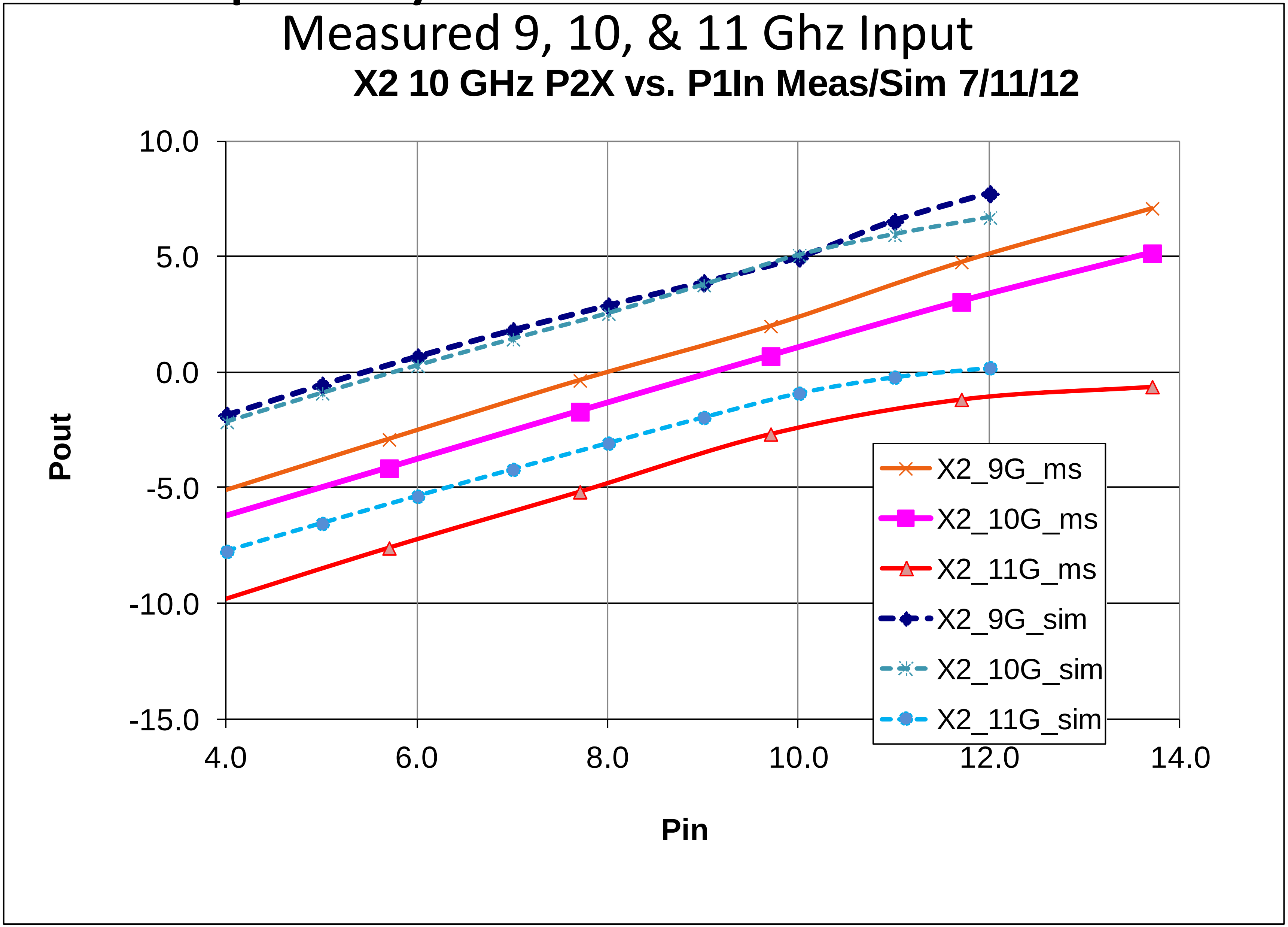
Pout2X—2nd Harmonic

Cnvloss—2nd Harm Conversion Loss

	11 GHz					
Doubler 10G		**4V at 13mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout10G(r**	**Pout120G**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	0.2	-13.7	**2.5**	**-10.2**	13.9
8.0	**5.7**	2.4	-11.1	**4.7**	**-7.6**	13.3
10.0	**7.7**	4.7	-8.7	**7.0**	**-5.2**	12.9
12.0	**9.7**	6.9	-6.2	**9.2**	**-2.7**	12.4
14.0	**11.7**	8.6	-4.7	**10.9**	**-1.2**	12.9
16.0	**13.7**	9.5	-4.1	**11.8**	**-0.6**	14.3

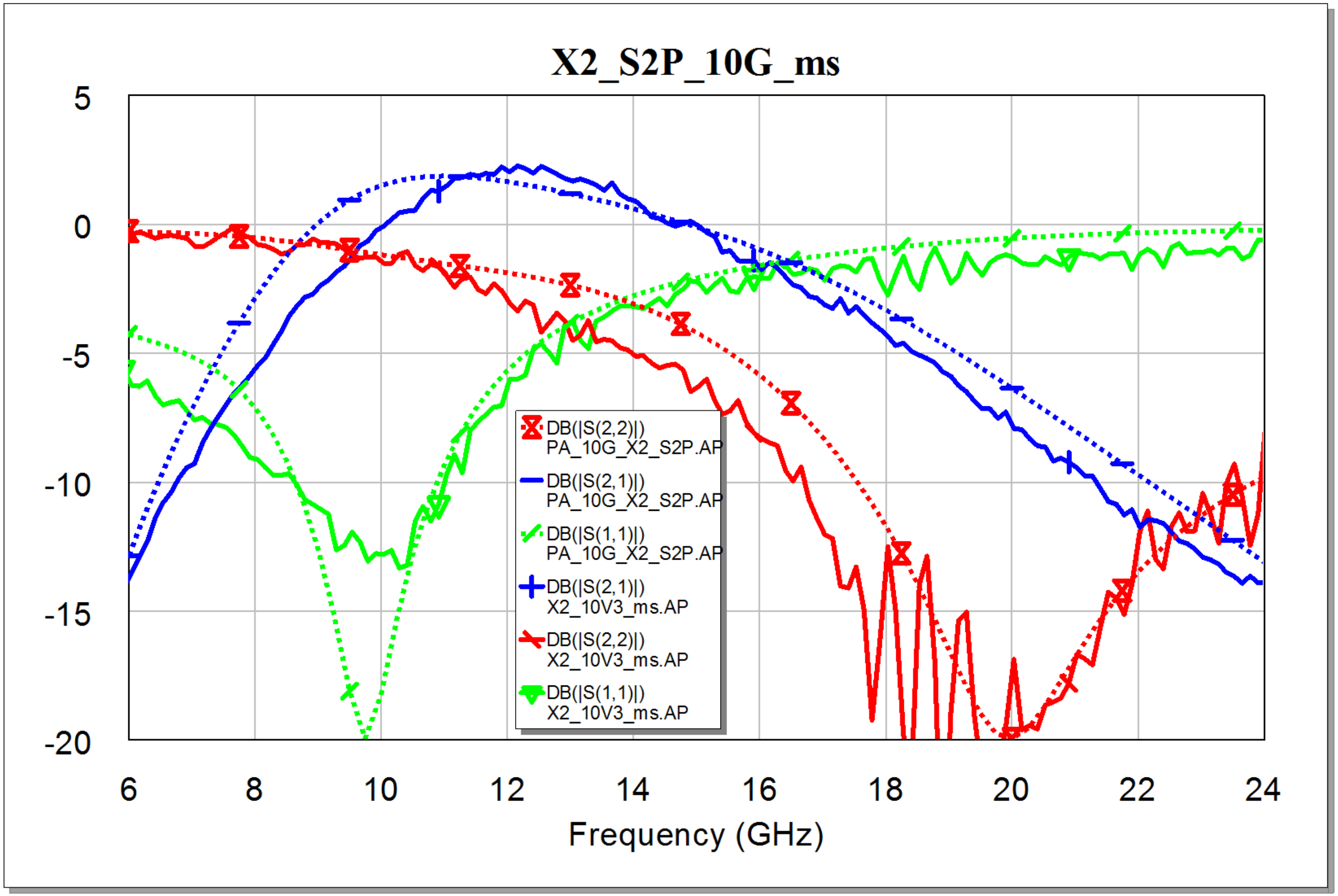
	9 GHz					
Doubler 10G		**4V at 13mA, vg=-3v**		**Die #1**		
SG	**Pin(corr)**	**Pout10G(r**	**Pout120G**	**Pout(corr)**	**Pout2X(cc**	**Cnvloss**
6.0	**3.7**	-5.0	-9.0	**-2.7**	**-5.5**	9.2
8.0	**5.7**	-2.5	-6.4	**-0.2**	**-2.9**	8.6
10.0	**7.7**	0.0	-3.9	**2.3**	**-0.4**	8.1
12.0	**9.7**	2.6	-1.5	**4.9**	**2.0**	7.7
14.0	**11.7**	4.5	1.3	**6.8**	**4.8**	6.9
16.0	**13.7**	5.4	3.6	**7.7**	**7.1**	6.6

Frequency Doubler 10 to 20 GHz



Frequency Doubler 10 to 20 GHz

Measured S-Parameters (solid) vs. Sim (dotted)



Frequency Doublers 16 to 32 GHz

Measured 15, 16, & 17 Ghz Input

8/10/2012			16.0 GHz					
Doubler 16G			4V at ~39mA, vg=-3v			Die #1		
SG	Pin(corr)	Pin(1)	PoutX1(m	PoutX2(ms)	Pout(corr)	Pout2X(cc	Cnvloss	dBc
9.3	**5.5**	**5.5**	-1.12	-23.5	**4.0**	**-14.0**	19.5	18.0
10.3	**6.5**	**6.5**	-0.18	-21.2	**4.9**	**-11.7**	18.2	16.6
11.3	**7.5**	**7.5**	0.75	-18.58	**5.9**	**-9.1**	16.6	14.9
12.3	**8.5**	**8.5**	1.64	-15.65	**6.7**	**-6.2**	14.6	12.9
13.3	**9.5**	**9.4**	2.55	-13.73	**7.7**	**-4.2**	13.7	11.9
14.3	**10.5**	**10.4**	3.43	-11.62	**8.5**	**-2.1**	12.5	10.7
15.3	**11.5**	**11.4**	4.29	-9.53	**9.4**	**0.0**	11.4	9.4
16.3	**12.5**	**12.3**	5.13	-7.85	**10.2**	**1.7**	10.7	8.6
17.3	**13.5**	**13.2**	5.85	-6.42	**11.0**	**3.1**	10.2	7.9
18.2	**14.4**	**14.2**	6.59	-5.23	**11.7**	**4.3**	9.9	7.4

8/10/2012	17 GHz							
Doubler 16G			4V at ~39mA, vg=-3v			Die #1		
SG	Pin(corr)	Pin(1)	PoutX1(m	PoutX2(m	Pout(corr)	Pout2X(cc	Cnvloss	dBc
9.1	**5.3**	**4.9**	-2.23	-25.4	**2.9**	**-15.9**	20.8	18.8
10.1	**6.3**	**5.9**	-1.27	-23.1	**3.8**	**-13.6**	19.5	17.4
11.0	**7.2**	**6.9**	-0.33	-20.79	**4.8**	**-11.3**	18.2	16.1
12.0	**8.2**	**7.9**	0.59	-18.22	**5.7**	**-8.7**	16.6	14.4
13.0	**9.2**	**8.9**	1.49	-15.65	**6.6**	**-6.2**	15.0	12.7
14.0	**10.2**	**9.8**	2.37	-13.39	**7.5**	**-3.9**	13.7	11.4
15.0	**11.2**	**10.8**	3.24	-11.32	**8.3**	**-1.8**	12.6	10.2
16.0	**12.2**	**11.7**	4.09	-9.57	**9.2**	**-0.1**	11.8	9.3
16.9	**13.1**	**12.6**	4.9	-8.02	**10.0**	**1.5**	11.2	8.5
17.9	**14.1**	**13.5**	5.68	-6.7	**10.8**	**2.8**	10.7	8.0

8/10/2012	15 GHz							
Doubler 16G			4V at ~39mA, vg=-3v			Die #1		
SG	Pin(corr)	Pin(1)	PoutX1(m	PoutX2(m	Pout(corr)	Pout2X(cc	Cnvloss	dBc
11.0	**7.2**	**5.5**	1.75	-18.6	**6.9**	**-9.1**	14.6	15.9
12.0	**8.2**	**6.5**	2.66	-16.4	**7.8**	**-6.9**	13.4	14.7
13.0	**9.2**	**7.5**	3.56	-13.91	**8.7**	**-4.4**	11.9	13.1
14.0	**10.2**	**8.5**	4.46	-11.56	**9.6**	**-2.1**	10.5	11.6
15.0	**11.2**	**9.4**	5.32	-9.57	**10.4**	**-0.1**	9.5	10.5
16.1	**12.3**	**10.4**	6.18	-7.77	**11.3**	**1.7**	8.7	9.6
17.0	**13.2**	**11.4**	7.00	-5.91	**12.1**	**3.6**	7.8	8.5
18.0	**14.2**	**12.3**	7.78	-4.72	**12.9**	**4.8**	7.6	8.1

Notes:

ms--measured

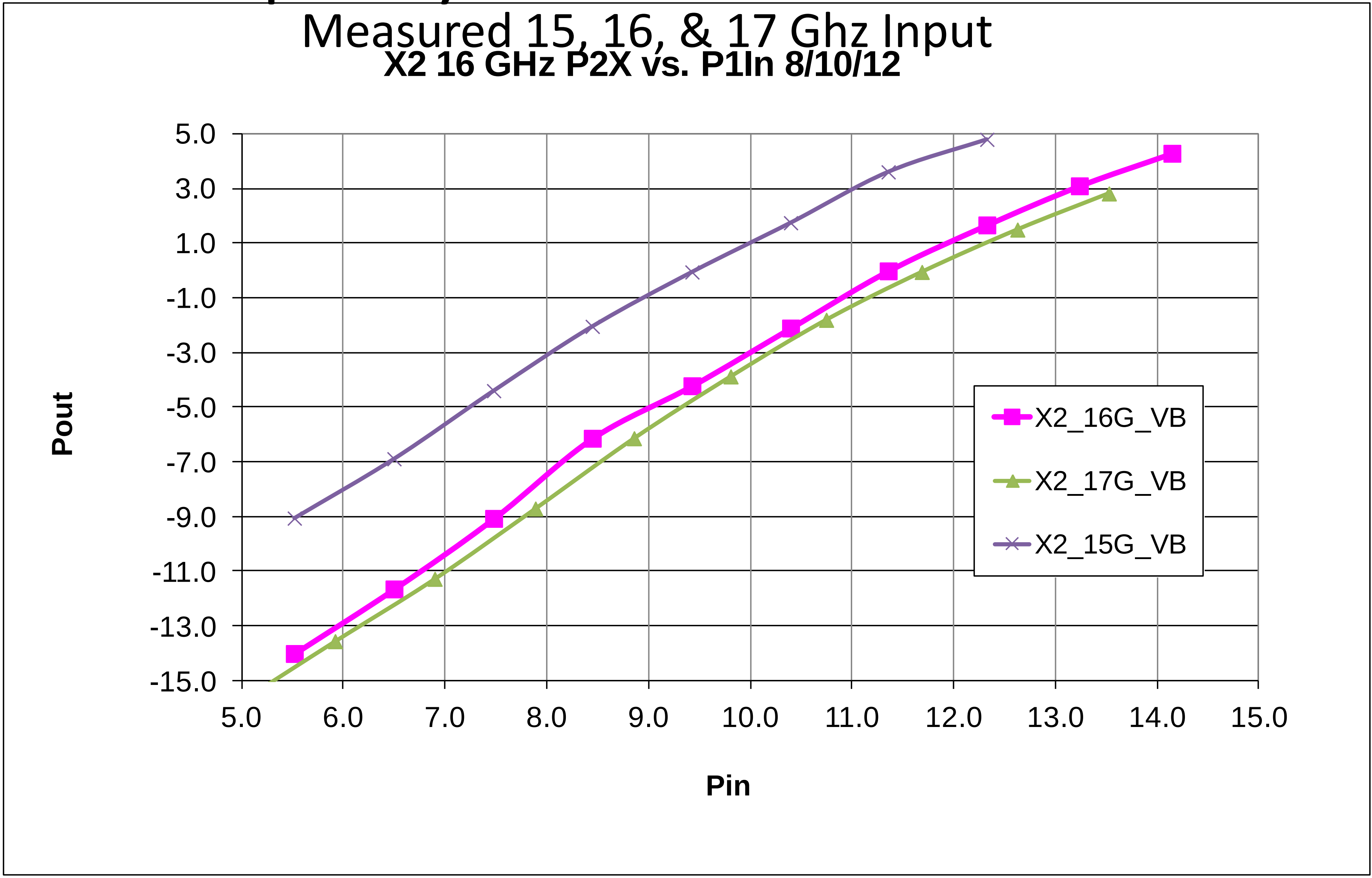
corr—corrected

Pout—Fundamental

Pout2X—2nd Harmonic

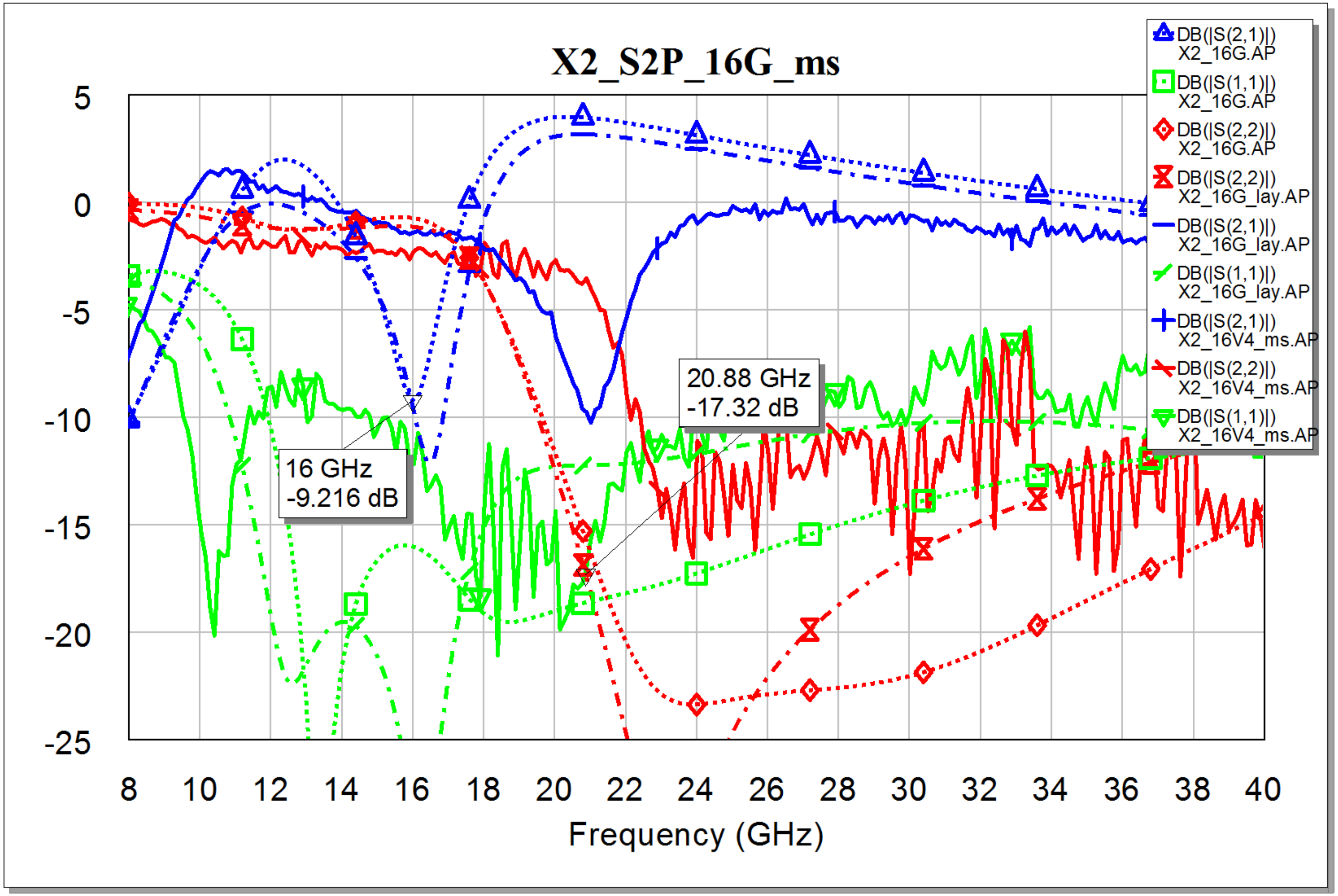
Cnvloss—2nd Harm Conversion Loss

Frequency Doubler 16 to 32 GHz



Frequency Doubler 16 to 32 GHz

Measured S-Parameters (solid) vs. Sim (dotted)



12) JHU11VCO -- JEP

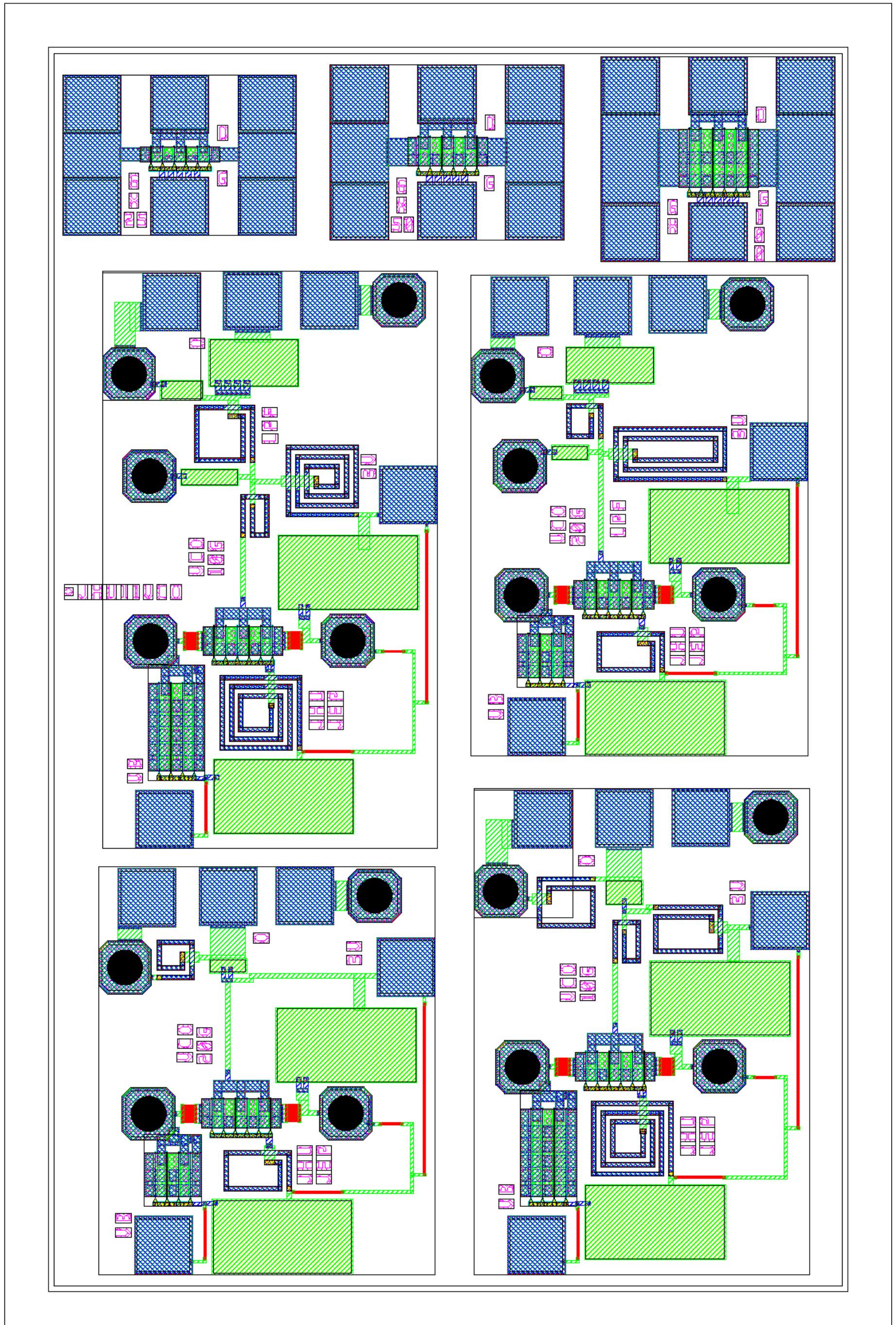
10, 20 GHz VCOs

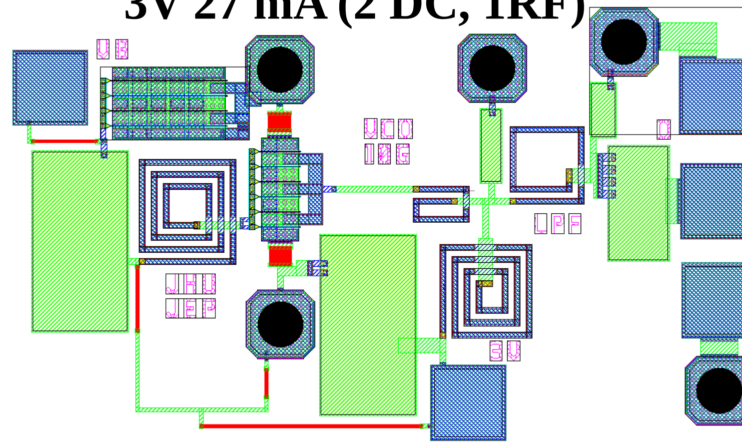
3V 27 mA (2 DC, 1RF)

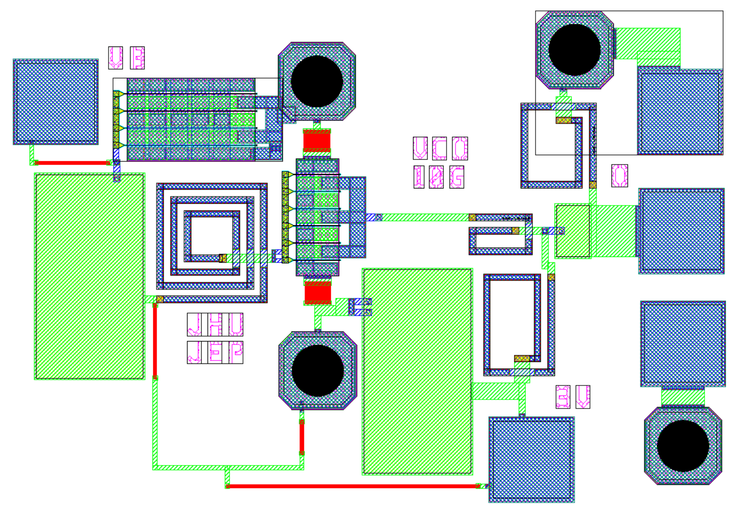
3V 27 mA (2 DC, 1RF)

3V 27 mA (2 DC, 1RF)

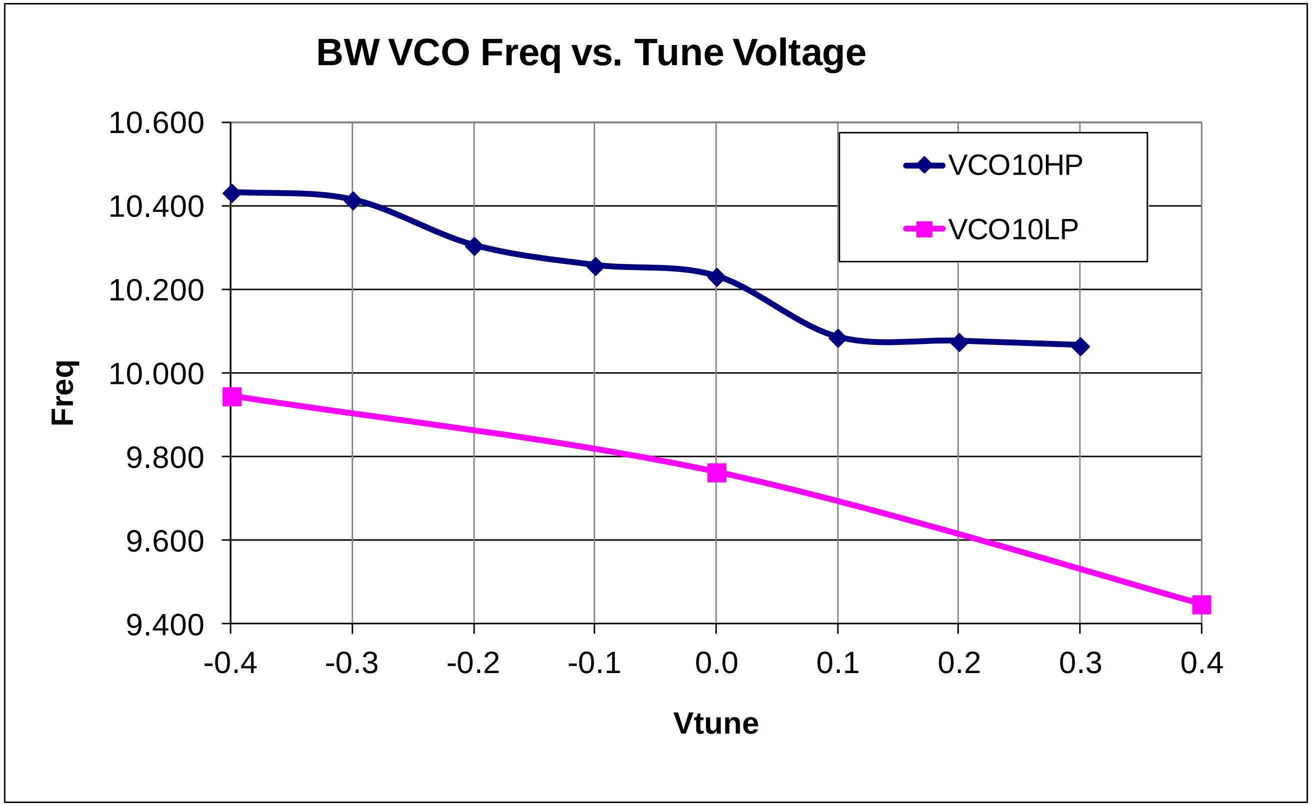
3V 27 mA (2 DC, 1RF)







Voltage Controlled Oscillator (VCO)—Meas 10 G



*LP VCO Had Lower RF Output Power but much better 2nd harmonic attenuation.

LPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
-0.4	9.942	12.7	-31.9
0.0	9.737	12.6	-29.6
0.4	9.662	12.5	-28.9

HPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
-0.4	10.136	12.2	1.4
0.0	9.921	12.2	1.2
0.4	9.812	12.2	0.7

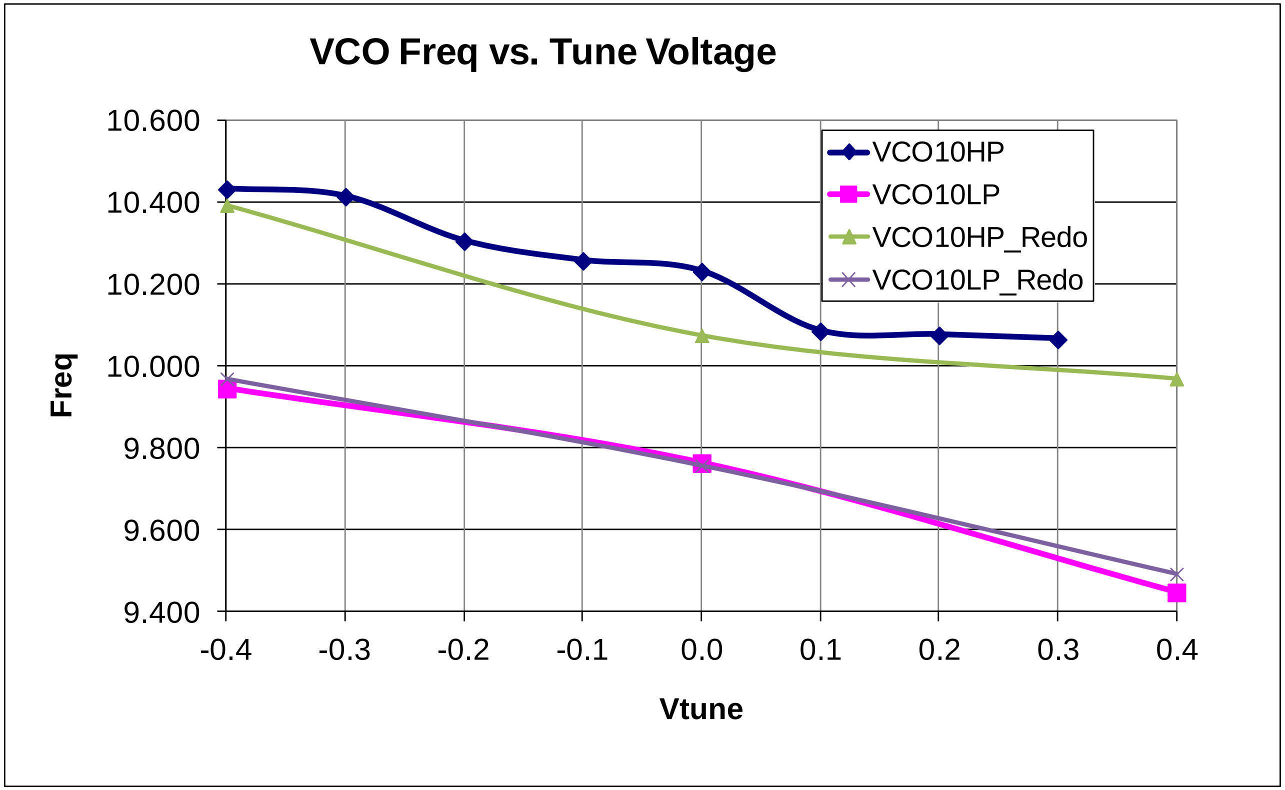
Simulation is Similar

HPF VCO	**3V at 35mA**			**Die #1**		
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout2X(ms)**	**Pout(corr)**	**Pout2X(corr)**	**dBc**
-0.4	10.433	5.8	-3.5	**8.2**	**0.5**	7.7
-0.3	10.415	5.9	-3.7	**8.2**	**0.4**	7.9
-0.2	10.306	7.2	-2.9	**9.6**	**1.1**	8.4
-0.1	10.258	6.9	-2.7	**9.2**	**1.3**	7.9
0.0	10.232	6.9	-2.2	**9.3**	**1.8**	7.4
0.1	10.086	7.7	-4.4	**10.1**	**-0.4**	10.4
0.2	10.076	7.3	-3.6	**9.6**	**0.5**	9.1
0.3	10.066	6.9	-3.4	**9.3**	**0.7**	8.6

LPF VCO	**3V at 34mA**			**Die #1**		
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout2X(m**	**Pout(corr)**	**Pout2X(cc**	**dBc**
-0.4	9.946	5.1	-39.0	**7.4**	**-35.0**	42.4
0.0	9.764	3.8	-37.7	**6.2**	**-33.7**	39.8
0.4	9.448	3.8	-37.0	**6.2**	**-33.0**	39.1

Notes:
ms--measured
corr—corrected
Pout—Fundamental
Pout2X—2nd Harmonic

Voltage Controlled Oscillator—Re-Meas 10 G



*Re-Meas LP VCO Had Similar RF Output Power
LPF: Much better 2nd harmonic attenuation.

LPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
-0.4	9.942	12.7	-31.9
0.0	9.737	12.6	-29.6
0.4	9.662	12.5	-28.9

HPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
-0.4	10.136	12.2	1.4
0.0	9.921	12.2	1.2
0.4	9.812	12.2	0.7

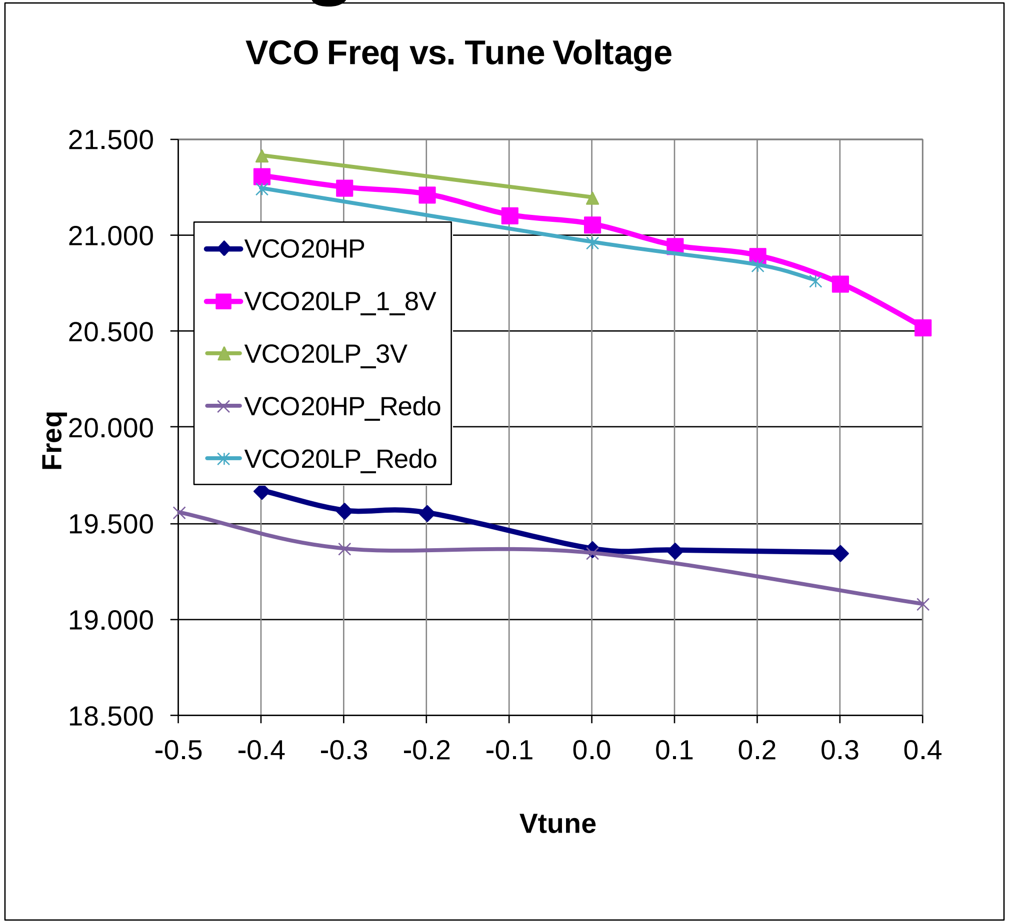
Re-Measured 8/1/12

HPF VCO	**3V at 34mA**		**Die #2**			
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout2X(m**	**Pout(corr)**	**Pout2X(cc**	**dBc**
-0.4	10.394	5.8	-4.4	**8.1**	**-0.4**	8.5
0.0	10.076	7.4	-4.2	**9.8**	**-0.1**	9.9
0.4	9.970	7.2	-3.7	**9.5**	**0.3**	9.2

LPF VCO	**3V at 32mA**		**Die #2**			
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout2X(m**	**Pout(corr)**	**Pout2X(cc**	**dBc**
-0.4	9.970	8.4	-34.5	**10.7**	**-30.5**	41.2
0.0	9.758	8.2	-34.0	**10.6**	**-30.0**	40.5
0.4	9.493	7.9	-33.0	**10.2**	**-29.0**	39.2

Notes:
ms--measured
corr—corrected
Pout—Fundamental
Pout2X—2nd Harmonic

Voltage Controlled Oscillator—Re-Meas 20 G



*Re-Meas LP VCO Had Similar Tuning Range to previous 1.8V meas.
HPF VCO consistent.
Non-Linear Sim had problems with convergence.

LPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
0.0	20.042	6.9	-52.8
0.15	19.690	6.9	-51.7
0.3	19.386	6.2	-53.6

HPF_Sim			
VBias (V)	**Freq (GHz**	**Pout**	**Pout2X**
0.0	19.947	6.7	-10.9
0.15	19.554	6.5	-10.8
0.3	19.190	6.3	-11.2

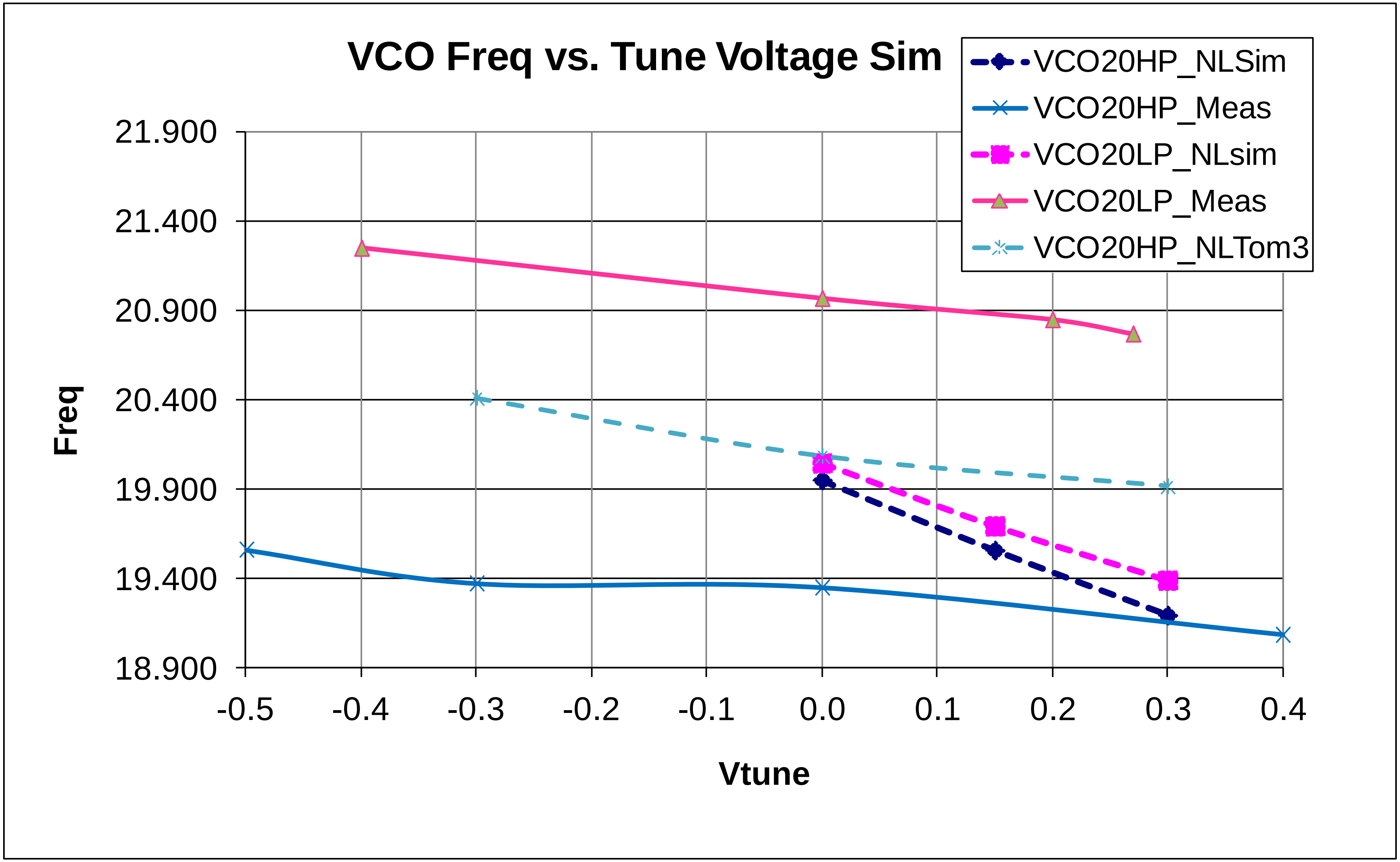
Re-Measured 8/1/12

HPF VCO	**3V at 24mA**		**Die #2**
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**
-0.5	19.560	6.7	**10.7**
-0.3	19.371	7.2	**11.2**
0.0	19.348	6.2	**10.2**
0.4	19.083	6.5	**10.5**

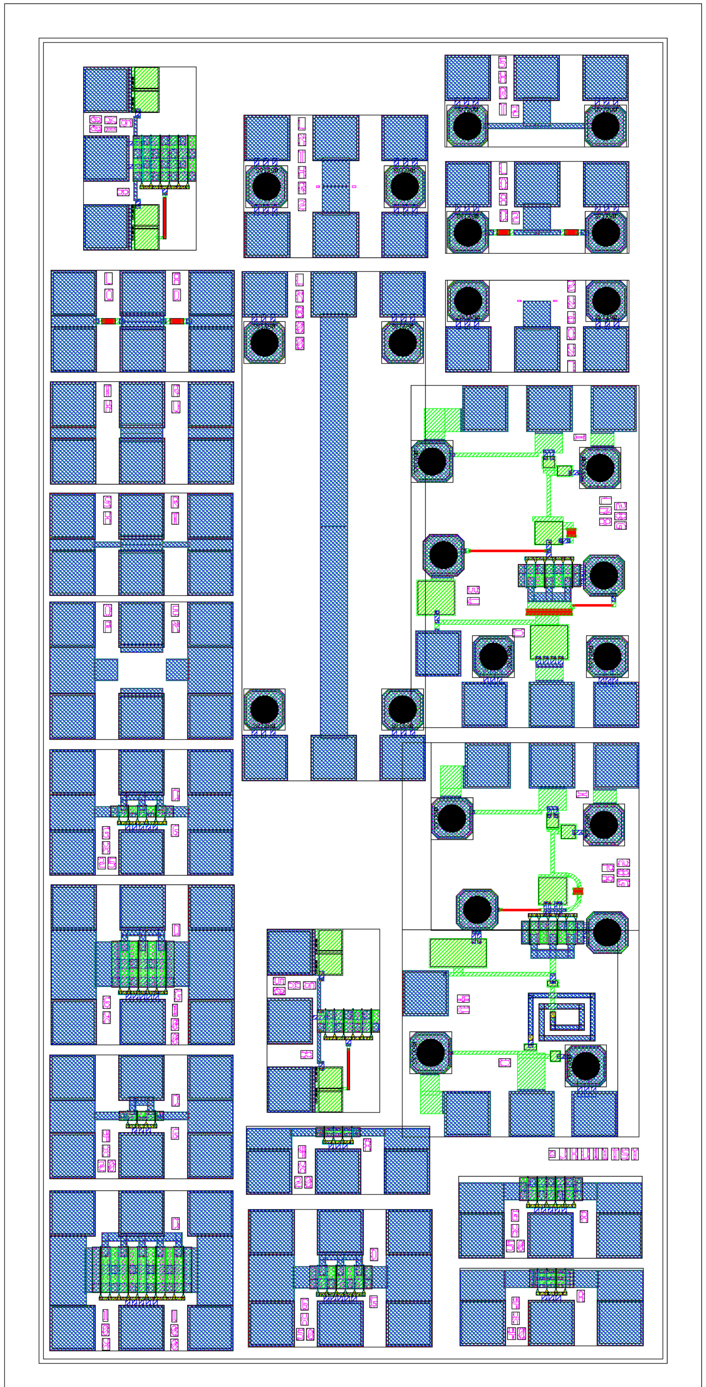
LPF VCO	**3V at 33mA**		**Die #2**
VBias (V)	**Freq (GHz**	**Pout(ms)**	**Pout(corr)**
-0.4	21.247	-2.3	**1.7**
0.0	20.966	0.4	**4.4**
0.2	20.847	-0.1	**3.9**
0.3	20.767	-0.7	**3.3**

Notes:
ms--measured
corr—corrected
Pout—Fundamental
Pout2X—2nd Harmonic

Voltage Controlled Oscillator (VCO)—Meas 20 G



*Non-Linear Simulation vs. Measured
Better Convergence with TOM3 Model!



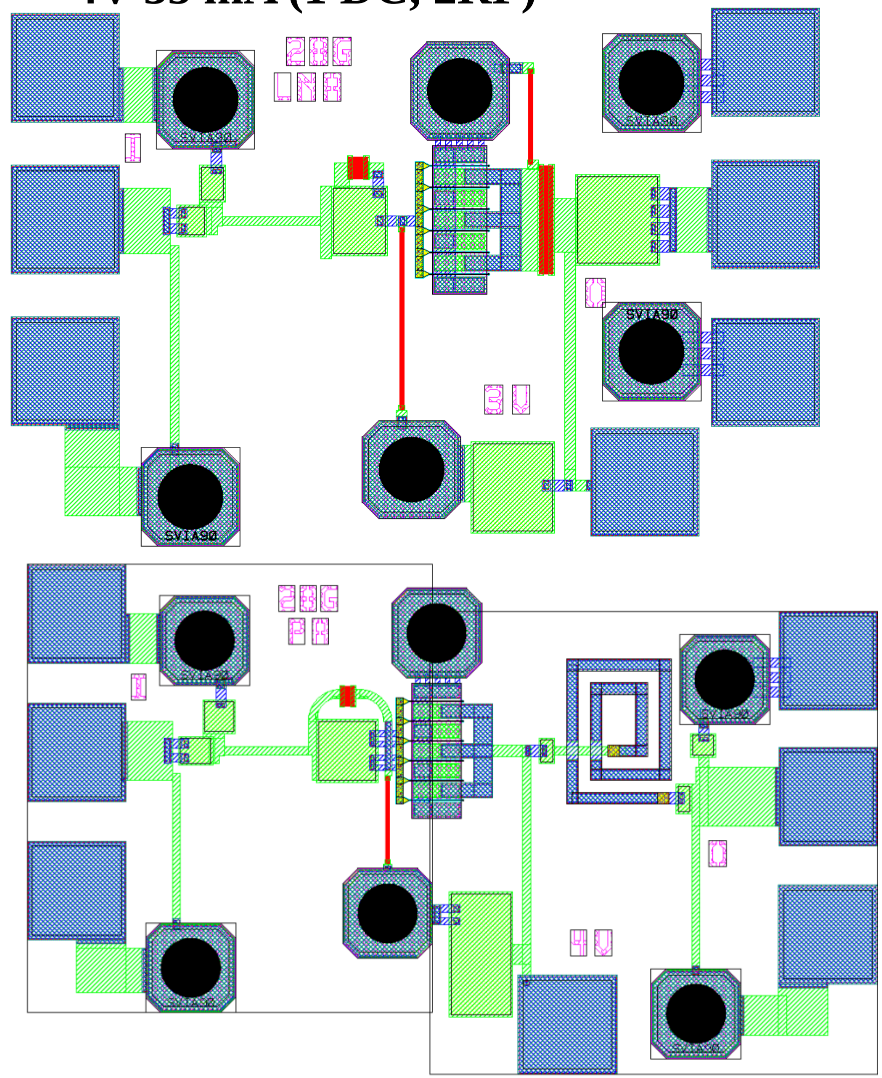
13) JHU11TST -- JEP

28 GHz LNA, PA

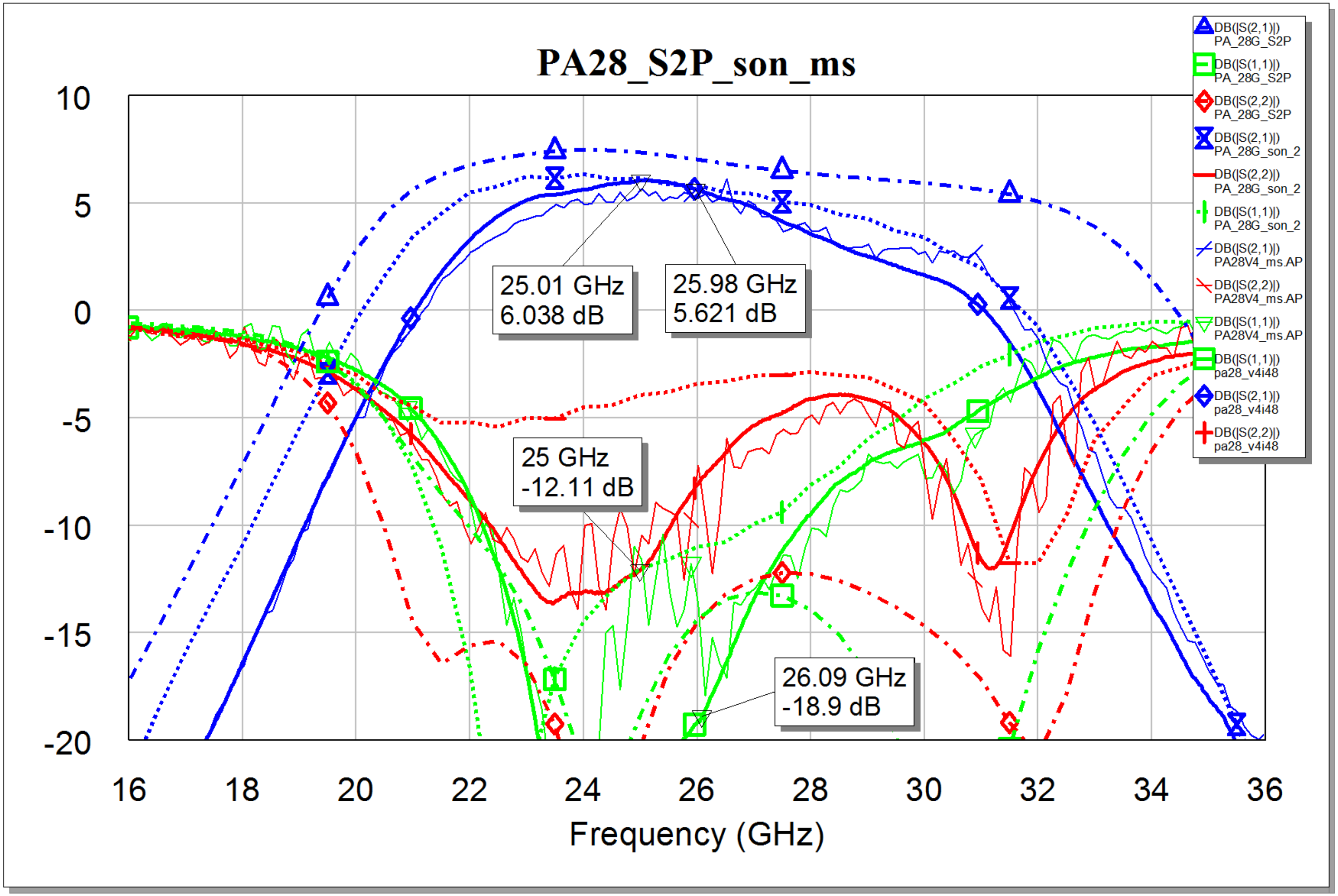
Test Devices

3V 27 mA (1 DC, 2RF)

4V 35 mA (1 DC, 2RF)

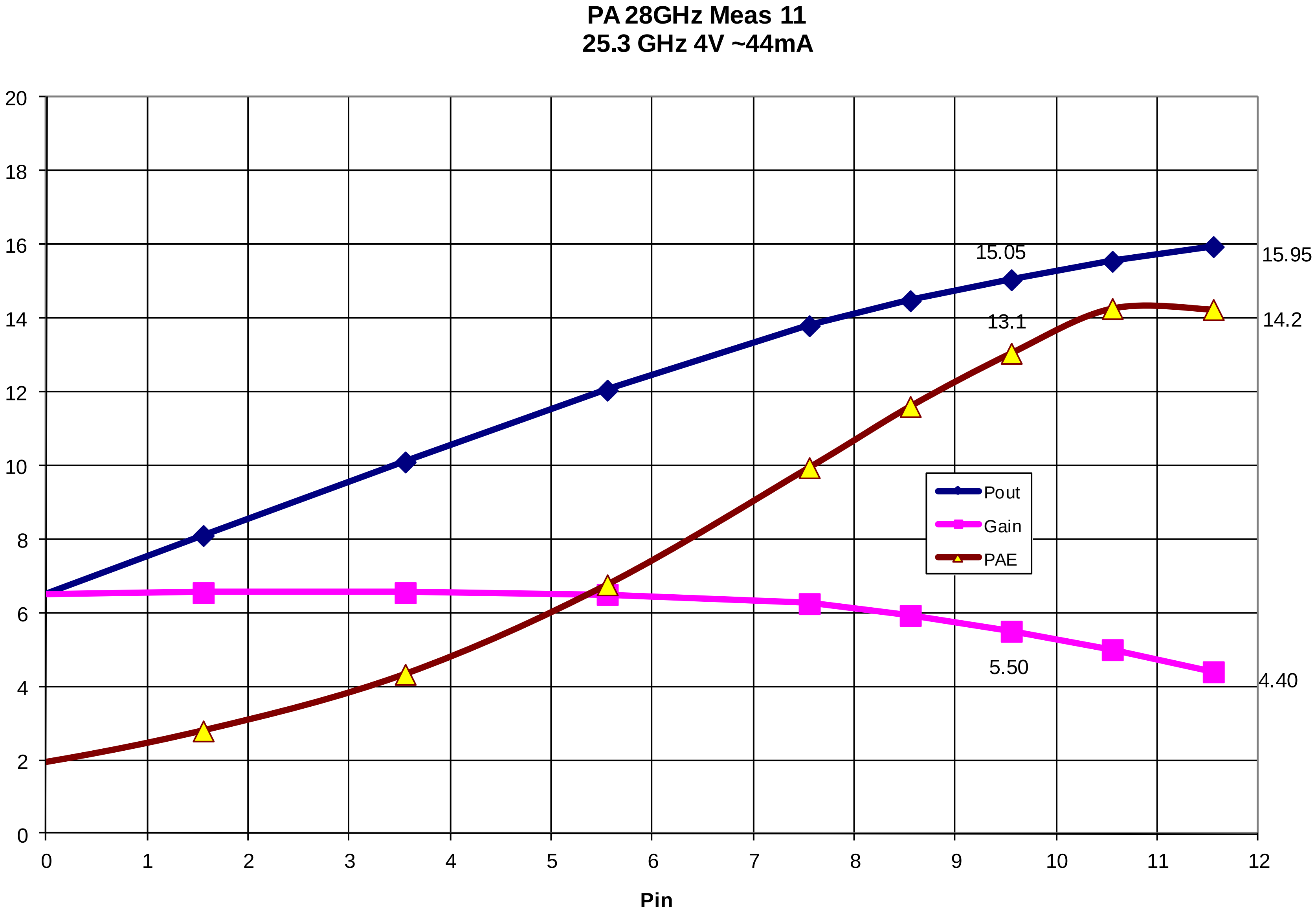


PA 28GHz—Measured vs. Sonnet, AWR



Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

PA 28GHz—Measured Performance



Low Gain & Measured at 25.3 GHz (equipment limitation!)

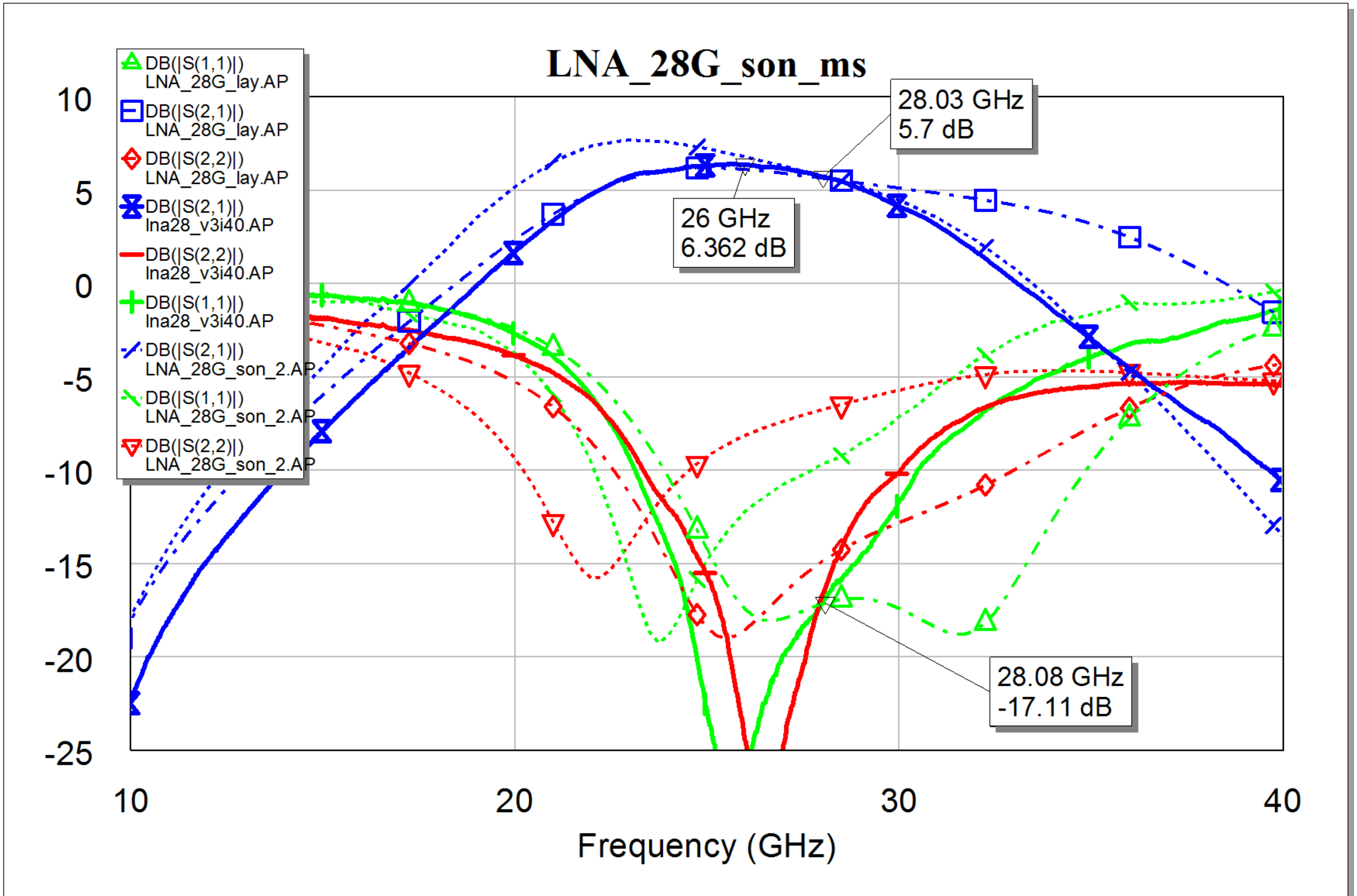
PA 28GHz—Measured Performance

JEP 28 GHz 4 V									
Measured at 25.35 GHz				Loss 8.9 dB for thru					
25.35 GHz	Die#1	**28 GHz Fall11 TQP13**				4V ; 50 mA			
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(4V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
0.0	-2.40	-4.45	2.05	6.50	44	176.0	1.60	0.9	0.7
2.0	-0.40	-2.45	4.05	6.50	44	176.0	2.54	1.4	1.1
4.0	1.60	-0.45	6.05	6.50	45	180.0	4.03	2.2	1.7
6.0	3.65	1.55	8.10	6.55	45	180.0	6.46	3.6	2.8
8.0	5.65	3.55	10.10	6.55	46	184.0	10.23	5.6	4.3
10.0	7.60	5.55	12.05	6.50	46	184.0	16.03	8.7	6.8
12.0	9.35	7.55	13.80	6.25	46	184.0	23.99	13.0	9.9
13.0	10.03	8.55	14.48	5.93	45	180.0	28.05	15.6	11.6
14.0	10.60	9.55	15.05	5.50	44	176.0	31.99	18.2	13.1
15.0	11.10	10.55	15.55	5.00	43	172.0	35.89	20.9	14.3
16.0	11.50	11.55	**15.95**	**4.40**	44	176.0	39.36	**22.4**	**14.2**

Notes:
corr—corrected
SG—Signal Generator
SA—Spectrum Analyzer

Low Gain & Measured at 25.3 GHz (equipment limitation!)

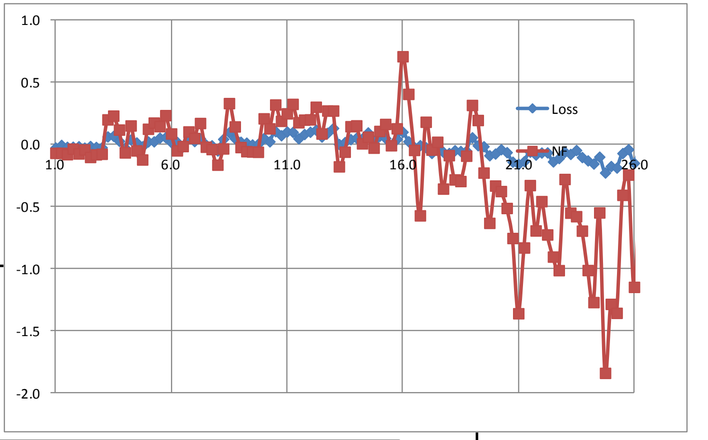
LNA 28GHz—Measured vs. Sonnet, AWR

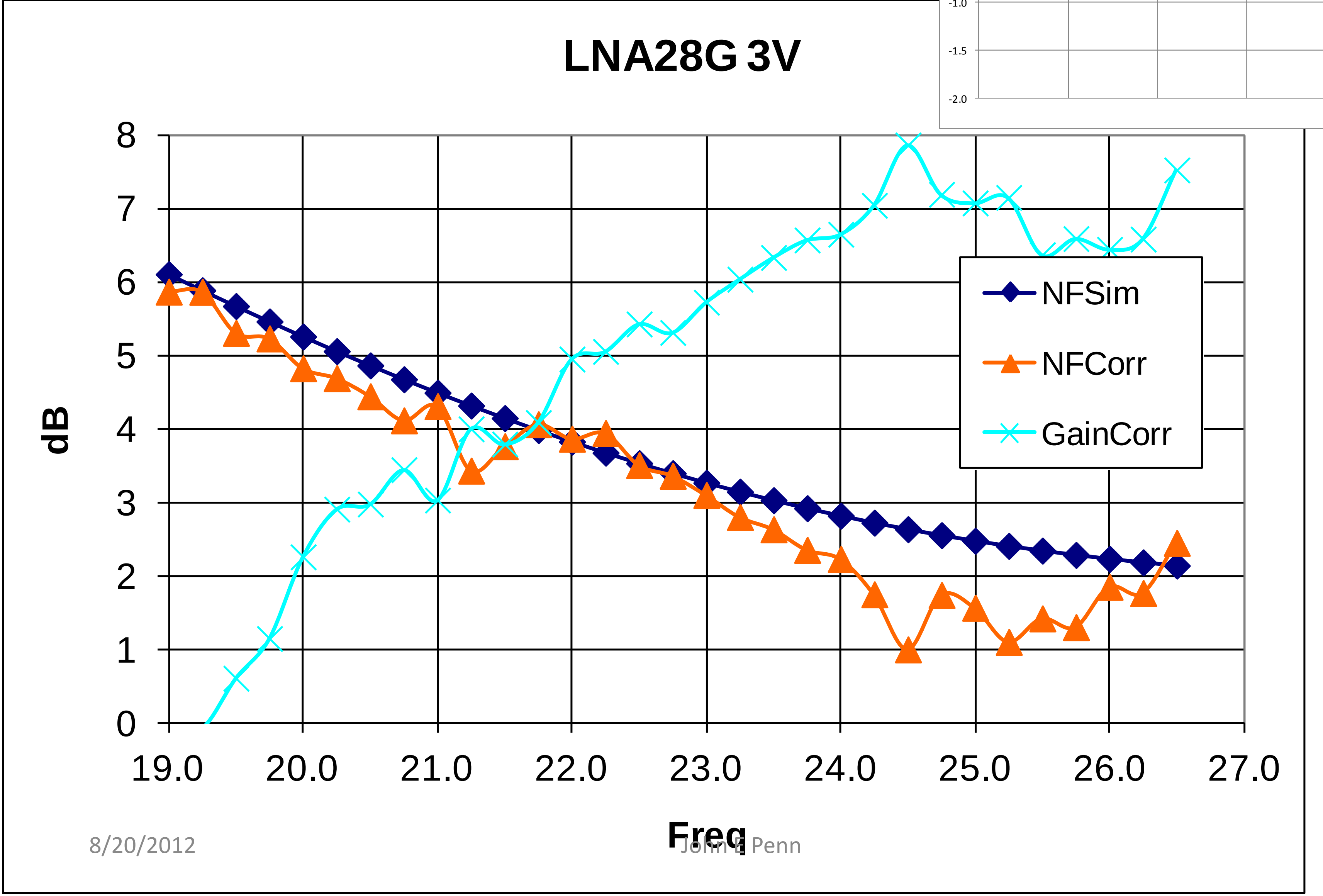


Solid-Meas, Dotted-Sonnet, Dot/Dash-AWR

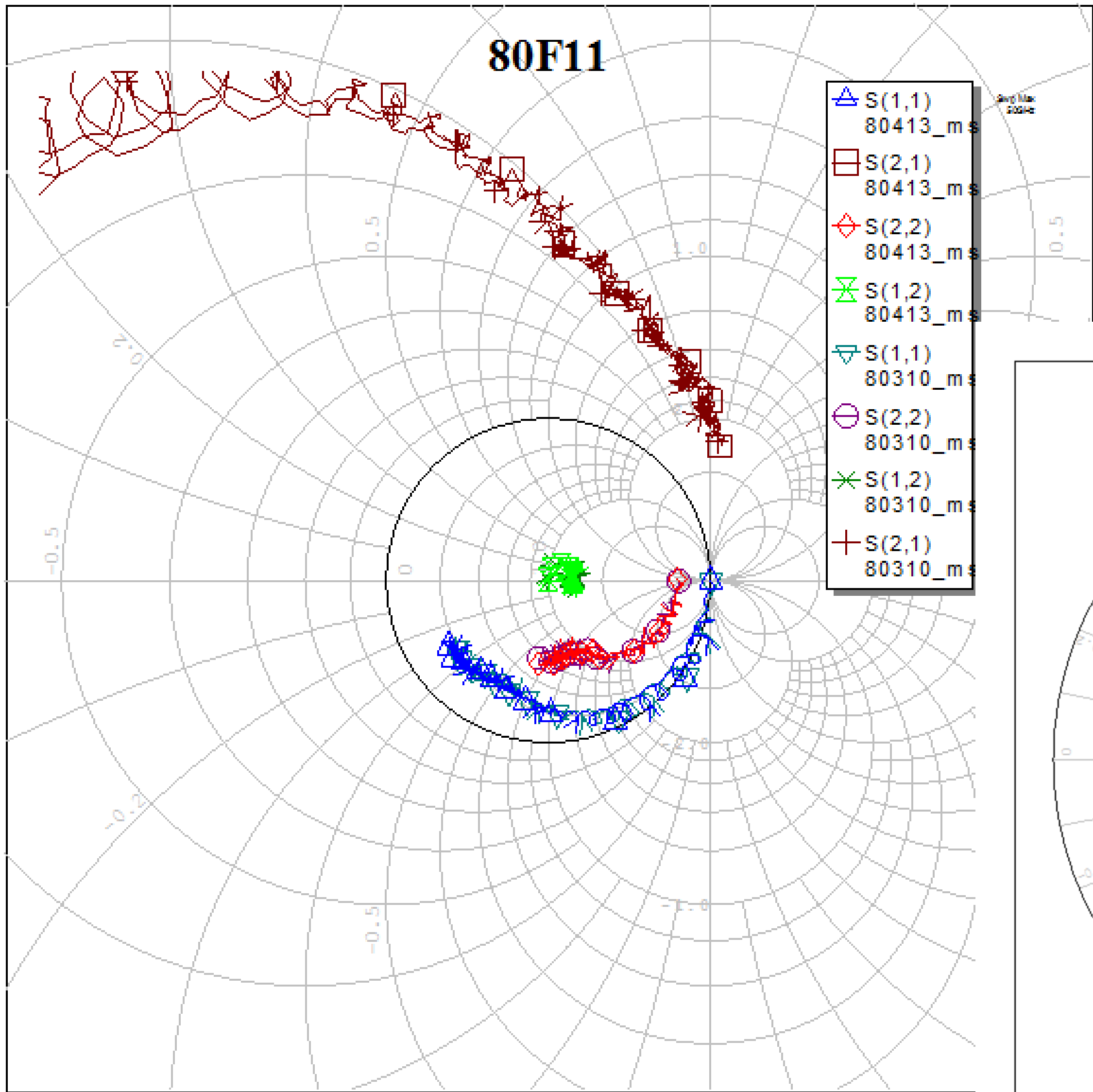
LNA 28GHz—Measured NF (to 26 GHz)

NF Low ~1dB at higher end, matches well below 23 GHz





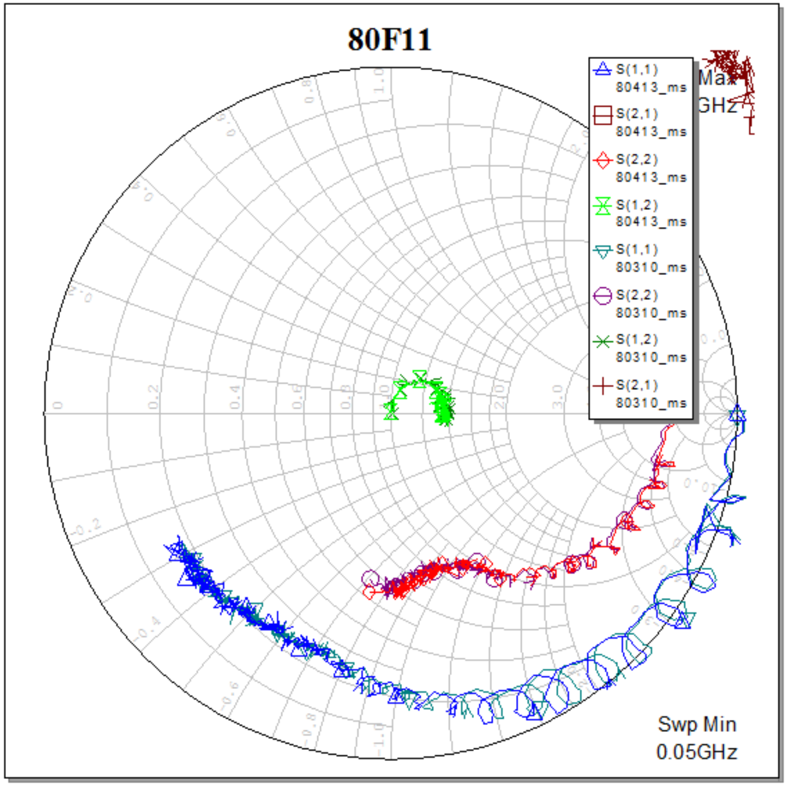
Devices 4x20 PHEMT



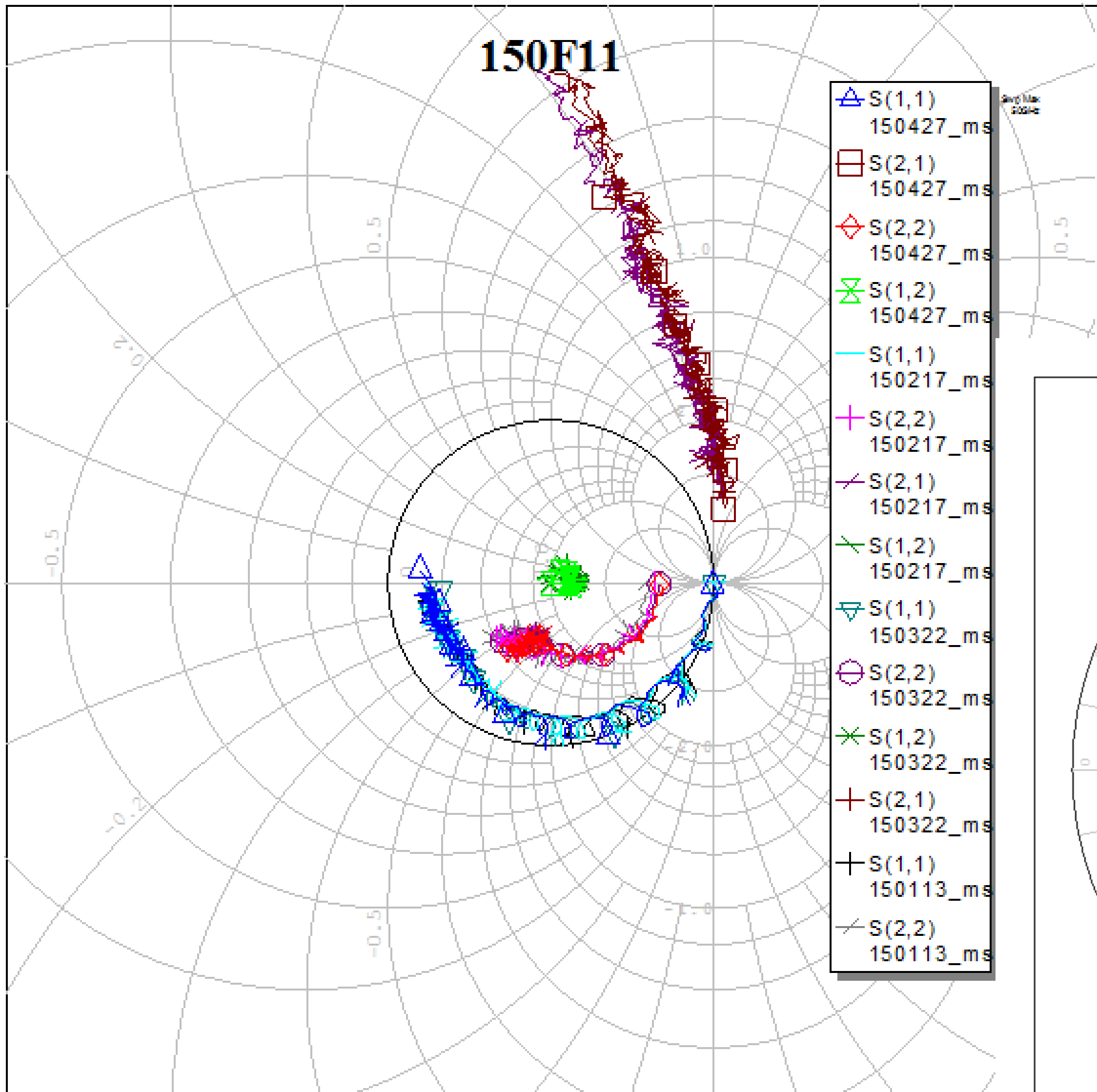
4x20 = 80

80310 3V 10 mA

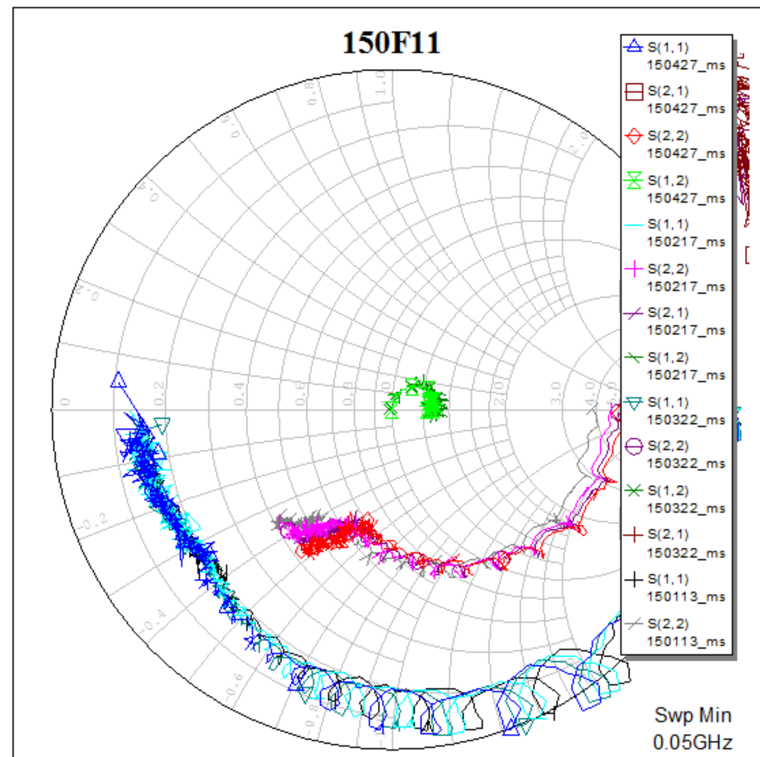
80413 4V 13 mA



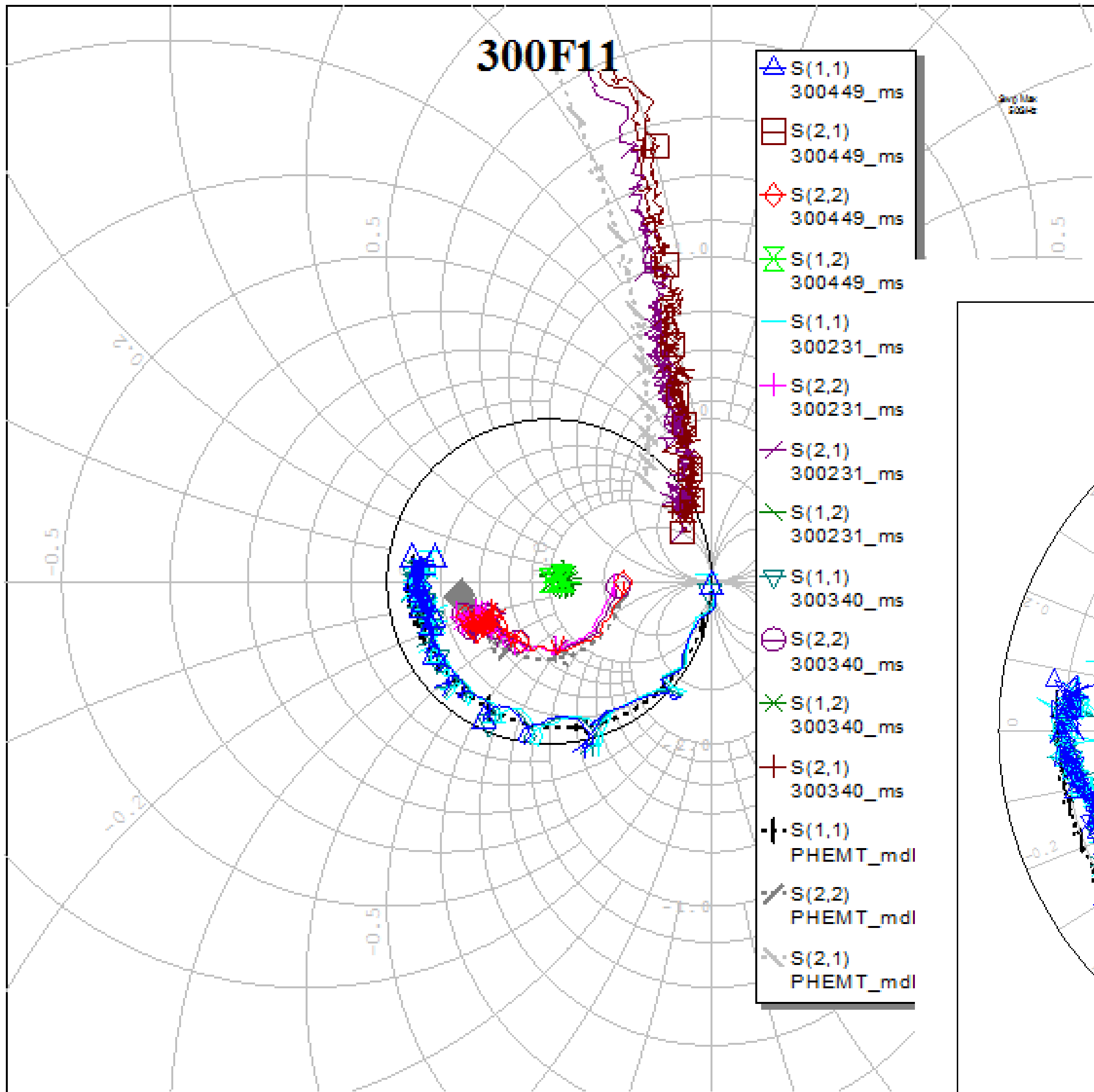
Devices 6x25 PHEMT



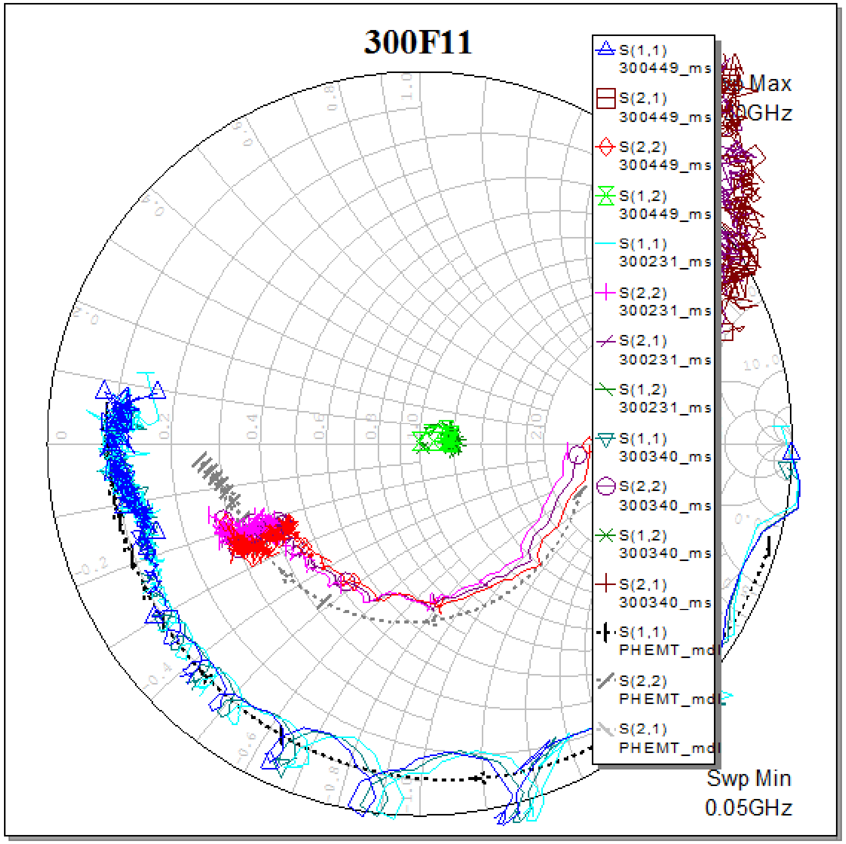
6x25 = 150
150113 1V 13 mA
150217 2V 17 mA
150322 3V 22 mA
150427 4V 27 mA



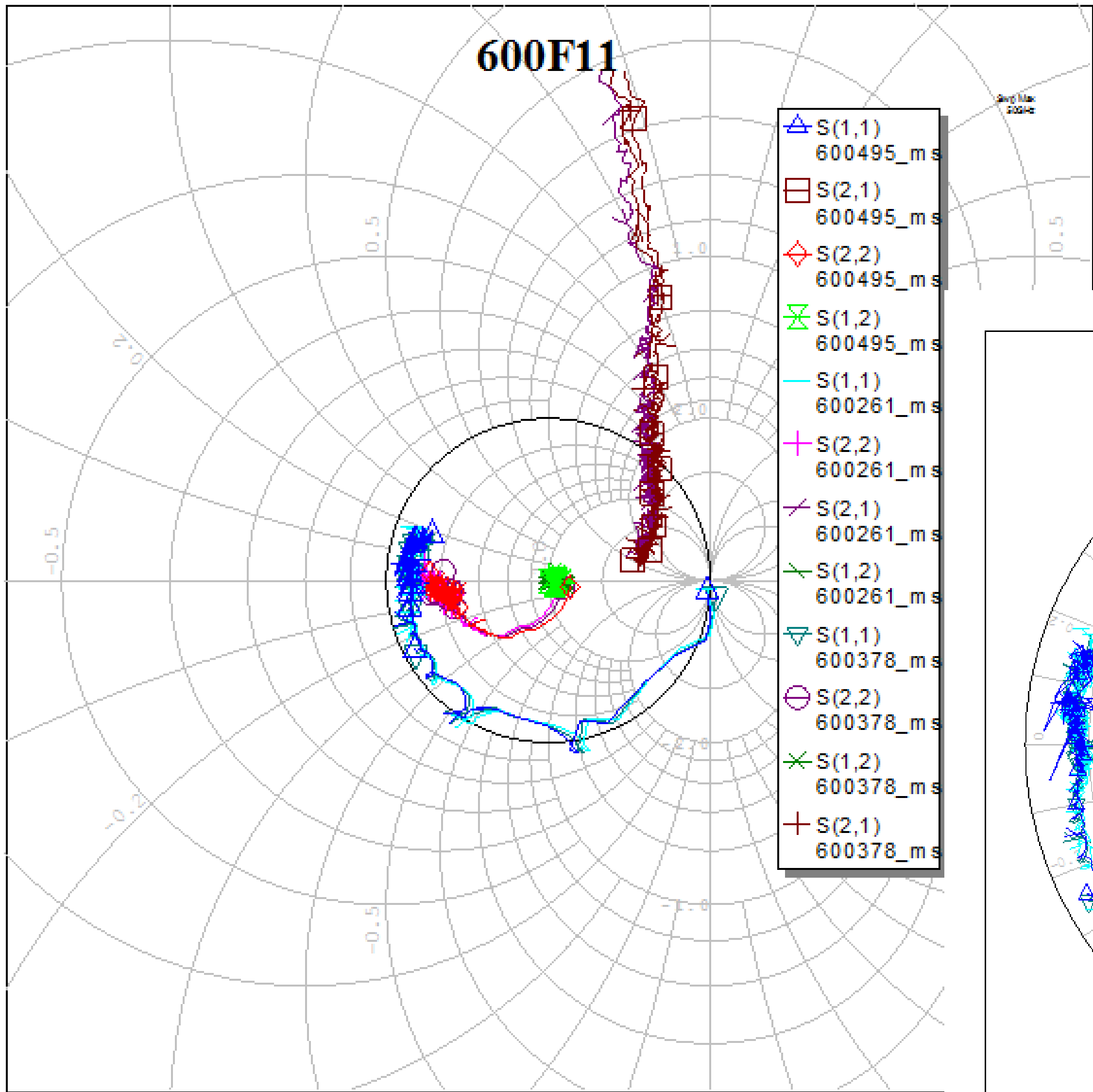
Devices 6x50 PHEMT (Meas. vs. PHEMT model)



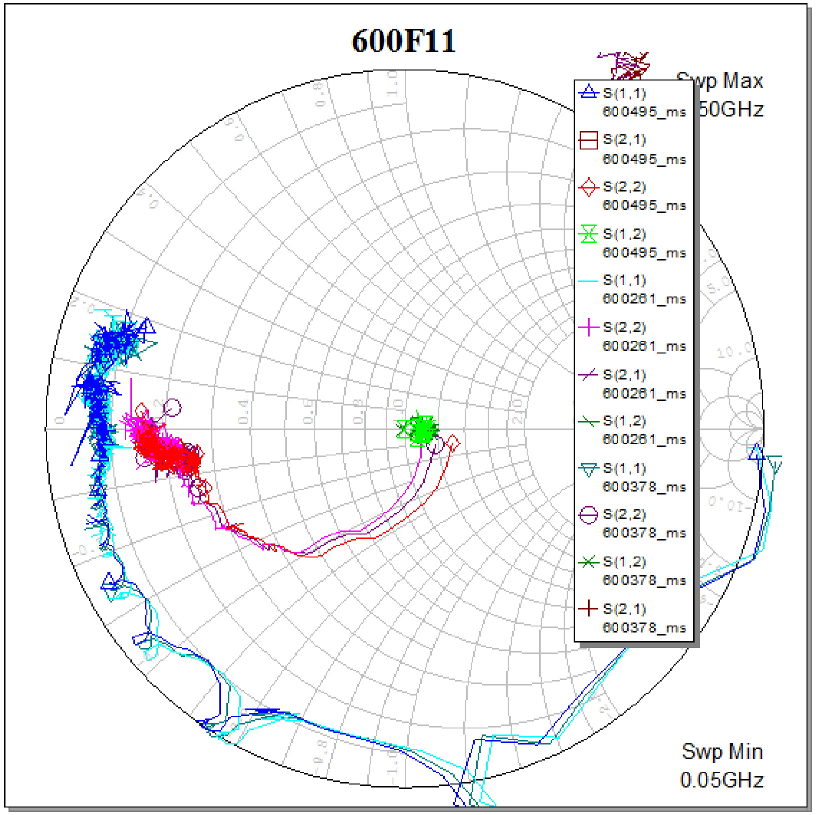
6x50 = 300
300137 1V 37 mA
300231 2V 31 mA
300340 3V 40 mA
300449 4V 49 mA



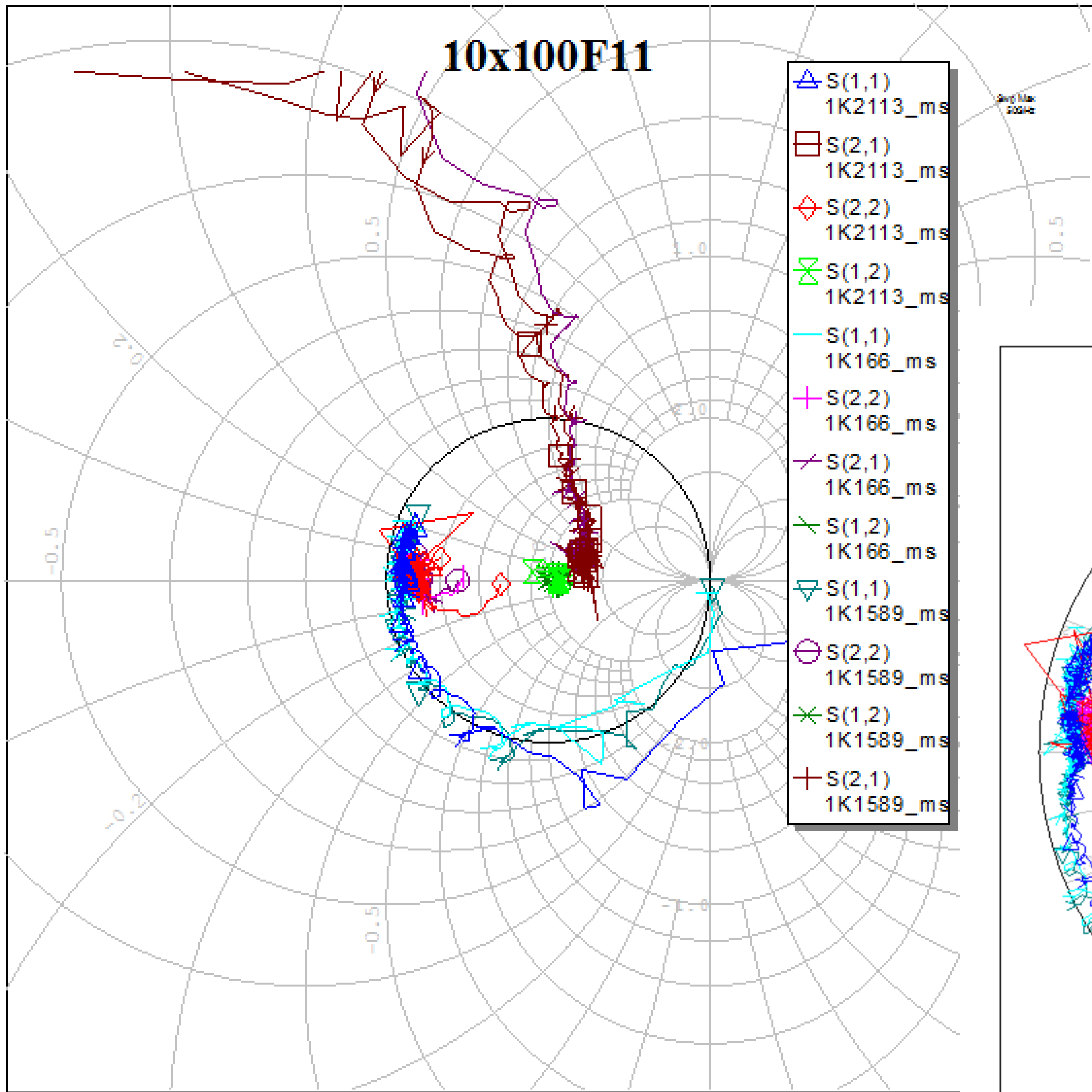
Devices 6x100 PHEMT



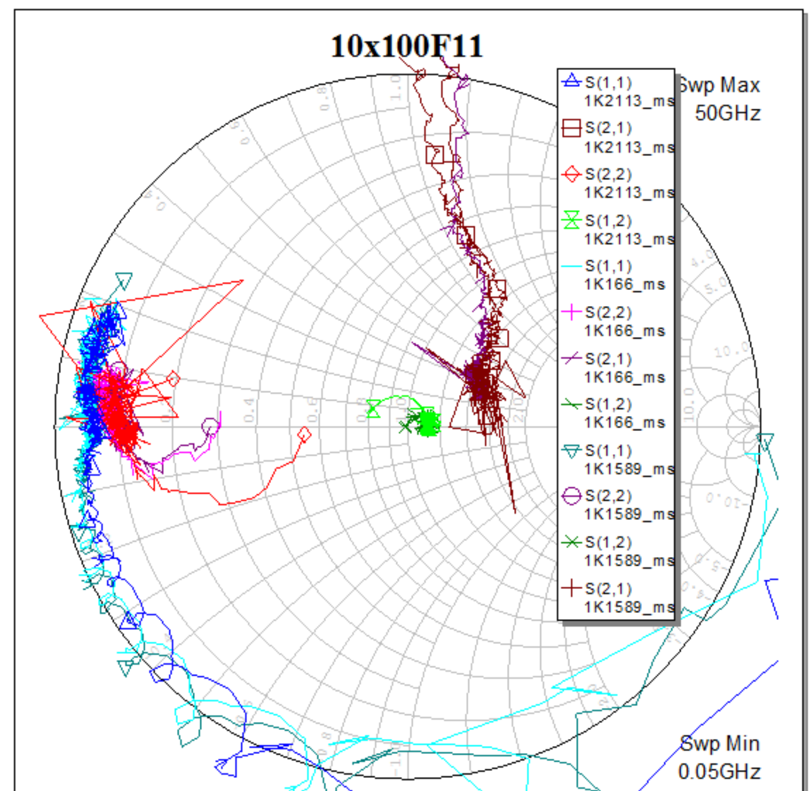
6x100 = 600
600154 1V 54 mA
600261 2V 61 mA
600378 3V 78 mA
600495 4V 95 mA



Devices 10x100 PHEMT

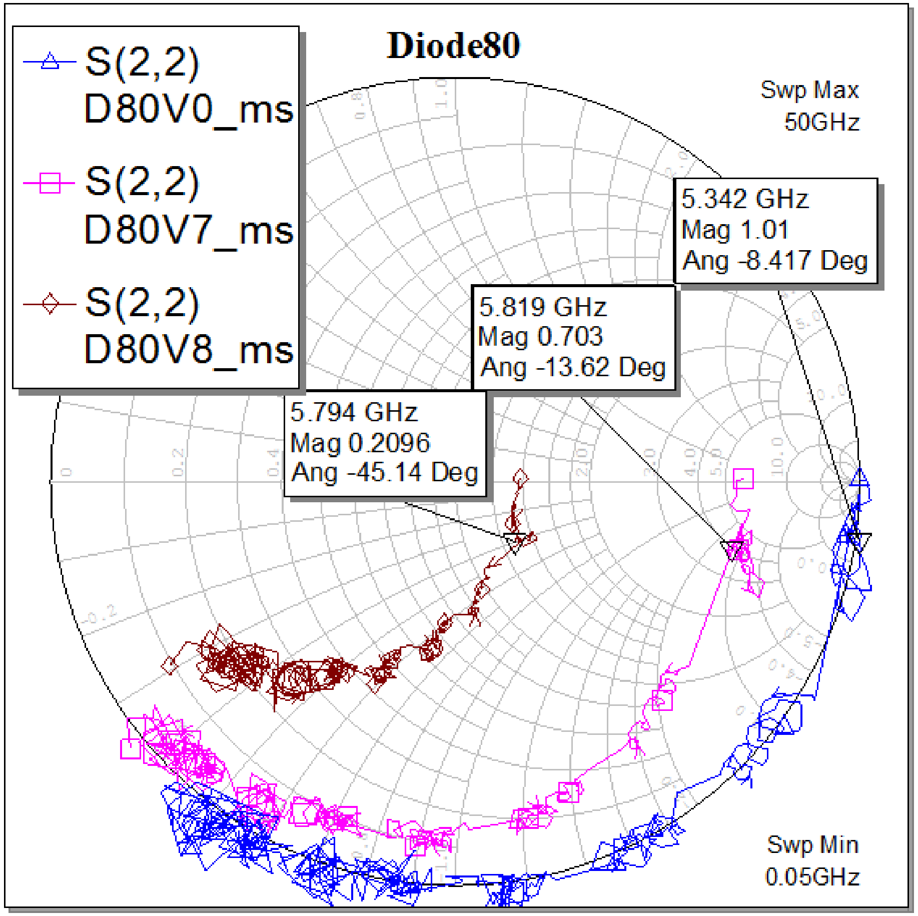


10x100 = 1K (JHU11PL8)
1K166 1V 66 mA
1K1589 1.5V 89 mA
1K2113 2V 113 mA



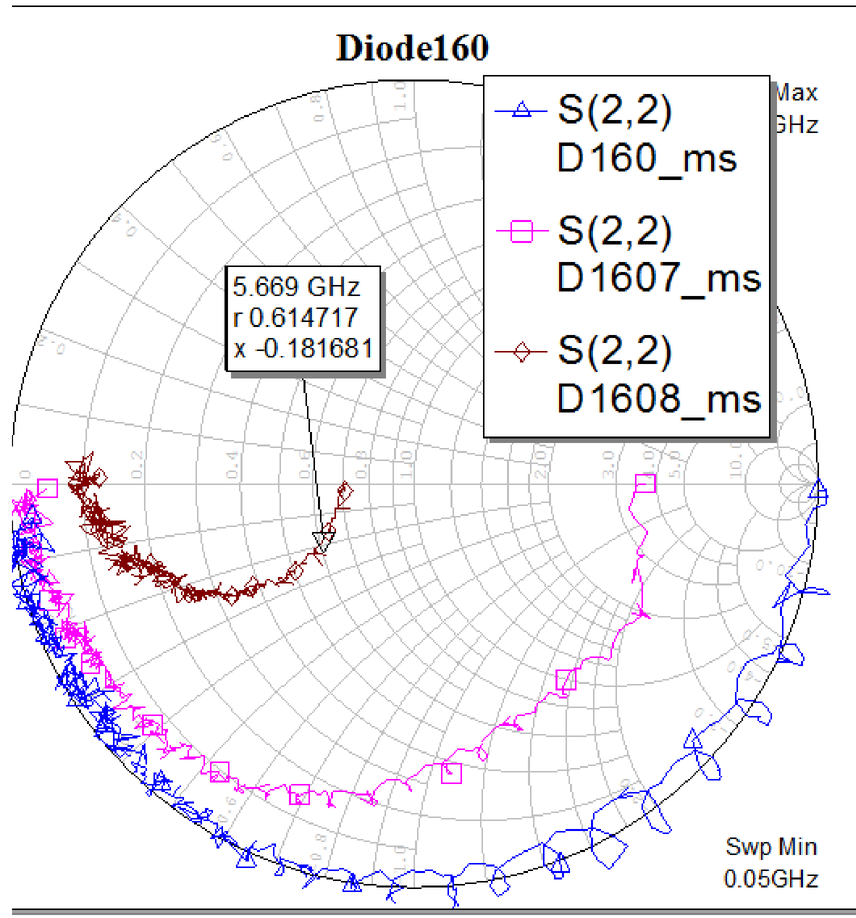
Diode 4x20 (0, 0.7, 0.8V)

4x20 = 80 Diode (S22 only)
d80v0 0V (poor match, looks like cap!)
d80v7 0.7V (good match)
d80v8 0.8V (better match!)



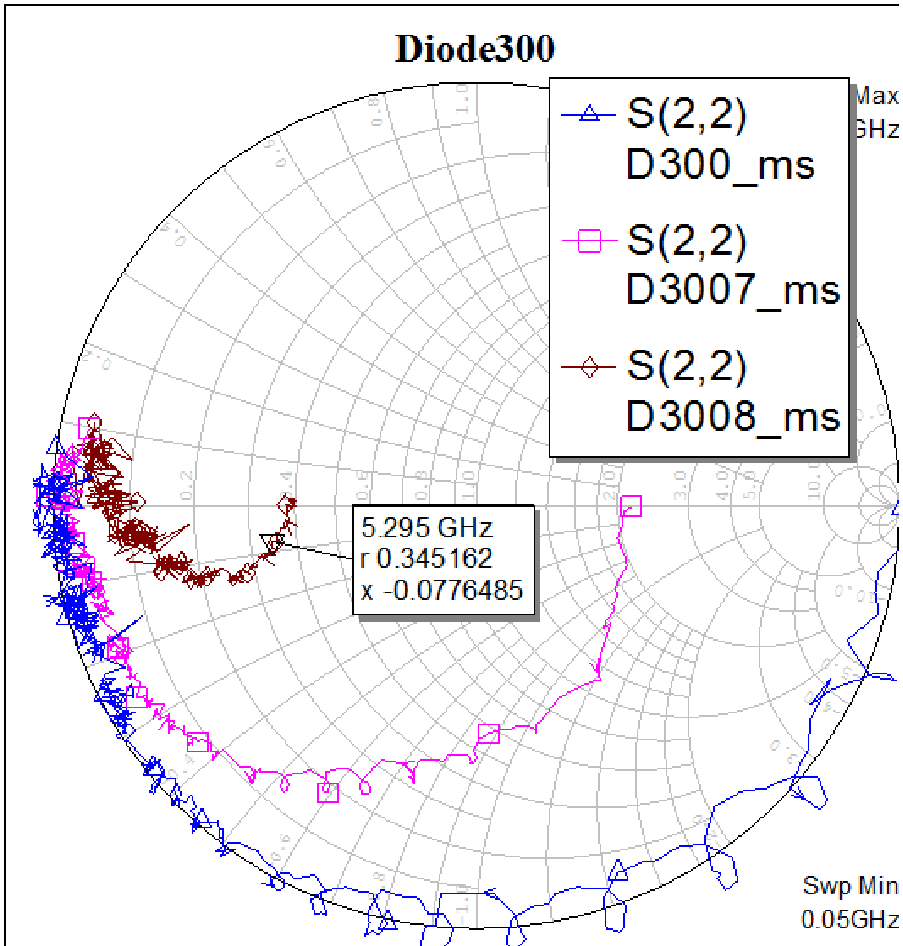
Diode 4x40 (0, 0.7, 0.8V)

Diodes 0, 0.7V, 0.8V
D160 0V
D1607 0.7V 1mA
D1608 0.8V 2mA



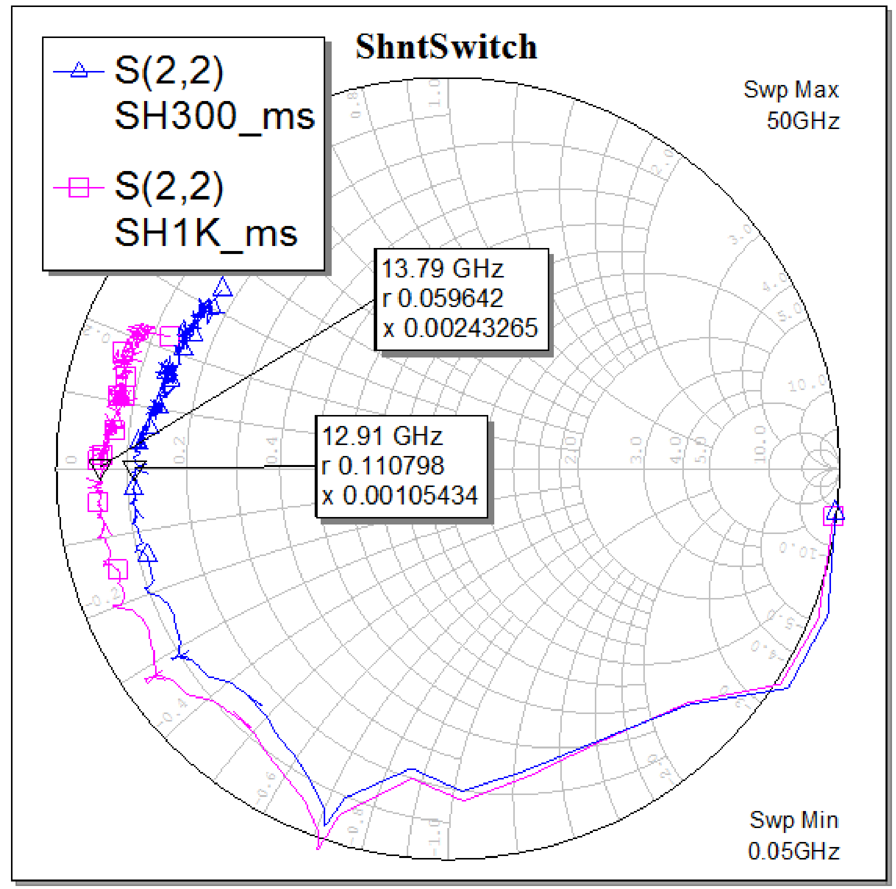
Diode 6x50 (0, 0.7, 0.8V)

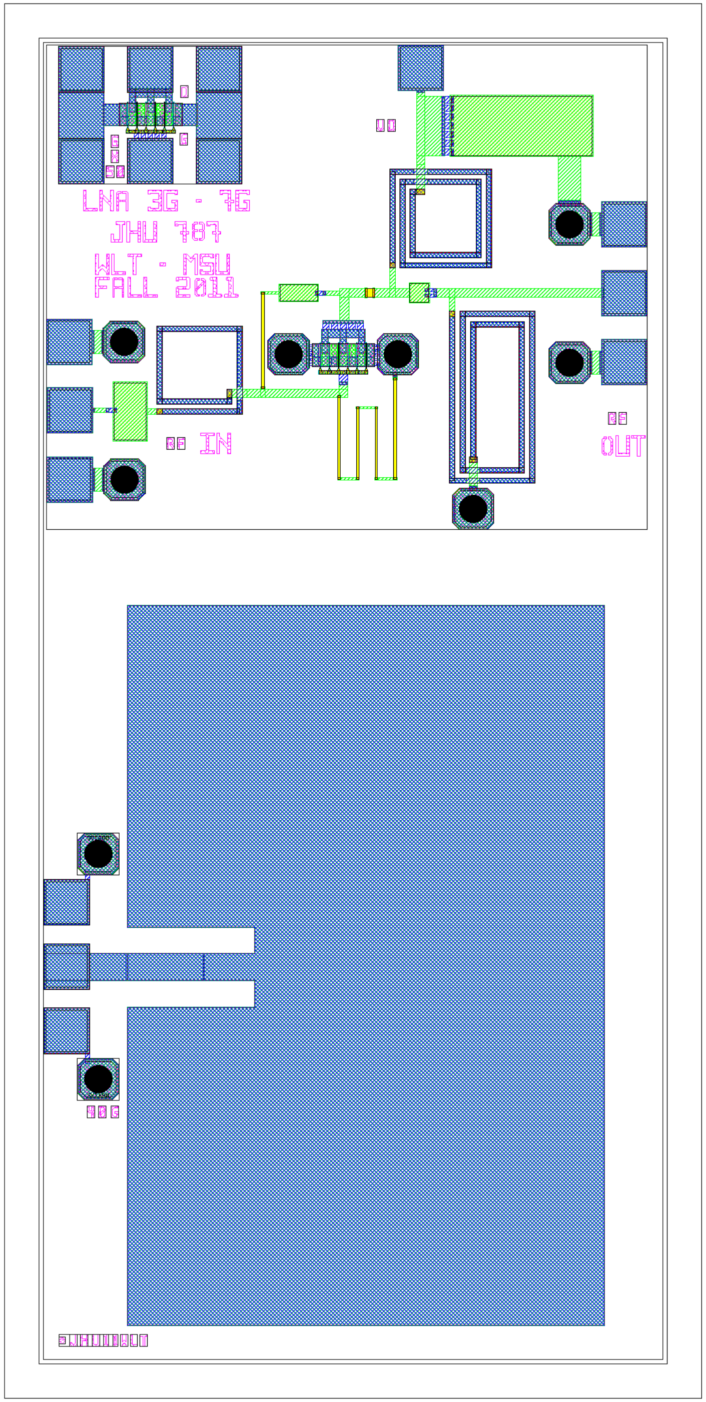
D300 0V
D3007 0.7V 1mA
D3008 0.8V 3mA



Shunt Switch 6x50, 10x100 (0V)

Shunt Switch (S22, 0V)
sh300 (6x50)
sh1K (10x100)





14) JHU11WLT

WLT LNA

Patch Antenna 40 GHz

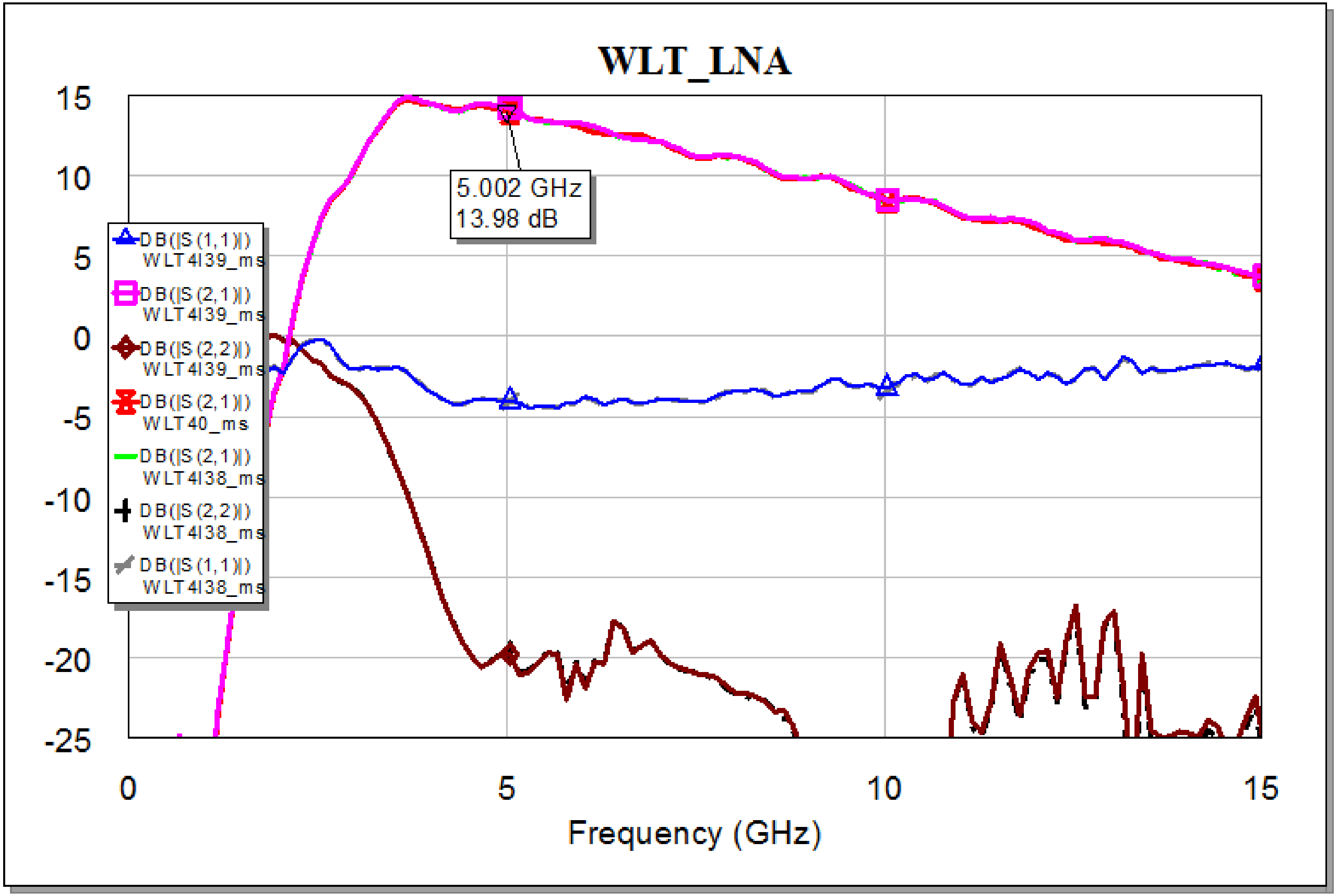
4V 35 mA (1 DC, 2RF)

(1 RF)

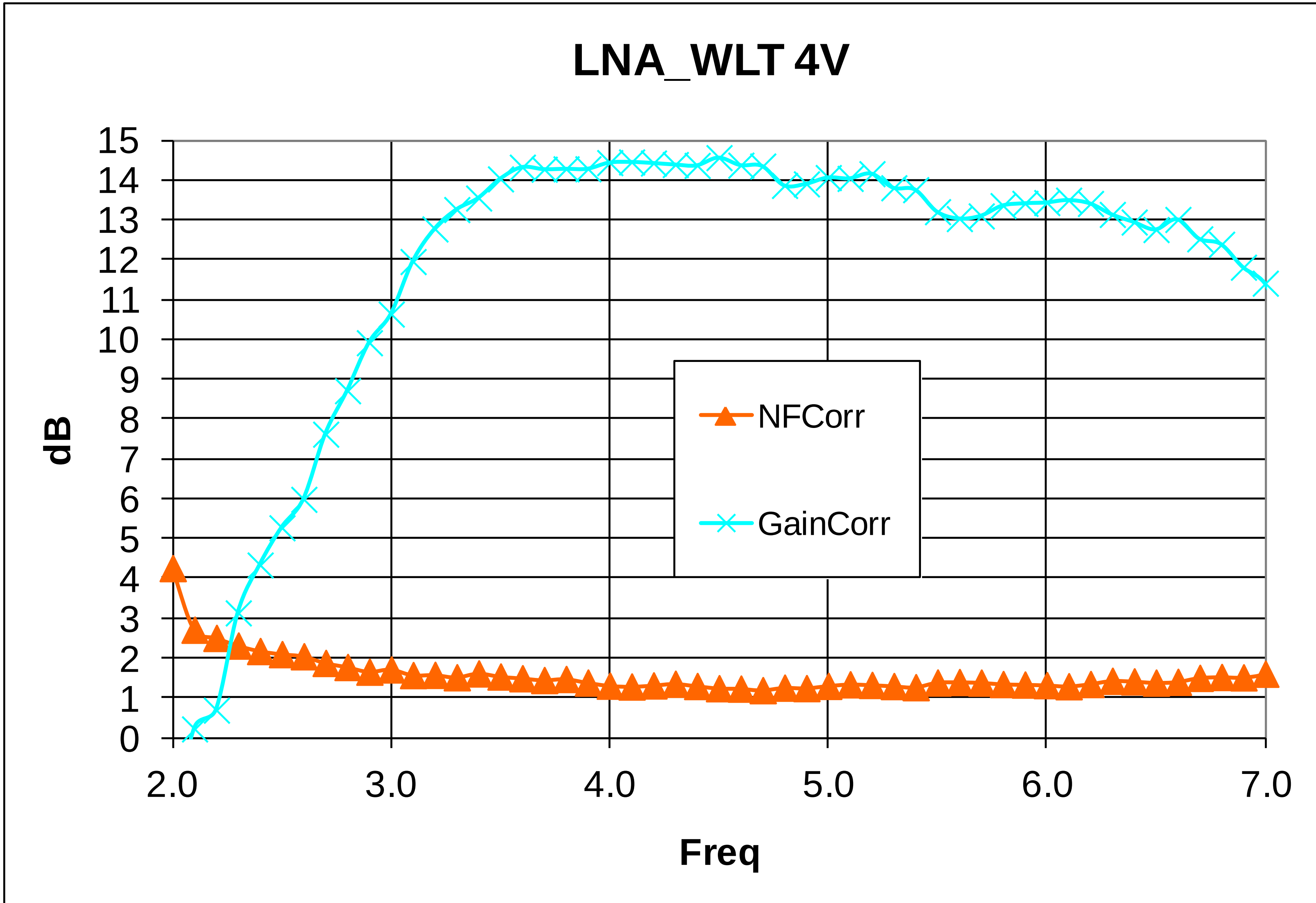
Broadband LNA design for constant flat noise figure. Worked well.

Patch Antenna at ~40 GHz—measured as one port only.

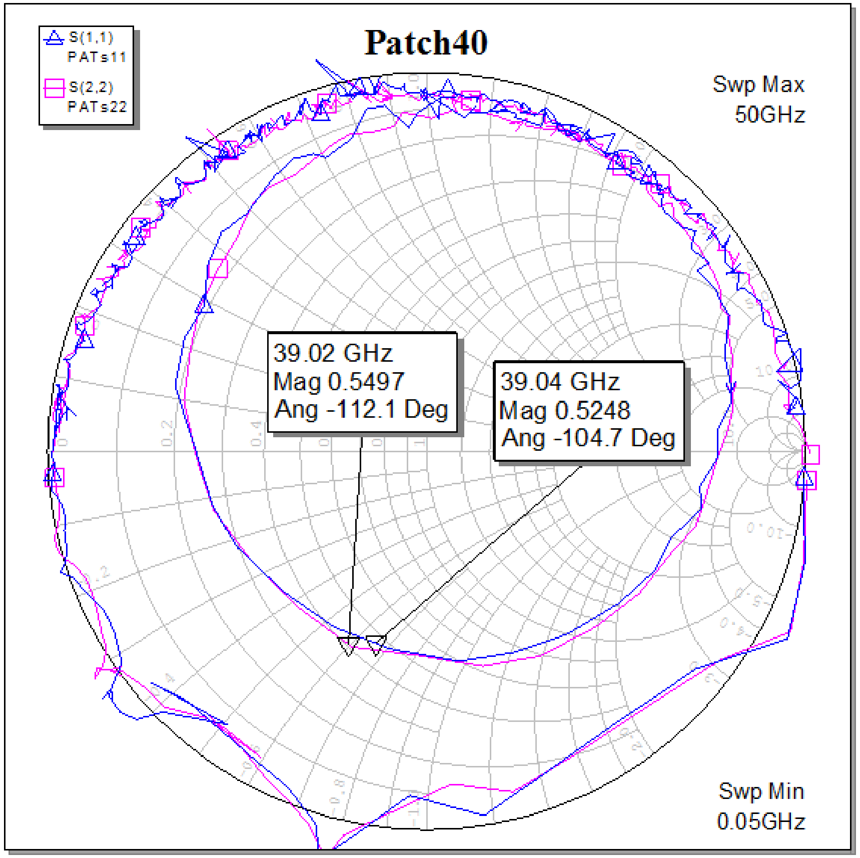
14) JHU11WLT
WLT LNA
Patch Antenna 40 GHz

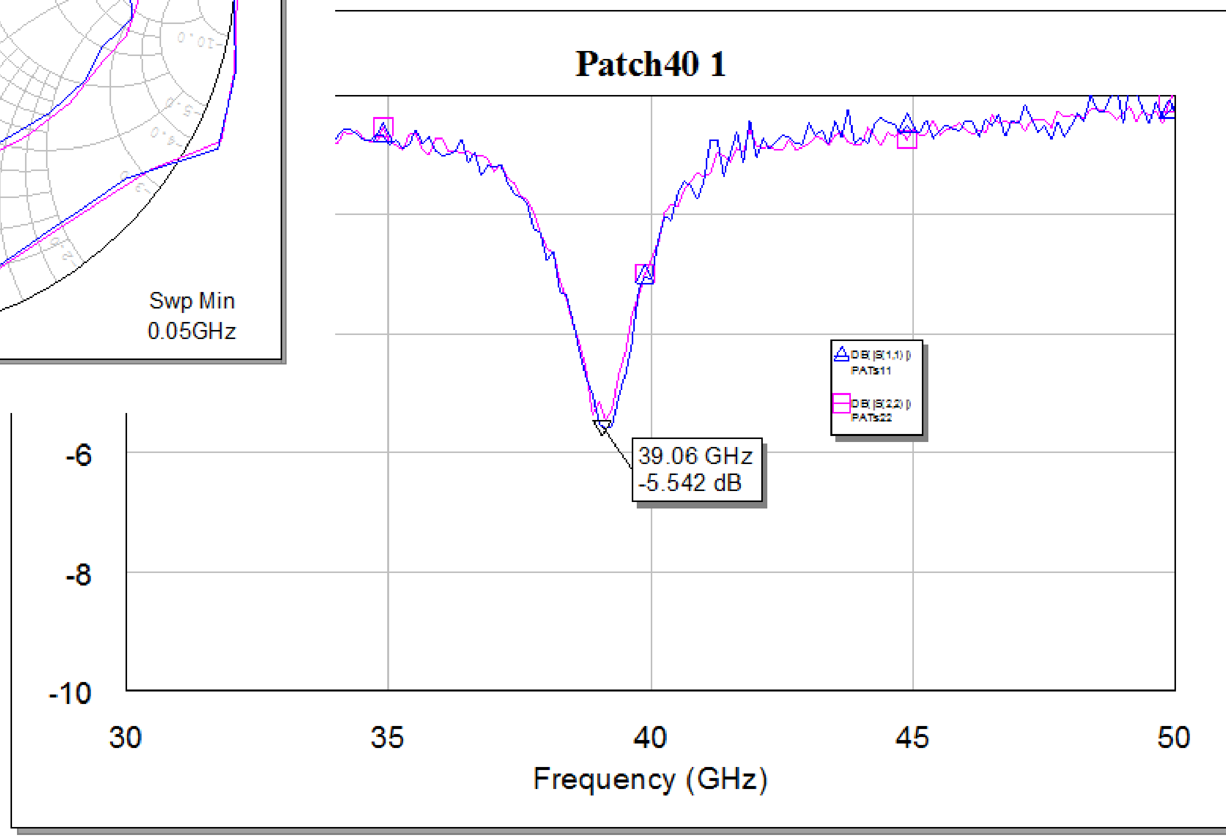


14) JHU11WLT
WLT LNA

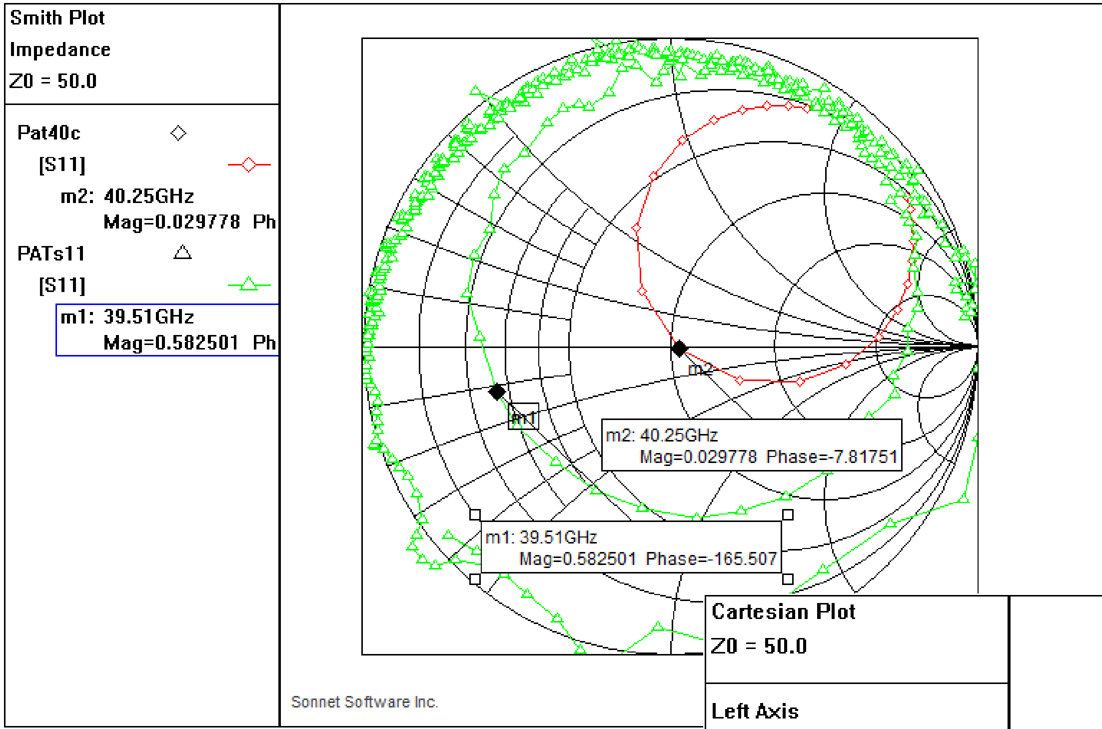


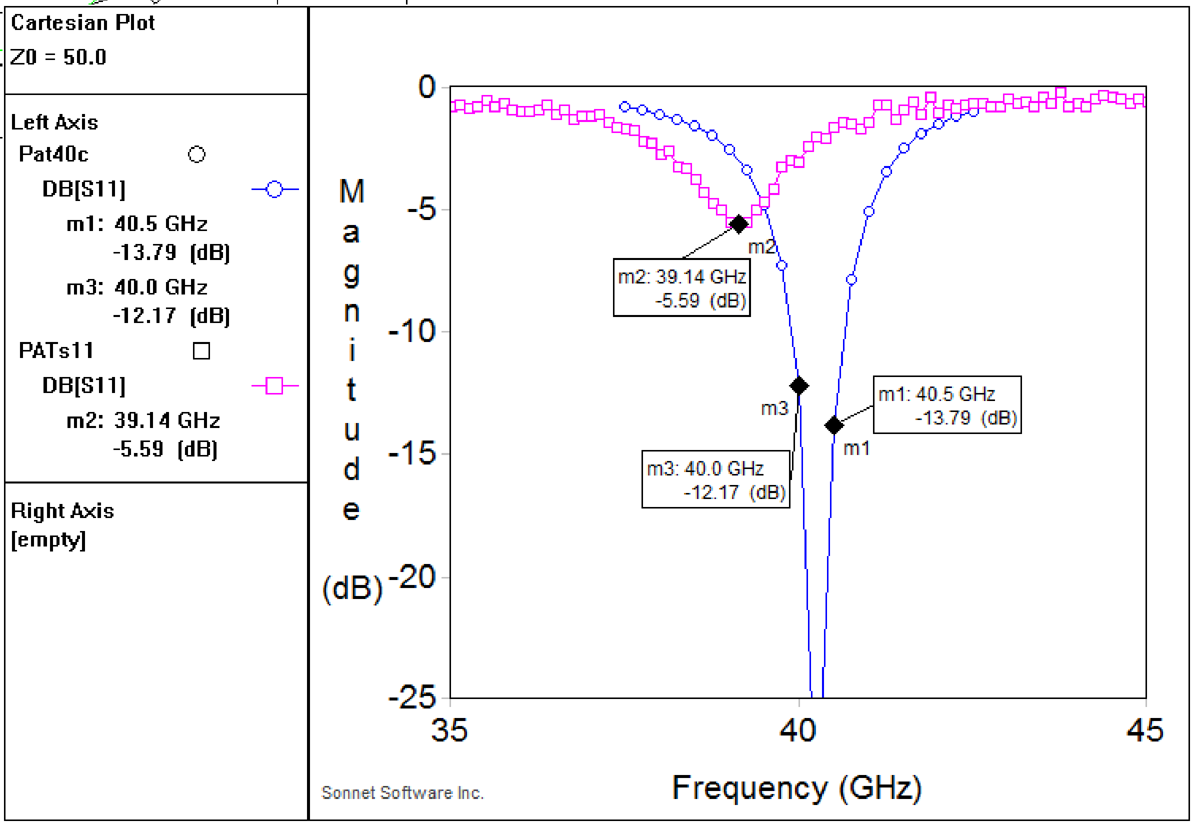
14) JHU11WLT
WLT LNA
Patch Antenna 40 GHz

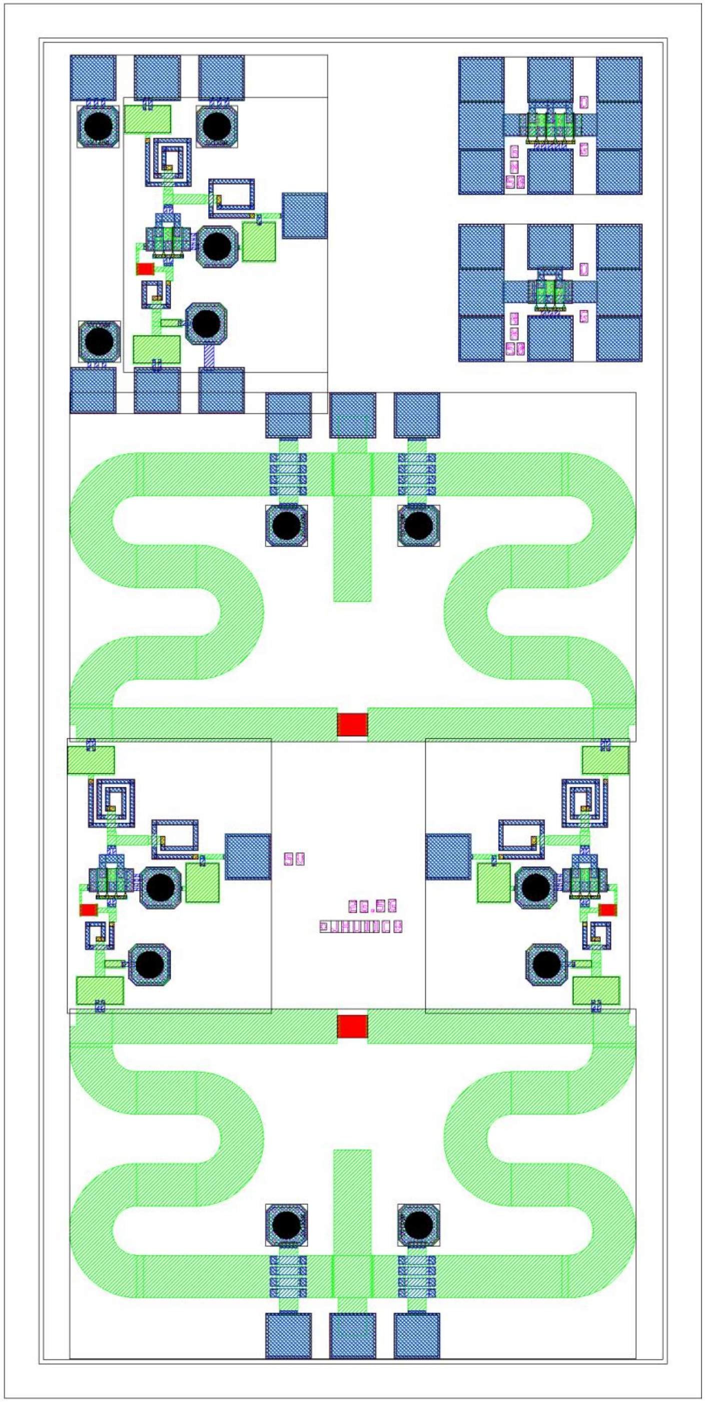




14) JHU11WLT
WLT LNA
Patch Antenna 40 GHz
vs. Sonnet







15) JHU11CW – Caroline Waiyaki
26 GHz Amp, combined
D6x50, D4x50

5V 45 mA (2 DC, 2RF)

5V 45 mA (1 DC, 2RF)

Single Stage Amplifier and parallel combined stages compared favorably to simulations for small signal parameters and DC bias.

15) JHU11CW – Caroline Waiyaki
26 GHz Amp, combined