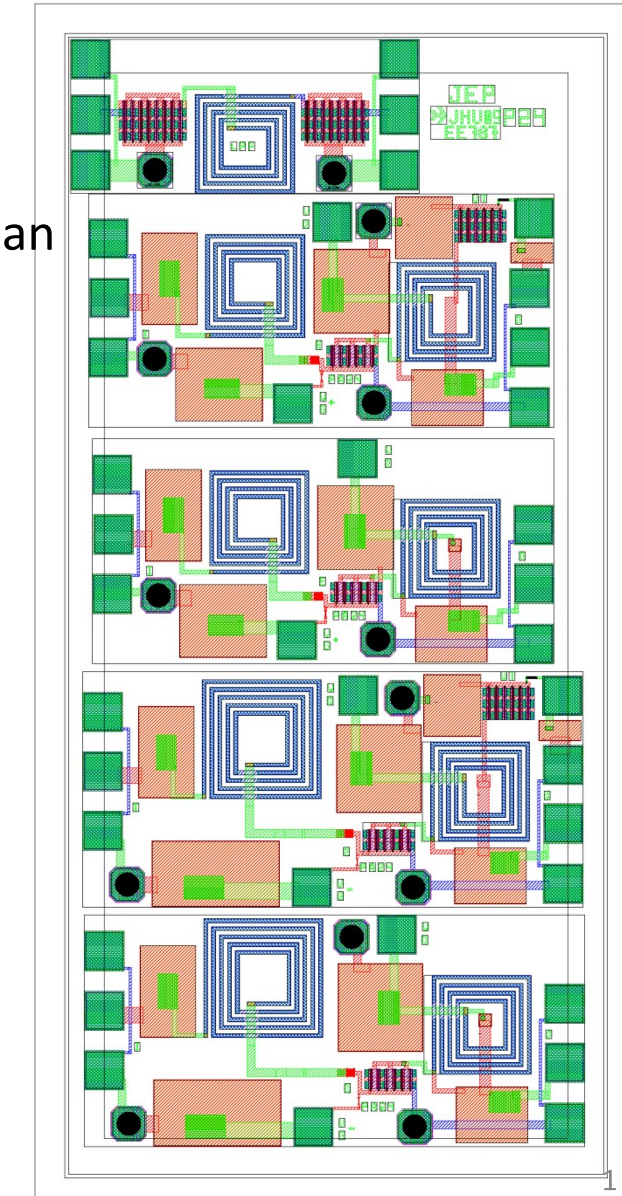
Test Plan JHU 2009 MMIC Designs

J.E. Penn

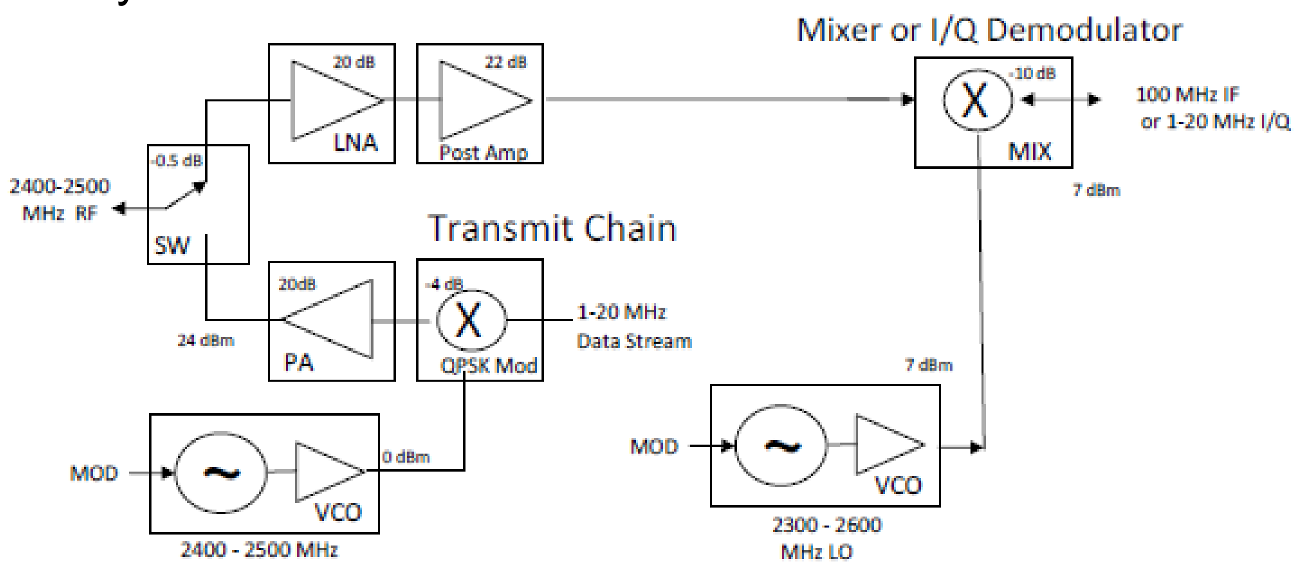
DRV: Robert Schaefer
LN1: Michael Dauberman
LN2: Clay Couey
PA1: Rowland Foster
PA2: Ken McKnight
IQM: David Nelson
MIX: Steve Moeglein
TRS: Chue Lee
VC1: Clay Couey
VC2: Dan Matlin

TR1: Chue Lee,
Michael Dauberman,
Rowland Foster



Test Summary for Fall JHU MMIC Designs 2009

The student projects for the Fall of 2009 were to design the RF blocks for a 2.4 GHz communications system. Below is a block diagram of the generic system with students designing Voltage Controlled Oscillators (VCO), amplifiers for low noise, power, and small signal drivers (LNA, PA, DRV), mixers, and a transmit/receive (TR) Switch. While the designs done over six weeks or so are individual die, the students were asked to think about the interaction of their circuit and successive circuits in the block diagram. An LNA, TR Switch, and PA were combined into a class die to test the affects of cascading some of the circuits in the system.



Chip Set for the 2400 - 2500 MHz ISM Bands

Test Summary for Fall JHU MMIC Designs 2009 (cont.)

The student designs generally DC biased and measured very close to what was expected from the simulations. Various test PHEMTs and circuits were included on the tile—where space was available. Four PHEMT test devices-Emode and Dmode; 4x15 um and 6x50 um--were measured and compared very well with typical TOM3 and TOM4 model simulations. One of the power amplifiers was conditionally stable at a lower than nominal DC bias for s-parameter measurements, but was tested successfully at nominal DC bias for power out versus power in performance that compared favorably with simulations. Another power amplifier design, a Doherty amp, could only be partially measured at lower DC bias conditions because it was oscillating during test. Overall, it was a very successful JHU Fall 2009 MMIC class for the design, fabrication, and test of the student's MMIC designs. Thanks again to TriQuint Semiconductor for fabrication, Gary Wray of AWR for lots of support, and AWR and Agilent for loaning software for the student's use in the course, and to my co-teacher, Dr. Michel Reece.

JEPenn

JHU09LN1: Michael Dauberman

Summary: 2.4 GHz LNA biased as expected and performed very close to simulations. Approximately 1 dB NF with 19 dB gain.

Test:

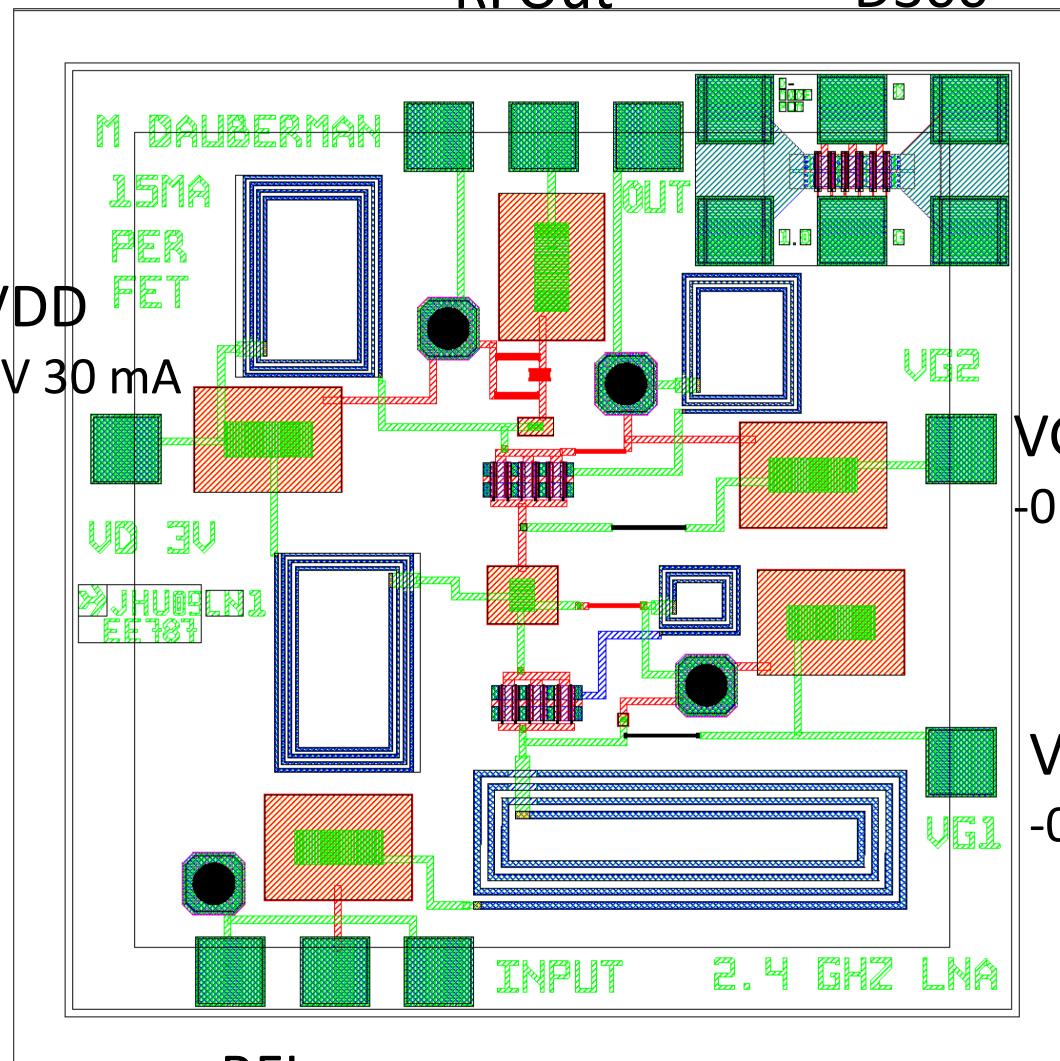
Power up LNA
Measure RFIn to RFOut
LNA: VG -0.5V VD 3V at 30 mA

VG1	VG2	VDD	Name
-0.5V	-0.5V	3V 26 mA	LN1V3
-0.5V	-0.5V	3.6V 30 mA	LN1V36

Good Gain, Good NF!

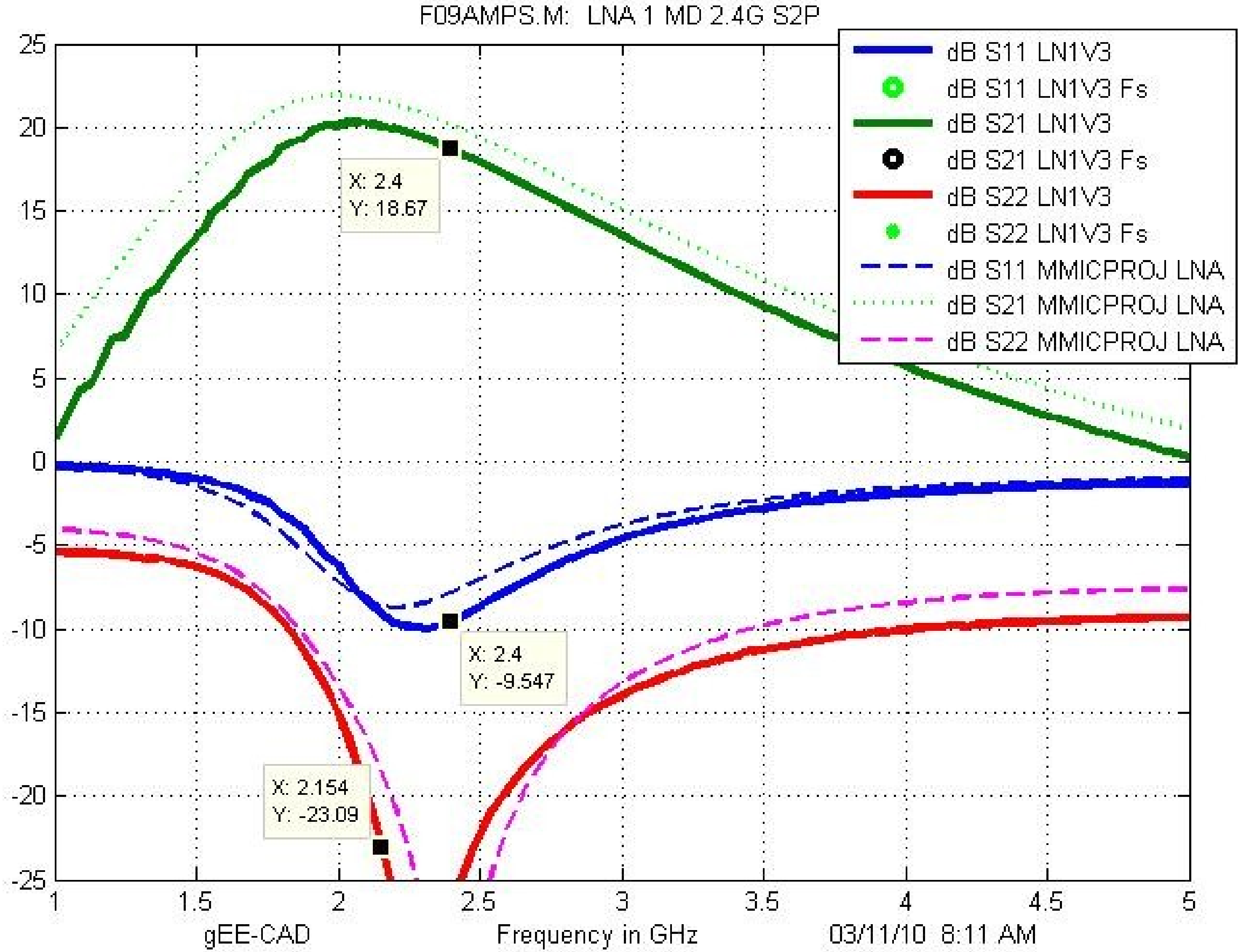
TEST PHEMT Dmode 300 um

VG	VDD	Name
-0.5V	3V 15 mA	D300V3I15
-0.25V	4V 42 mA	D300V4I42



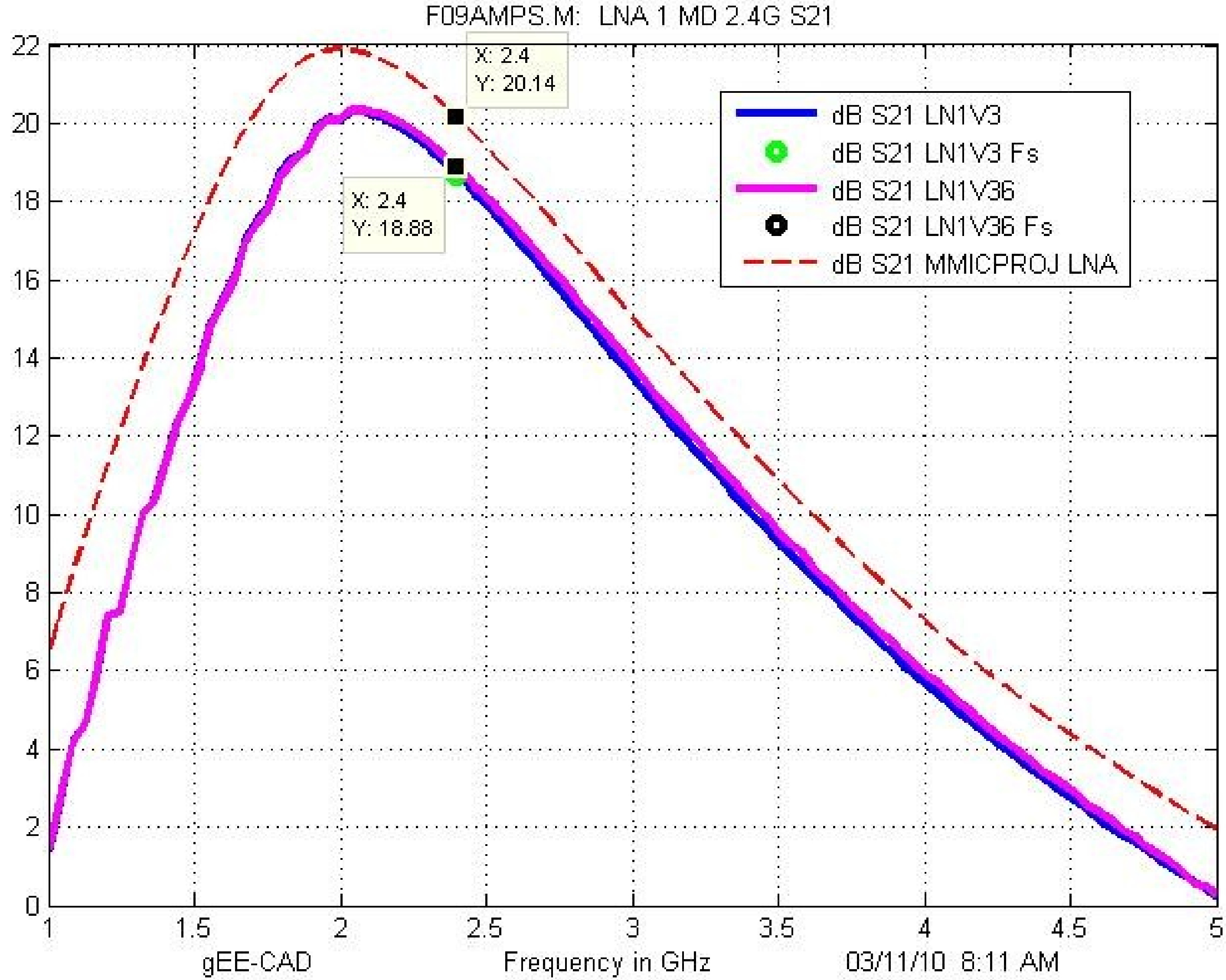
JHU09LN1

S-Parameters Measurement (Solid) vs. Simulation (Dotted)



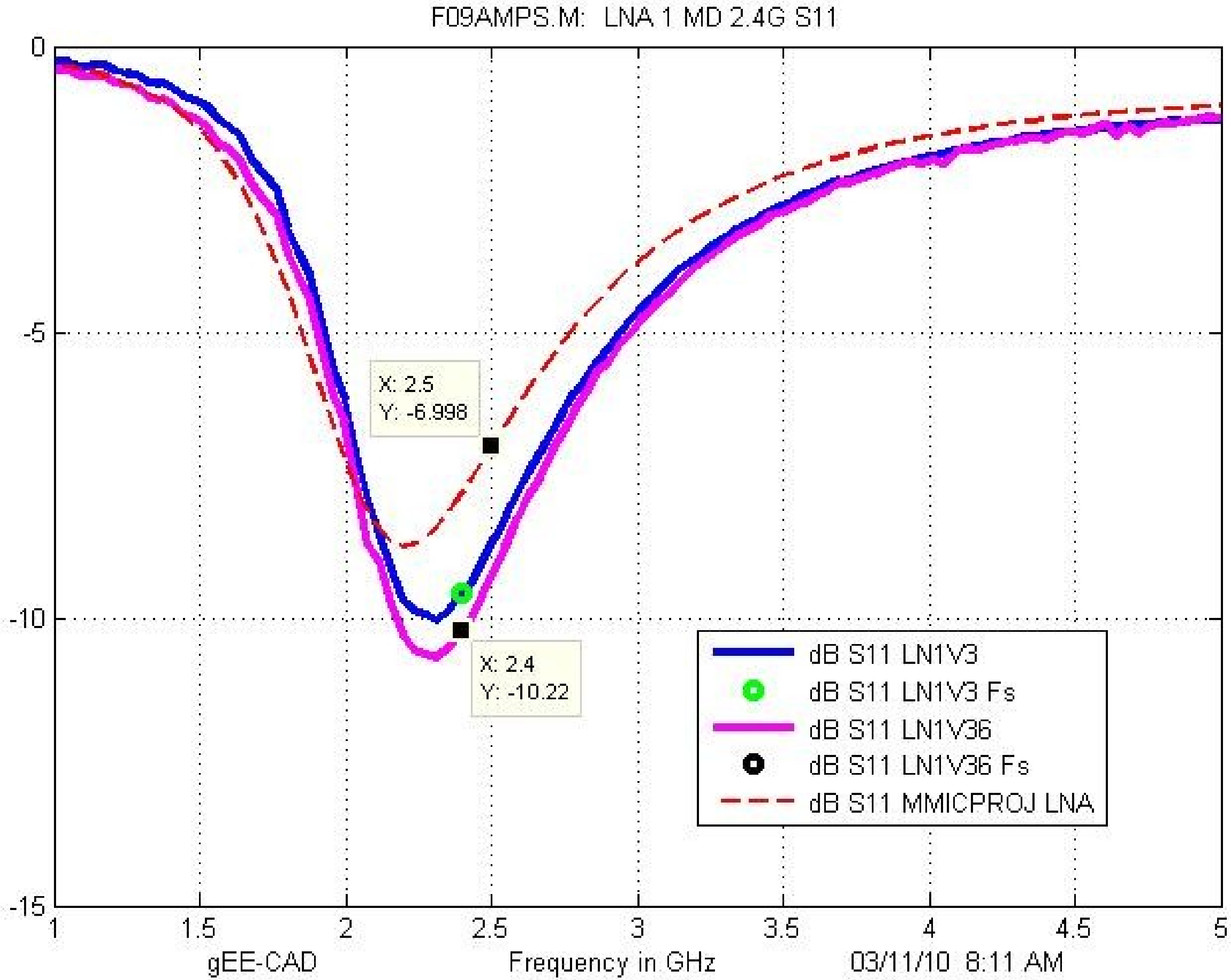
JHU09LN1

Gain Measurement (Solid) vs. Simulation (Dotted)



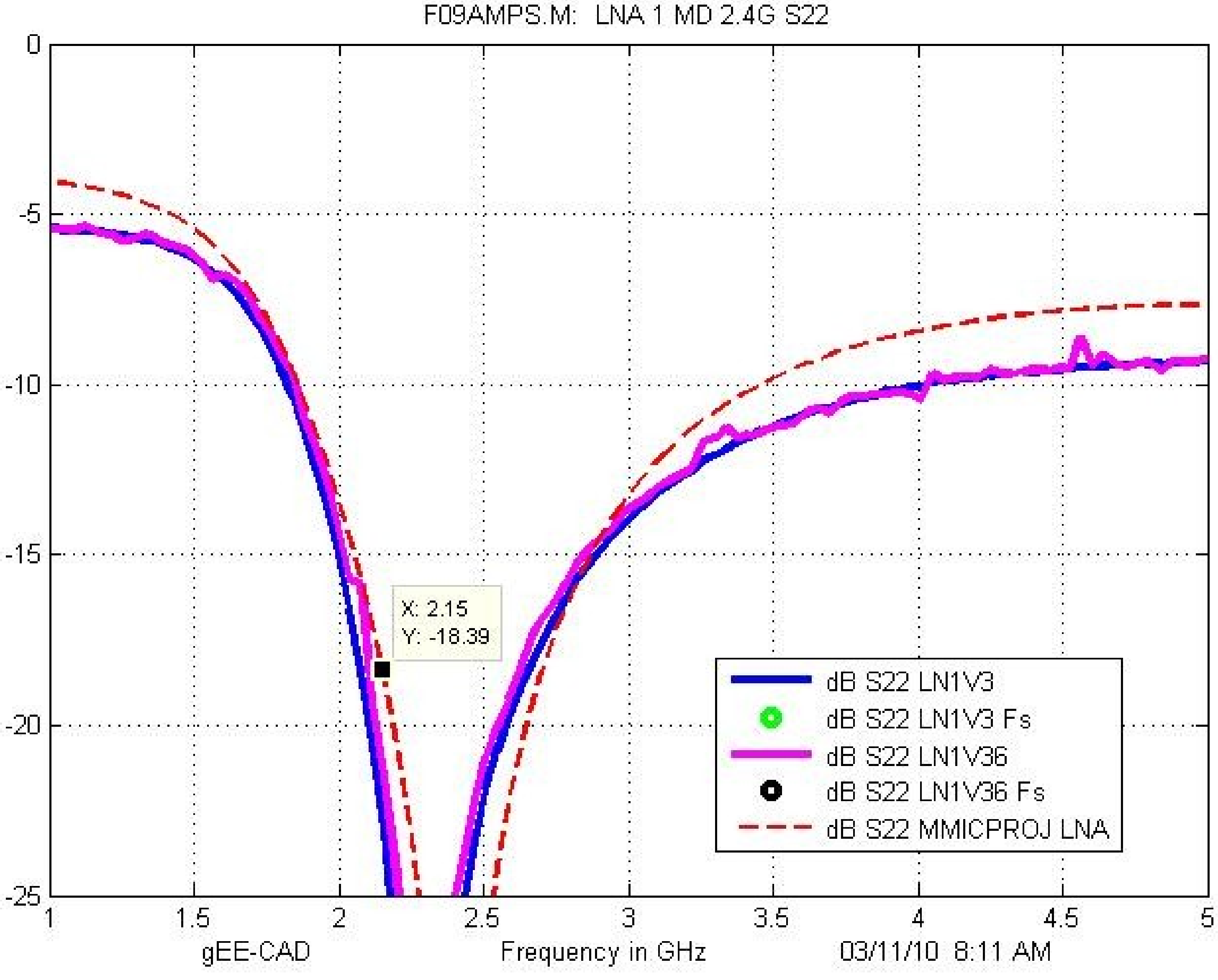
JHU09LN1

Return Loss S11 (Solid) vs. Simulation (Dotted)



JHU09LN1

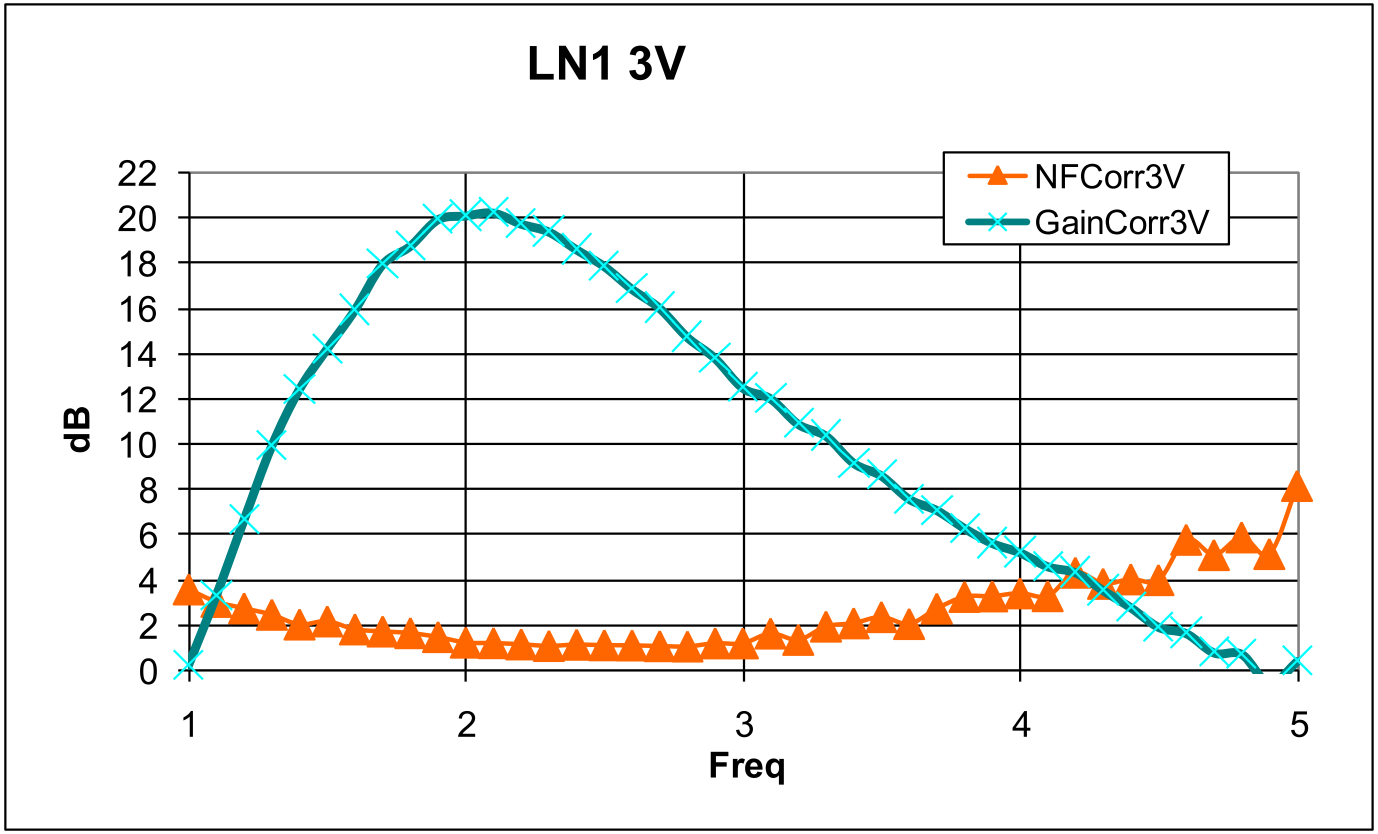
Return Loss S22 (Solid) vs. Simulation (Dotted)



JHU09LN1

Measured NF

Freq(GHz)	Gaincorr	NFCorr2
1.20	6.64	2.75
1.30	9.91	2.47
1.40	12.42	2.04
1.50	14.22	2.18
1.60	15.93	1.83
1.70	17.95	1.74
1.80	18.77	1.66
1.90	19.94	1.49
2.00	20.11	1.25
2.10	20.23	1.22
2.20	**19.75**	**1.17**
2.30	**19.40**	**1.10**
2.40	**18.61**	**1.16**
2.50	**17.87**	**1.13**
2.60	**16.87**	**1.12**
2.70	16.02	1.09
2.80	14.74	1.08
2.90	13.81	1.22
3.00	12.49	1.21
3.10	12.02	1.65
3.20	10.89	1.37



JHU09PA1 Rowland Foster

Summary: 2.4 GHz PA worked well but had some marginal stability during s-parameter measurements. Achieved better results during Pout vs. Pin measurements.

Test:

Power up PA

Measure RFIn to RFOut

PA: VG -0.25V VD 3V at 300 mA

VG1 VG2 VDD Name

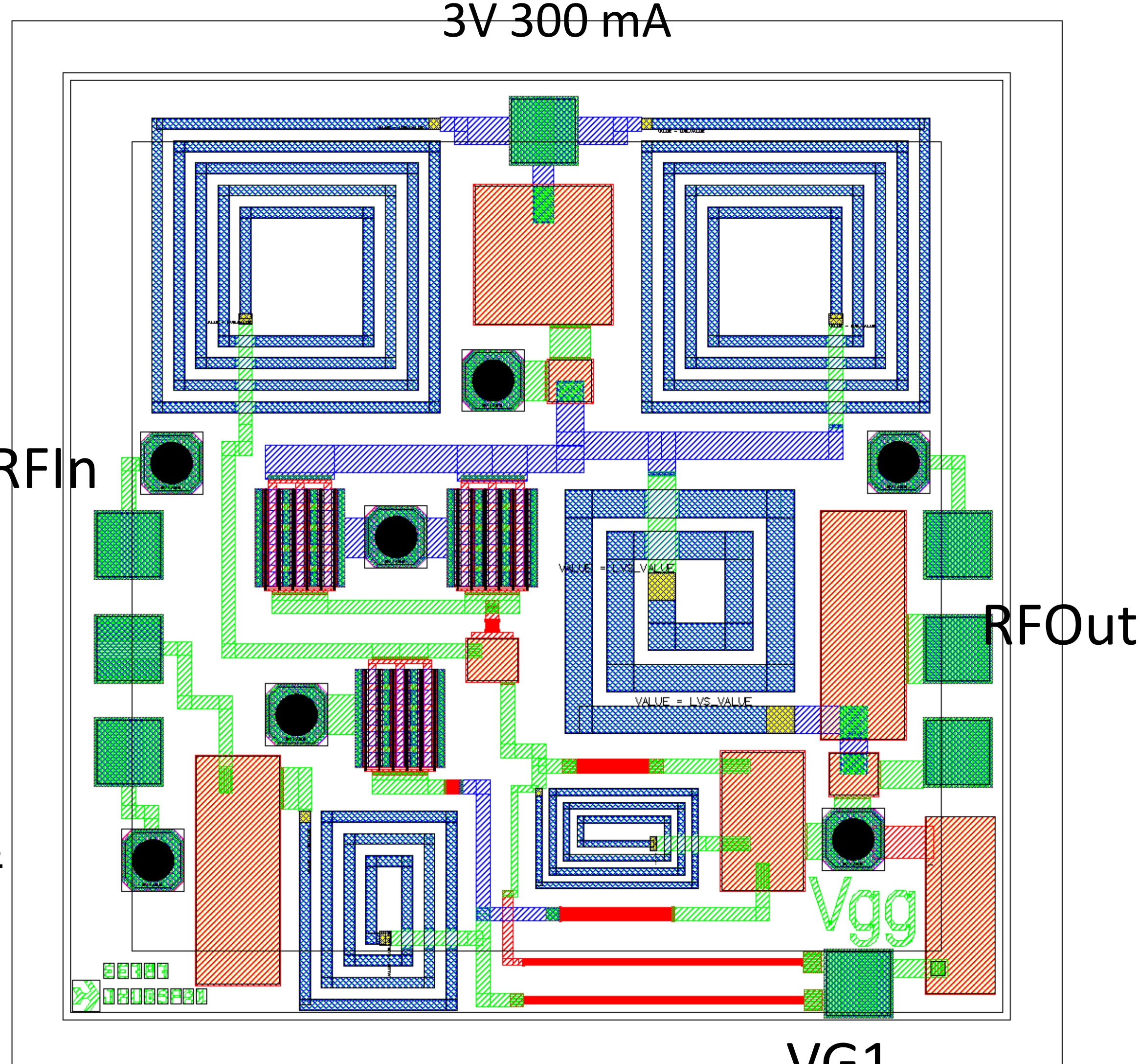
-0.7V 3V 31 mA PA1331

-0.7V 3V 33 mA Die #2 PA1333B

Low Gain, Low DC Bias due to potential instabilities. Able to Bias w/ proper DC and good gain for Pout vs. Pin Measurements. High DC power consumption for individual die testing of such a small die!

VDD

3V 300 mA

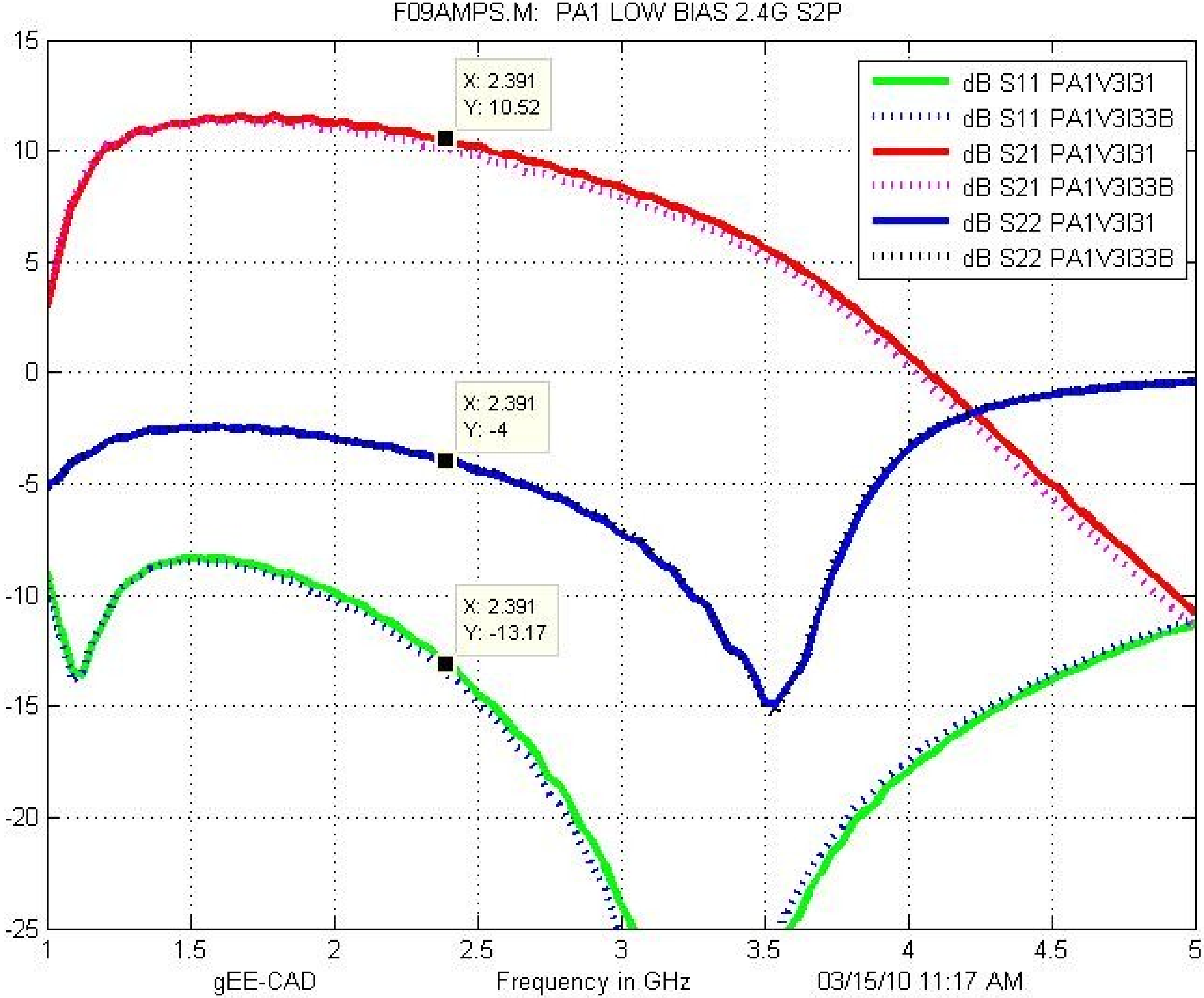


VG1

-0.25V

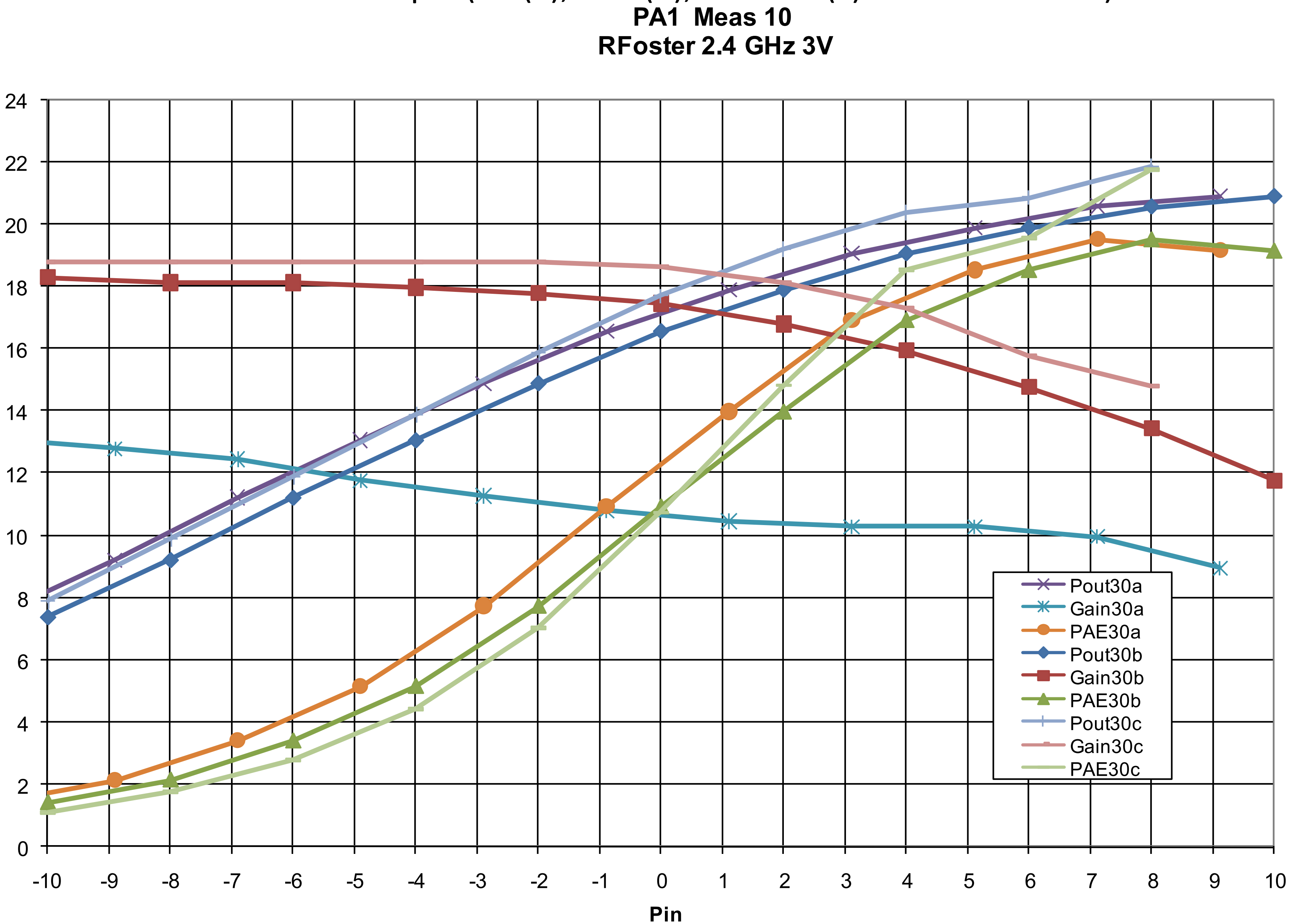
JHU09PA1

PA1 Two Die with Low DC Bias to avoid stability problems (31 mA vs. 300 mA)



JHU09PA1

PA1 Pout at 3 DC bias pts (35 (a), 128 (b), 181 mA (c) vs. 300 mA sim.)



JHU09PA1

PA1 Pout at 3 DC bias pts (35 (a), 128 (b), 181 mA (c) vs. 300 mA sim.)

2.4 GHz	Die#1	**PAD24V GHz Dmode Fall09 TQPED**				3.0V ;35 mA		vgs=-0.6 or -0.68V	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.0V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	1.33	-10.90	2.23	13.13	35	105.0	1.67	1.6	1.5
-8.0	3.00	-8.90	3.90	12.80	36	108.0	2.45	2.3	2.2
-6.0	4.67	-6.90	5.57	12.47	38	114.0	3.61	3.2	3.0
-4.0	6.00	-4.90	6.90	11.80	42	126.0	4.90	3.9	3.6
-2.0	7.50	-2.90	8.40	11.30	47	141.0	6.92	4.9	4.5
0.0	9.00	-0.90	9.90	10.80	54	162.0	9.77	6.0	5.5
2.0	10.67	1.10	11.57	10.47	65	195.0	14.35	7.4	6.7
4.0	12.50	3.10	13.40	10.30	80	240.0	21.88	9.1	8.3
6.0	14.50	5.10	15.40	10.30	97	291.0	34.67	11.9	10.8
8.0	16.17	7.10	17.07	9.97	116	348.0	50.93	14.6	13.2
10.0	17.17	9.10	18.07	8.97	134	402.0	64.12	16.0	13.9

2.4 GHz	Die#1	**PAD24 GHz Dmode Fall09 TQPED**				3.0V; 128 mA		vgs=-0.3V	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.0V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	6.50	-10.90	7.40	18.30	127	381.0	5.50	1.4	1.4
-8.0	8.33	-8.90	9.23	18.13	128	384.0	8.38	2.2	2.1
-6.0	10.33	-6.90	11.23	18.13	128	384.0	13.27	3.5	3.4
-4.0	12.17	-4.90	13.07	17.97	129	387.0	20.28	5.2	5.2
-2.0	14.00	-2.90	14.90	17.80	131	393.0	30.90	7.9	7.7
0.0	15.67	-0.90	16.57	17.47	136	408.0	45.39	11.1	10.9
2.0	17.00	1.10	17.90	16.80	144	432.0	61.66	14.3	14.0
4.0	18.17	3.10	19.07	15.97	155	465.0	80.72	17.4	16.9
6.0	19.00	5.10	19.90	14.80	170	510.0	97.72	19.2	18.5
8.0	19.67	7.10	20.57	13.47	186	558.0	114.02	20.4	19.5
10.0	20.00	9.10	20.90	11.80	200	600.0	123.03	20.5	19.1
12.0	20.33	11.10	21.23	10.13	211	633.0	132.74	21.0	18.9

JHU09PA1

PA1 Pout at 3 DC bias pts (35 (a), 128 (b), 181 mA (c) vs. 300 mA sim.)

~20% PAE at 3 dB compression (3V)

2.4 GHz	Die#1	**PAD24 GHz Dmode Fall09 TQPED**				3.0V; 181 mA		vgs=-0.1V	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.0V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-10.0	7.00	-10.90	7.90	18.80	181	543.0	6.17	1.1	1.1
-8.0	9.00	-8.90	9.90	18.80	181	543.0	9.77	1.8	1.8
-6.0	11.00	-6.90	11.90	18.80	181	543.0	15.49	2.9	2.8
-4.0	13.00	-4.90	13.90	18.80	181	543.0	24.55	4.5	4.5
-2.0	15.00	-2.90	15.90	18.80	181	543.0	38.90	7.2	7.1
0.0	16.83	-0.90	17.73	18.63	181	543.0	59.29	10.9	10.8
2.0	18.33	1.10	19.23	18.13	185	555.0	83.75	15.1	14.9
4.0	19.50	3.10	20.40	17.30	193	579.0	109.65	18.9	18.6
6.0	20.00	5.10	20.90	15.80	204	612.0	123.03	20.1	19.6
8.0	21.00	7.10	21.90	14.80	229	687.0	154.88	22.5	21.8

JHU09TRS Chue Lee

Summary: 2.4 GHz TR Switch worked very well with low insertion loss (0.7 dB) and broad band operation.

Test:

Measure P1 to P3
Set T1/T2 to 0,1V

T1/T2	VDD(L)	VDD(P)	Name
0 1			TRS1ON
1 0			TRS1OFF

Worked Well, low insertion loss!

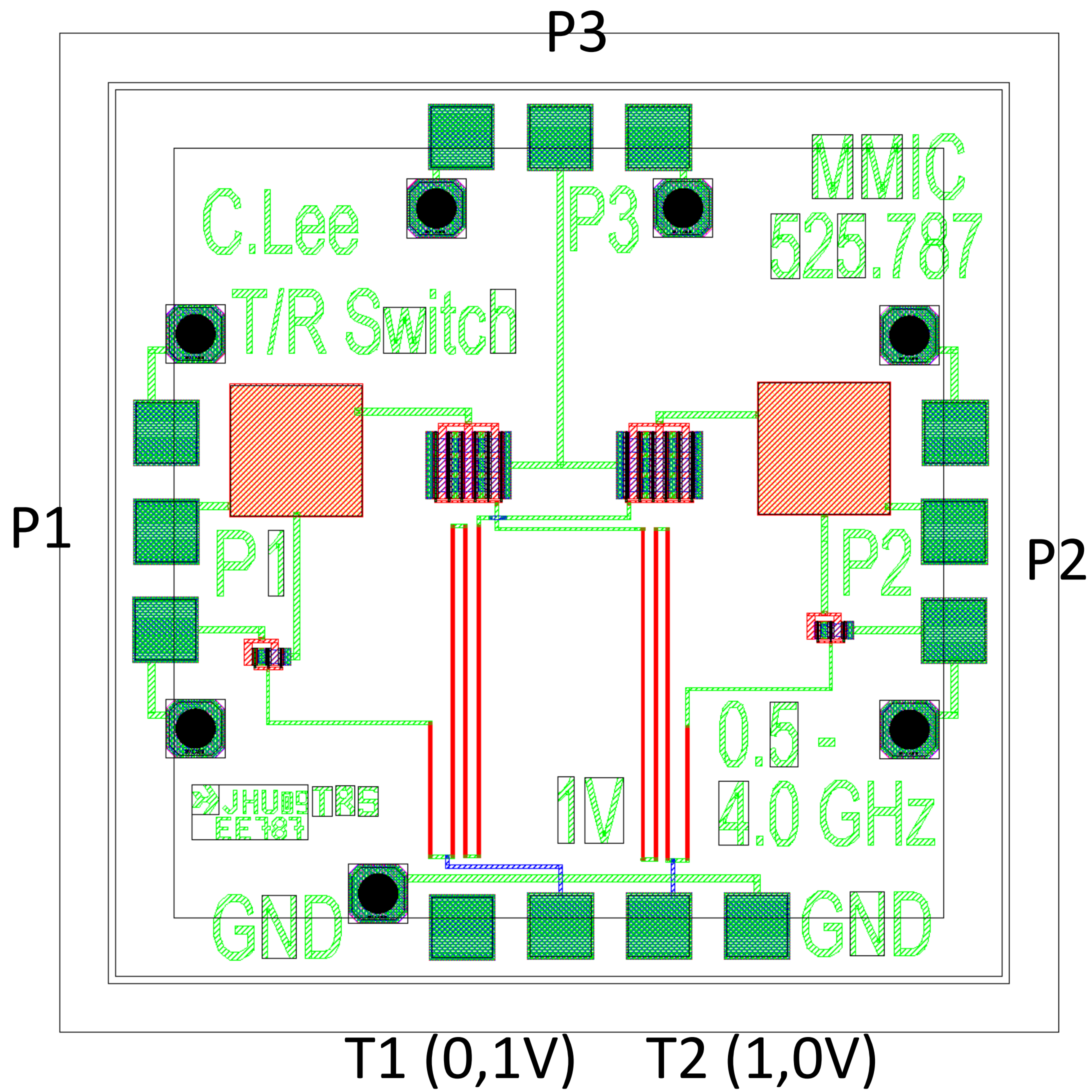
Measure P2 to P3
Set T1/T2 to 0,1V

T1/T2	VDD(L)	VDD(P)	Name
0 1			TRS2ON
1 0			TRS2OFF

Duplicates P1/P3 Measurement…

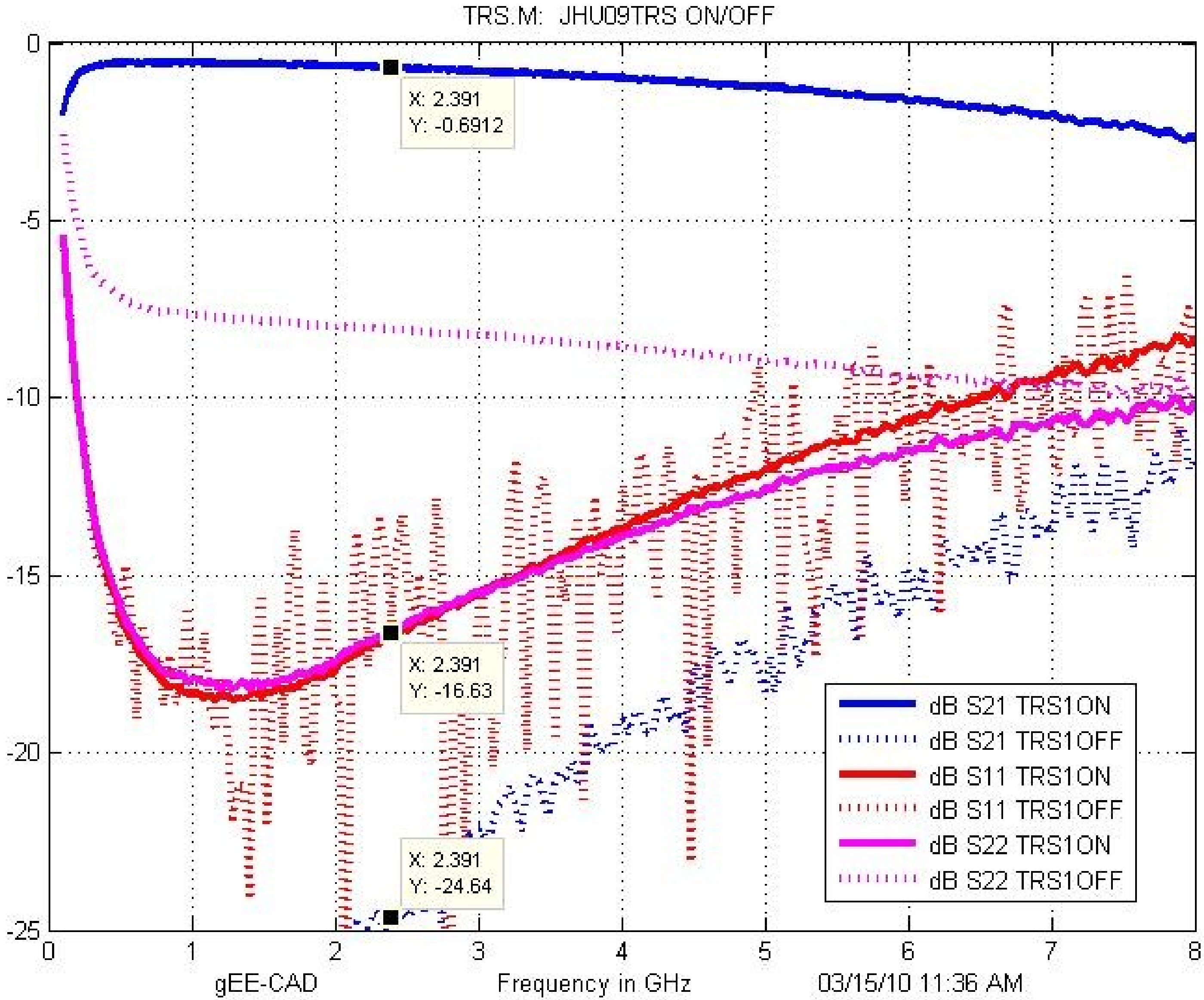
Measure P1 to P2
Set T1/T2 to 0,1V

T1/T2	VDD(L)	VDD(P)	Name
0 1			TRS12ISO
1 0			TRS12IS2



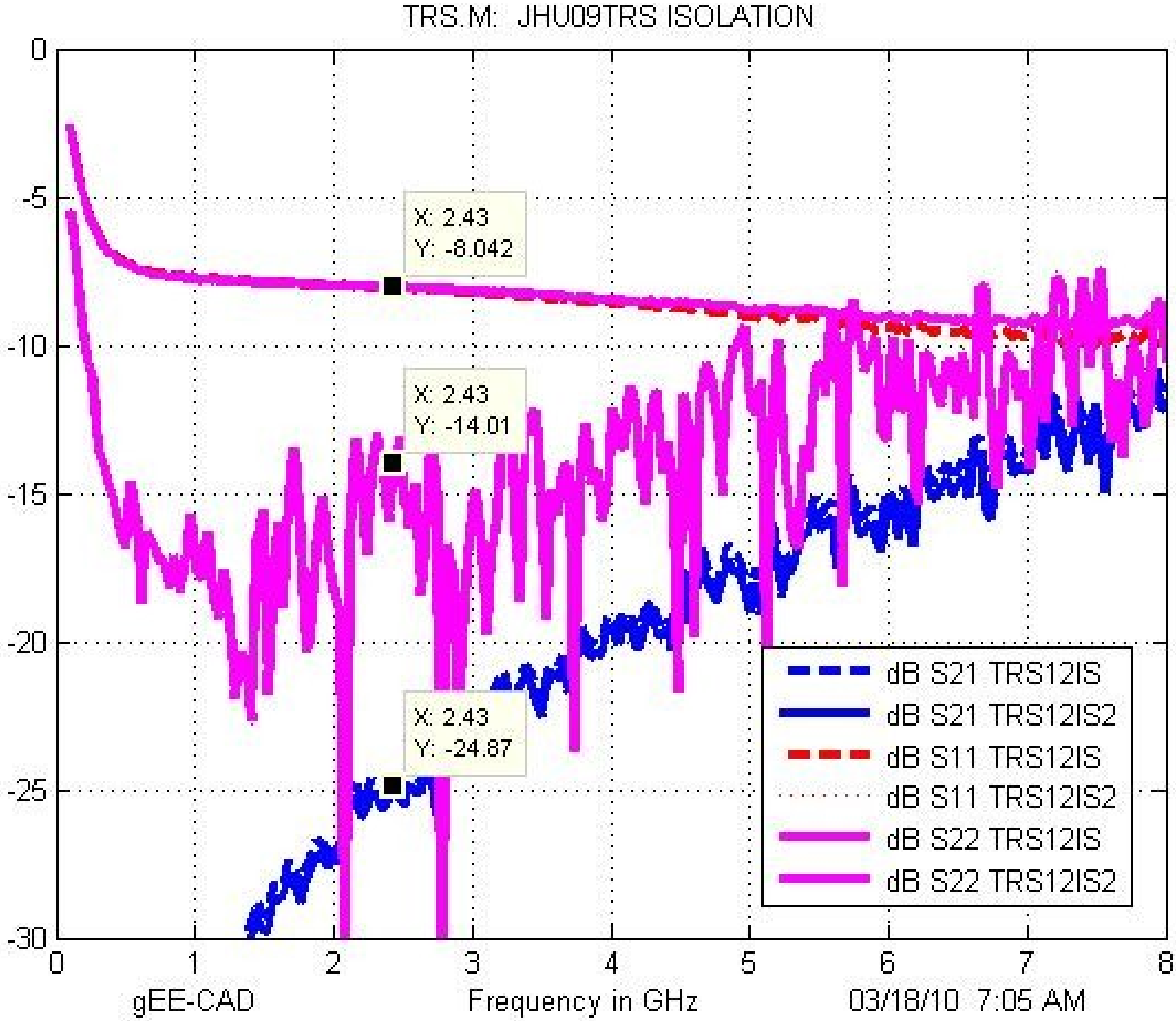
JHU09TRS

TRS Switch On/Off 24 dB isolation, 0.7 dB Insertion Loss



JHU09TRS

TRS Switch On/Off 25 dB Isolation P1 to P2 (1-3, or 2-3)



JHU09TR1: Class Project—PA1, LN1, and TRS

Summary: This combined several of the student's designs into a module with a 2.4 GHz PA, LNA, and TR Switch. It worked well and compared to the individual measurements plus 0.5 dB loss for the switch. PA was inadvertently fed from the TR Switch instead of output to it.

Test:

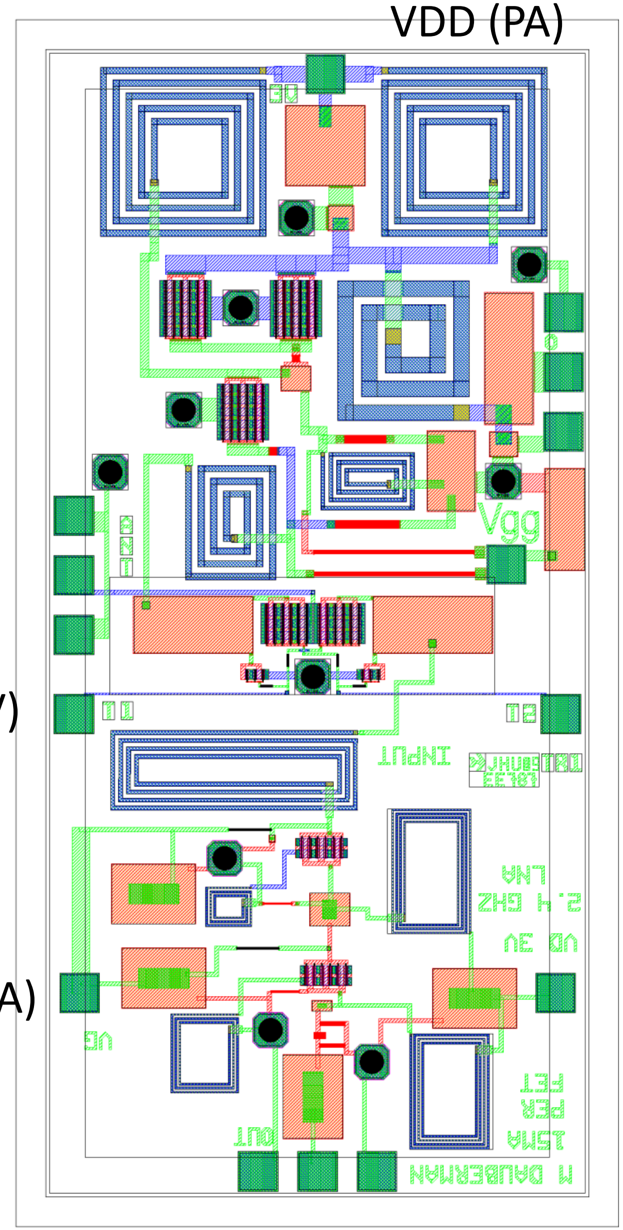
Power up LNA Measure Ant to LNAOut
Set T1/T2 to 0,1V
LNA: VG -0.5V VD 3V at 30 mA

T1/T2 VDD(L) VDD(P) Name
0 1 TR1LON
1 0 TR1LOFF

Measures Well with LNA, about 0.5 dB more NF but good gain.

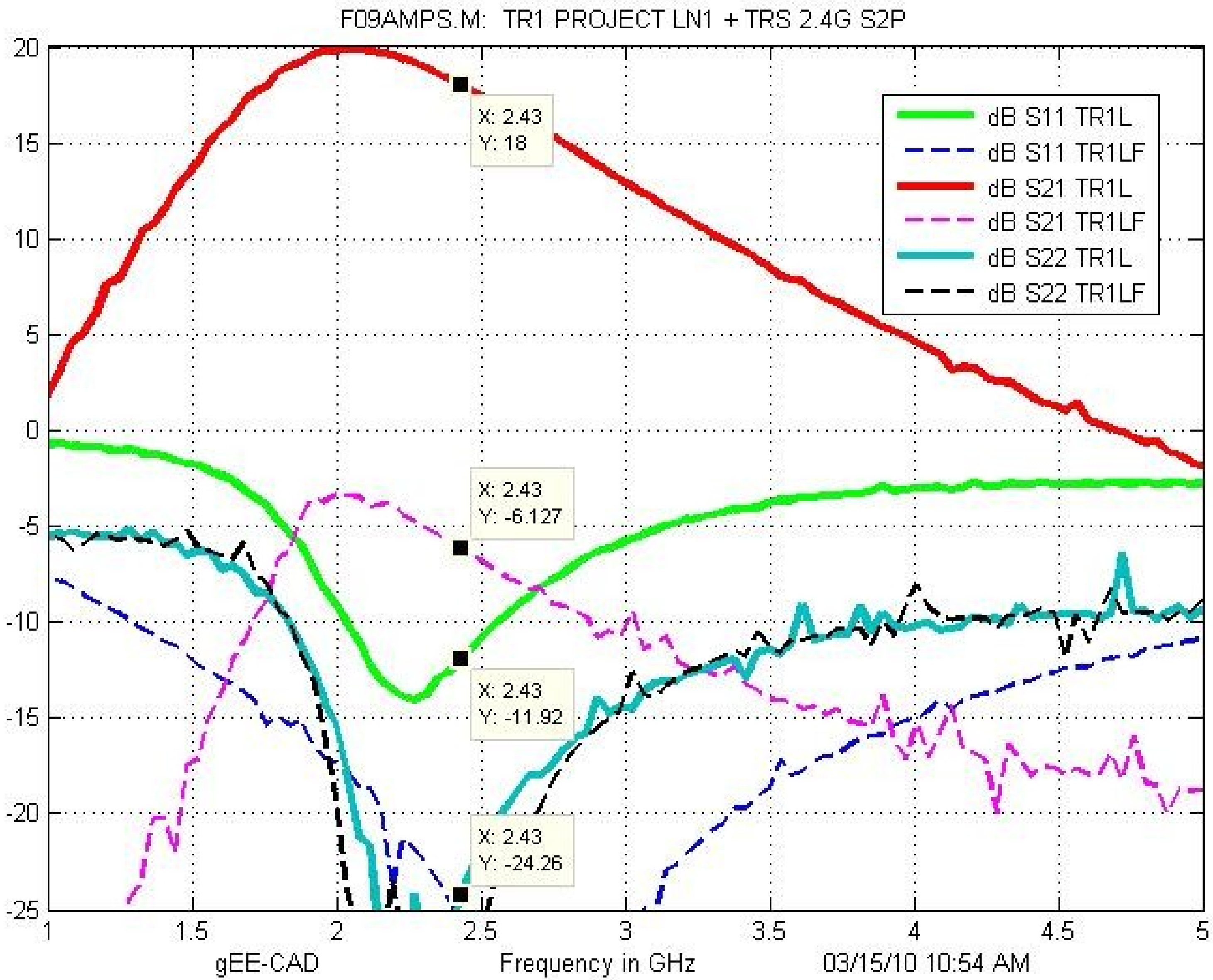
Power up PA Measure PAIn to Ant
Set T1/T2 to 0,1V
PA: VG -0.25V VD 3V at 300 mA

T1/T2 VDD(L) VDD(P) Name
0 1 TR1POFF
1 0 TR1PON



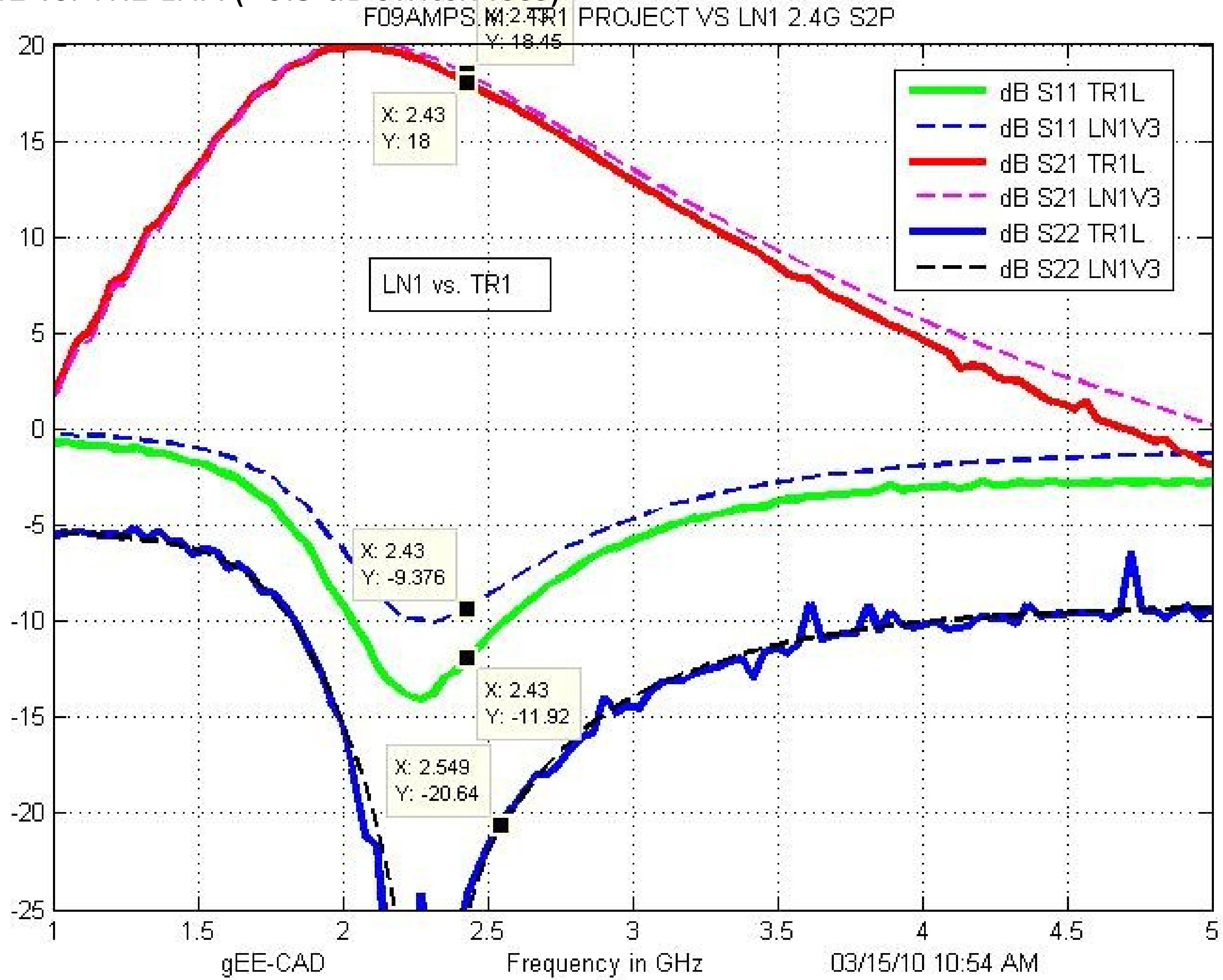
JHU09TR1

TR1 LNA On/Off 24 dB isolation



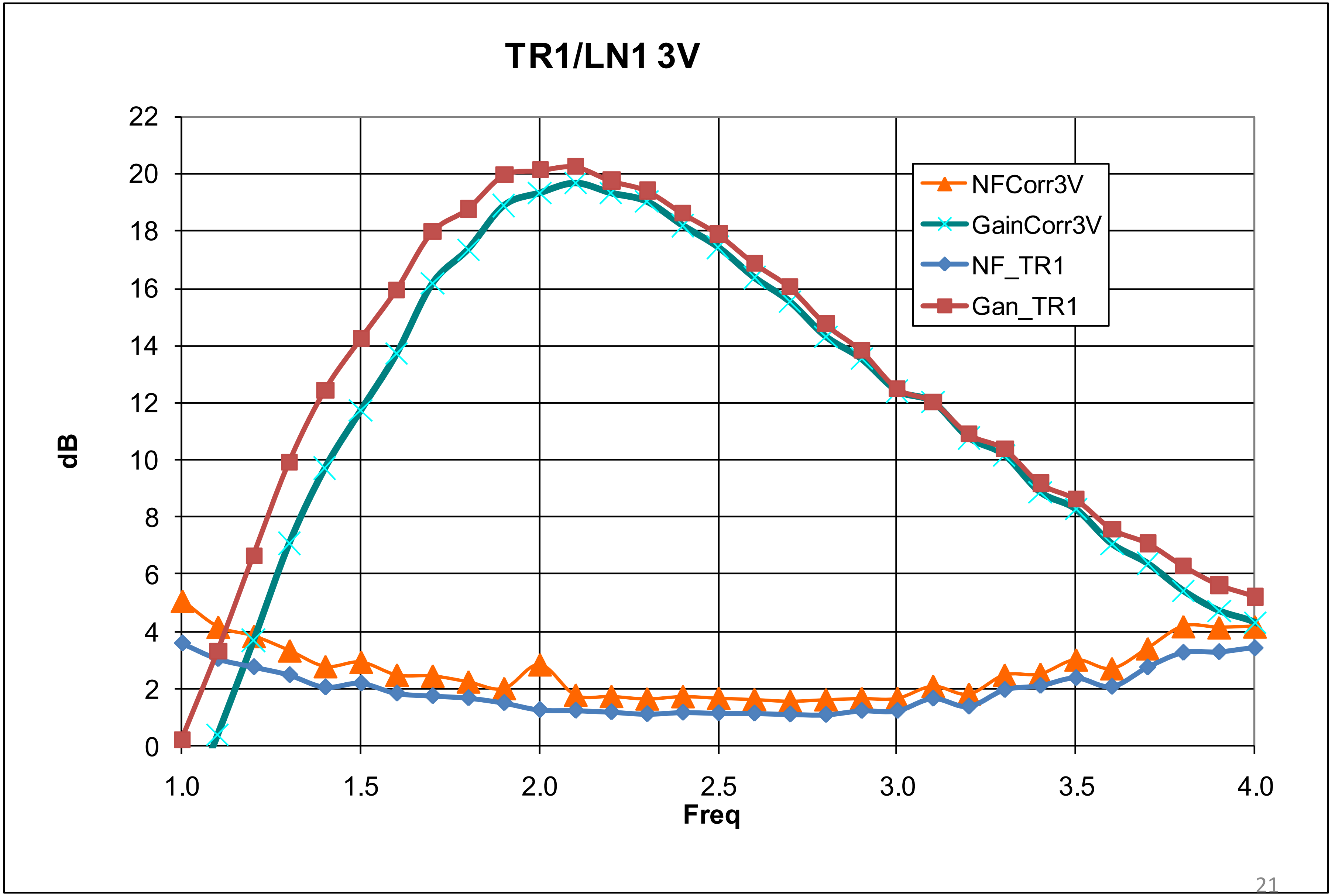
JHU09TR1

LN1 vs. TR1 LNA (~0.5 dB switch loss)



JHU09TR1

LN1 vs. TR1 LNA (~0.5 dB switch loss)



JHU09TR1

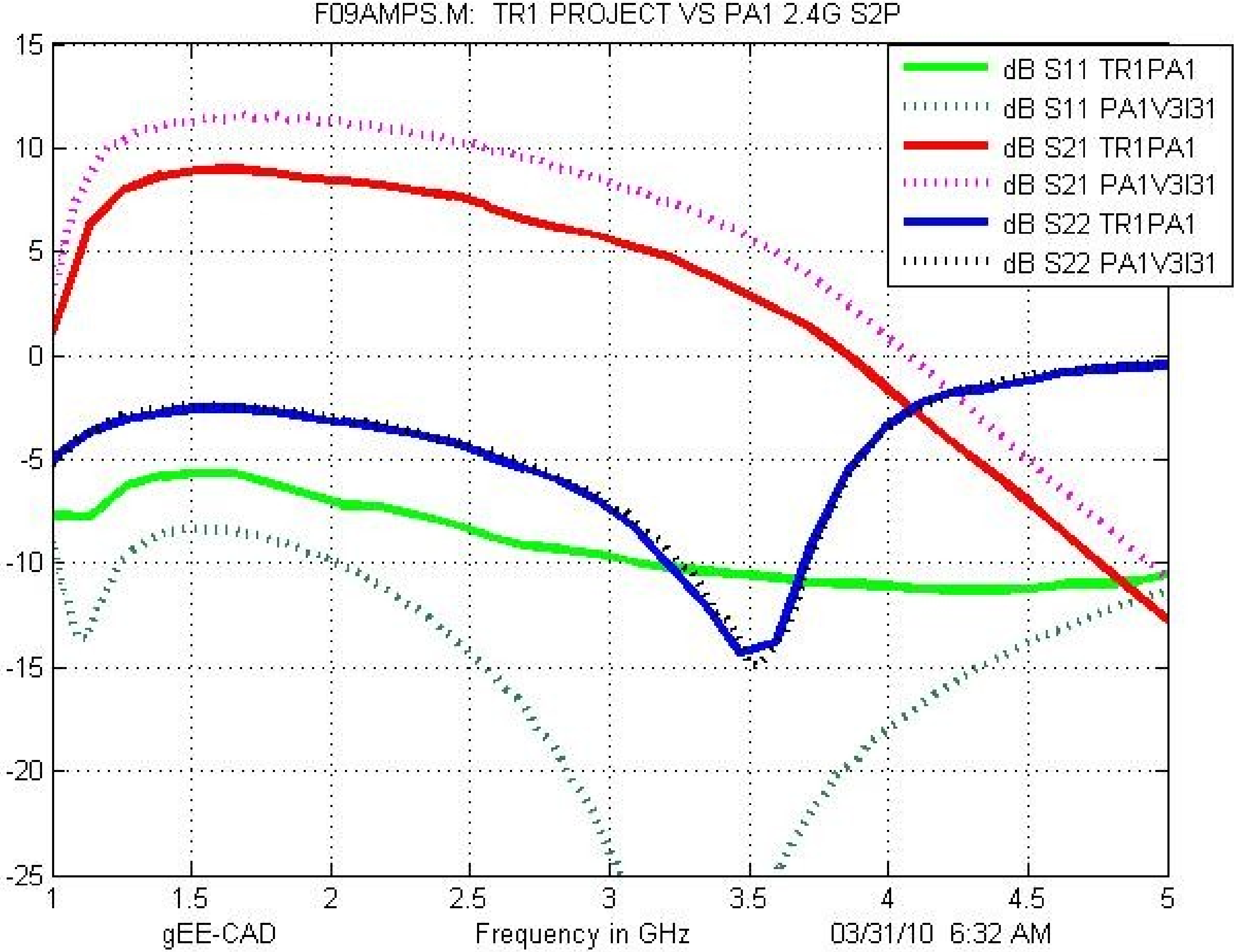
LN1 vs. TR1 LNA (~0.5 dB switch loss)

TR1				LN1			
Freq(GHz)	**Gaincorr**	**NFCorr2**		**Gaincorr**	**NFCorr2**	DeltaG	DeltaNF
1.20	3.70	3.84		6.64	2.75	-2.93	1.09
1.30	7.10	3.33		9.91	2.47	-2.80	0.86
1.40	9.73	2.77		12.42	2.04	-2.69	0.73
1.50	11.74	2.93		14.22	2.18	-2.48	0.74
1.60	13.72	2.48		15.93	1.83	-2.21	0.65
1.70	16.17	2.44		17.95	1.74	-1.77	0.71
1.80	17.37	2.23		18.77	1.66	-1.39	0.57
1.90	18.90	2.00		19.94	1.49	-1.04	0.51
2.00	19.34	2.84		20.11	1.25	-0.77	1.59
2.10	19.68	1.77		20.23	1.22	-0.55	0.55
2.20	**19.34**	**1.72**		**19.75**	**1.17**	**-0.41**	**0.55**
2.30	**19.04**	**1.64**		**19.40**	**1.10**	**-0.36**	**0.54**
2.40	**18.20**	**1.72**		**18.61**	**1.16**	**-0.41**	**0.56**
2.50	**17.44**	**1.66**		**17.87**	**1.13**	**-0.44**	**0.53**
2.60	**16.39**	**1.61**		**16.87**	**1.12**	**-0.48**	**0.49**
2.70	15.54	1.55		16.02	1.09	-0.48	0.46
2.80	14.32	1.61		14.74	1.08	-0.41	0.53
2.90	13.54	1.65		13.81	1.22	-0.26	0.43
3.00	12.43	1.65		12.49	1.21	-0.07	0.44
3.10	12.03	2.08		12.02	1.65	0.01	0.43
3.20	10.79	1.80		10.89	1.37	-0.10	0.43

JHU09TR1

PA1 vs. TR1 PA (~0.5 dB switch loss, note S11 of TR1PA1 includes TRSwitch)

Measured at Low DC Bias and Low Gain (Stability!)



JHU09TR1

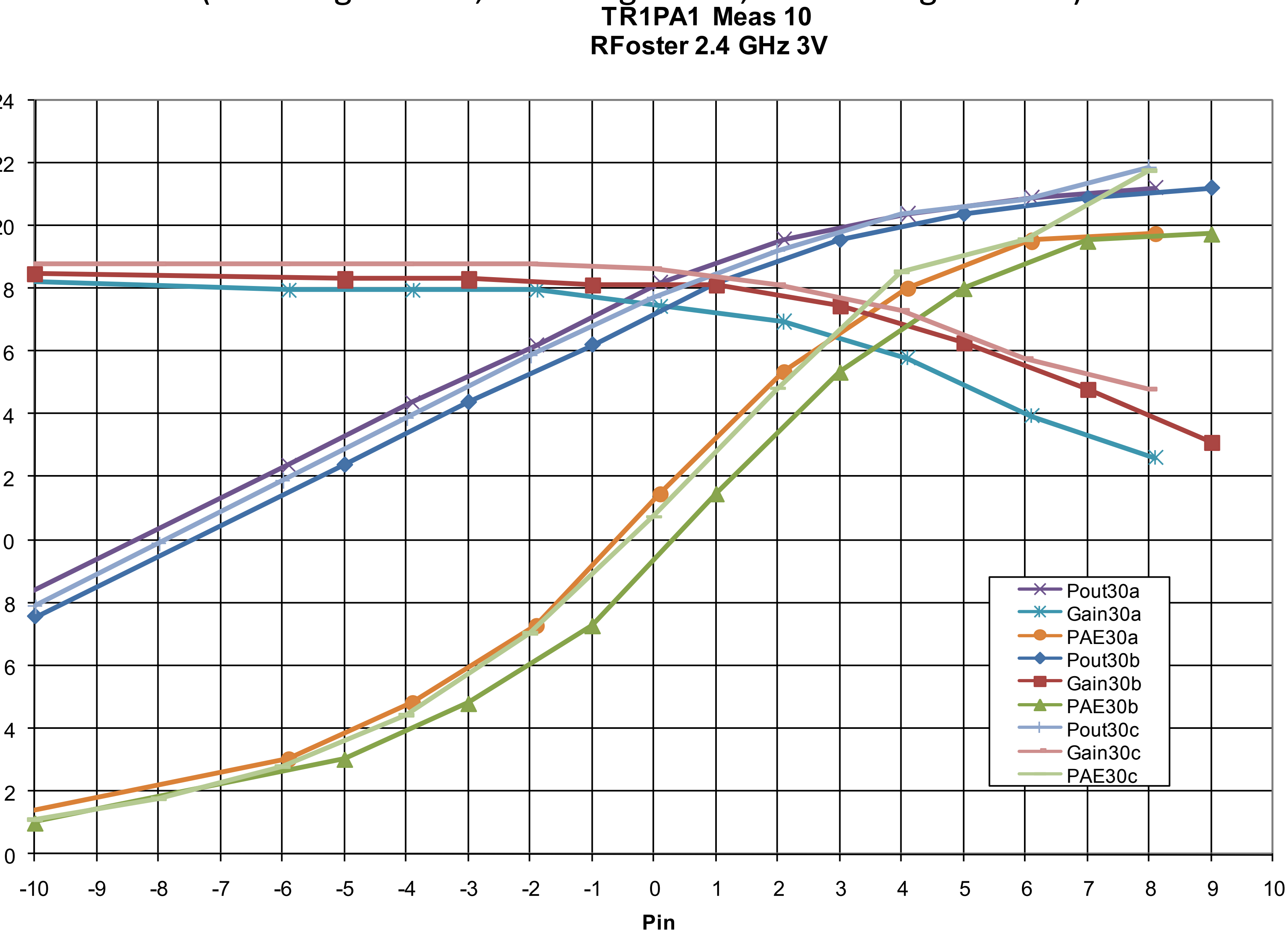
TR1 PA (~0.5 dB switch loss) Measured at Nominal DC Bias

TR1 Project Power Amp		Meas s2p at -0.65V 3V 30 mA (low gain/bias)							
Rowland Foster									
2.4 GHz	Die#1	**TR1PA24V GHz Dmode Fall09 TQPED**				3.0V ;145 mA		vgs=-0.25V	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.0V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-20.0	-3.50	-20.90	-2.60	18.30	145	435.0	0.55	0.1	0.1
-15.0	1.50	-15.90	2.40	18.30	145	435.0	1.74	0.4	0.4
-10.0	6.50	-10.90	7.40	18.30	145	435.0	5.50	1.3	1.2
-5.0	11.17	-5.90	12.07	17.97	146	438.0	16.11	3.7	3.6
-3.0	13.17	-3.90	14.07	17.97	147	441.0	25.53	5.8	5.7
-1.0	15.17	-1.90	16.07	17.97	148	444.0	40.46	9.1	9.0
1.0	16.67	0.10	17.57	17.47	151	453.0	57.15	12.6	12.4
3.0	18.17	2.10	19.07	16.97	158	474.0	80.72	17.0	16.7
5.0	19.00	4.10	19.90	15.80	168	504.0	97.72	19.4	18.9
7.0	19.17	6.10	20.07	13.97	175	525.0	101.62	19.4	18.6
9.0	19.83	8.10	20.73	12.63	191	573.0	118.30	20.6	19.5

2.4 GHz	Die#1	**TR1PA24V GHz Dmode Fall09 TQPED**				3.0V; 187 mA		vgs=-0.1V	
Pin(SG)	**Pout(SA)**	**Pin(corr)**	**Pout(corr)**	**Gain**	**I1(3.0V)**	**PDC(mw)**	**Pout(mw)**	**Drn Eff**	**PAE**
-20.0	-3.17	-20.90	-2.27	18.63	187	561.0	0.59	0.1	0.1
-15.0	1.67	-15.90	2.57	18.47	187	561.0	1.81	0.3	0.3
-10.0	6.67	-10.90	7.57	18.47	187	561.0	5.71	1.0	1.0
-5.0	11.50	-5.90	12.40	18.30	188	564.0	17.38	3.1	3.0
-3.0	13.50	-3.90	14.40	18.30	188	564.0	27.54	4.9	4.8
-1.0	15.33	-1.90	16.23	18.13	189	567.0	41.98	7.4	7.3
1.0	17.33	0.10	18.23	18.13	190	570.0	66.53	11.7	11.5
3.0	18.67	2.10	19.57	17.47	193	579.0	90.57	15.6	15.4
5.0	19.50	4.10	20.40	16.30	198	594.0	109.65	18.5	18.0
7.0	20.00	6.10	20.90	14.80	203	609.0	123.03	20.2	19.5
9.0	20.33	8.10	21.23	13.13	213	639.0	132.74	20.8	19.8

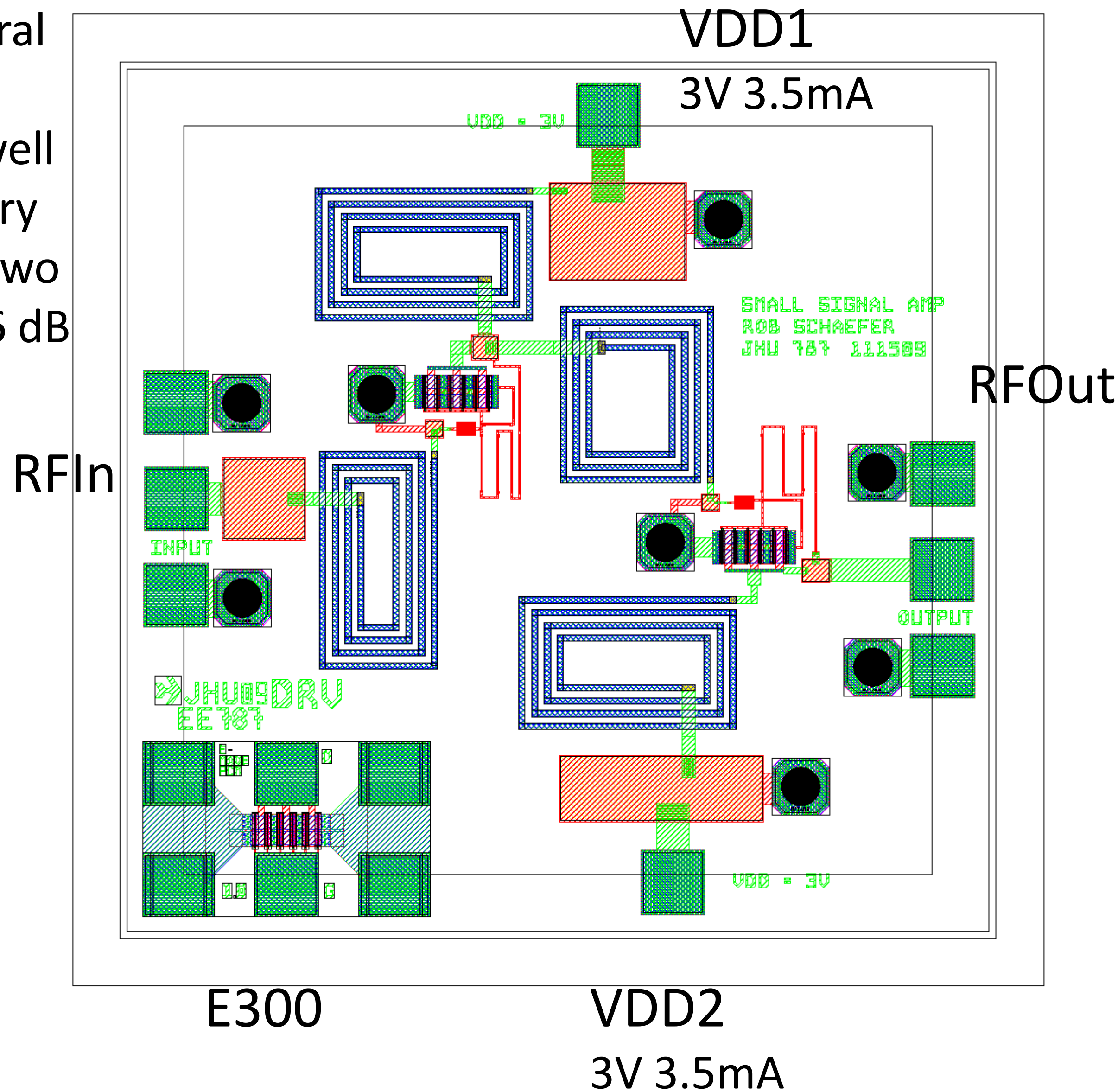
JHU09TR1

TR1 PA (~0.5 dB switch loss) vs PA1 Measured at Nominal DC Bias
(a=TR1 vgs -0.25V, b=TR1 vgs -0.1V, c=PA1 at vgs = -0.1V)



JHU09DRV Robert Schaefer

Summary: This 2.4 GHz general purpose amplifier (driver) worked well and compared well to simulations. This was a very low DC power consumption two stage amplifier with about 26 dB of gain and good return loss.



Test:

Power up LNA
Measure RFIn to RFOut
VD 3V at 7mA

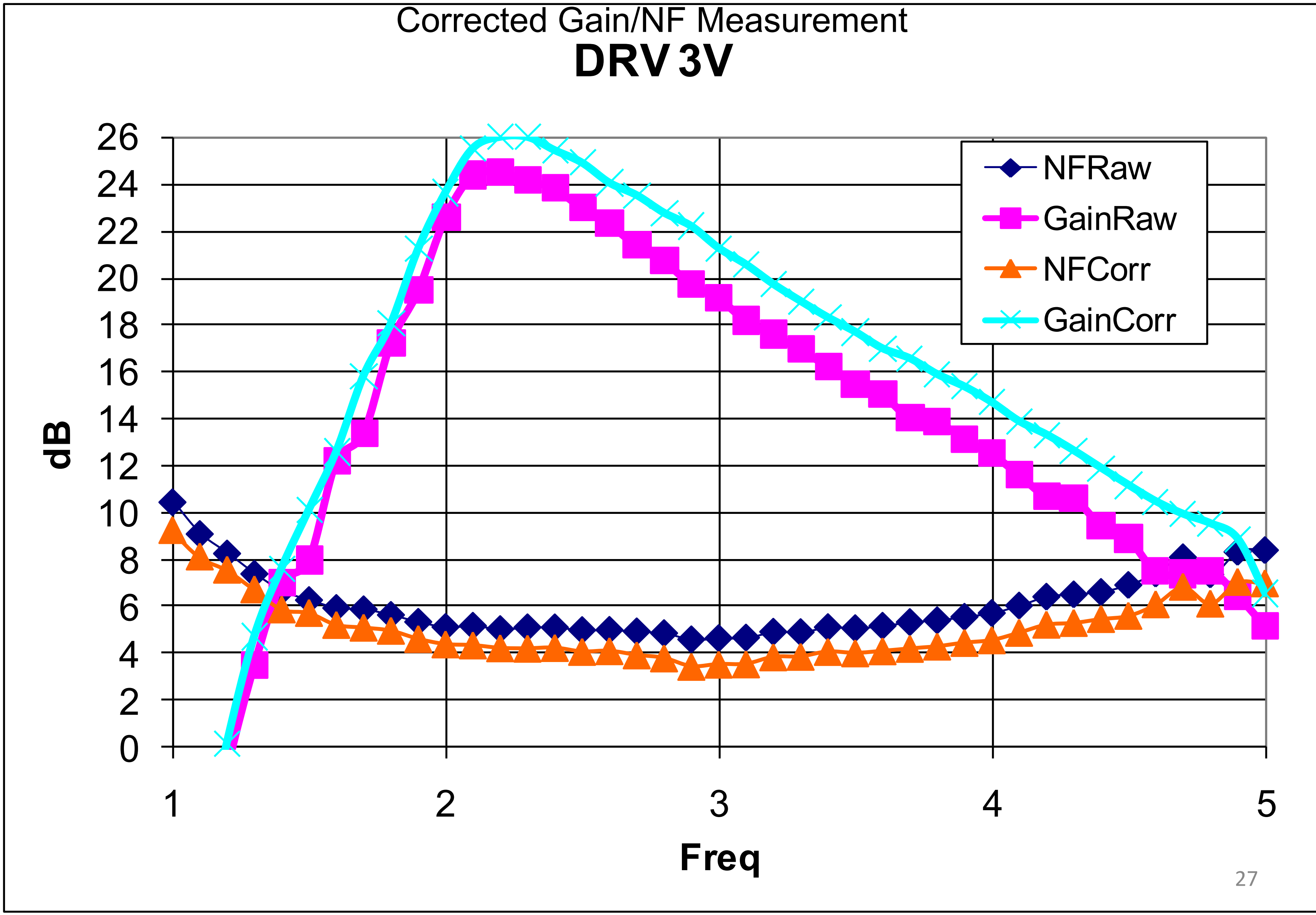
VDD	Name
2.8V 3, 4 mA	DRV28
3.0V 6, 6 mA	DRV3
3.2V 8, 9 mA	DRV32

More Gain at Higher Bias. Worked Well!

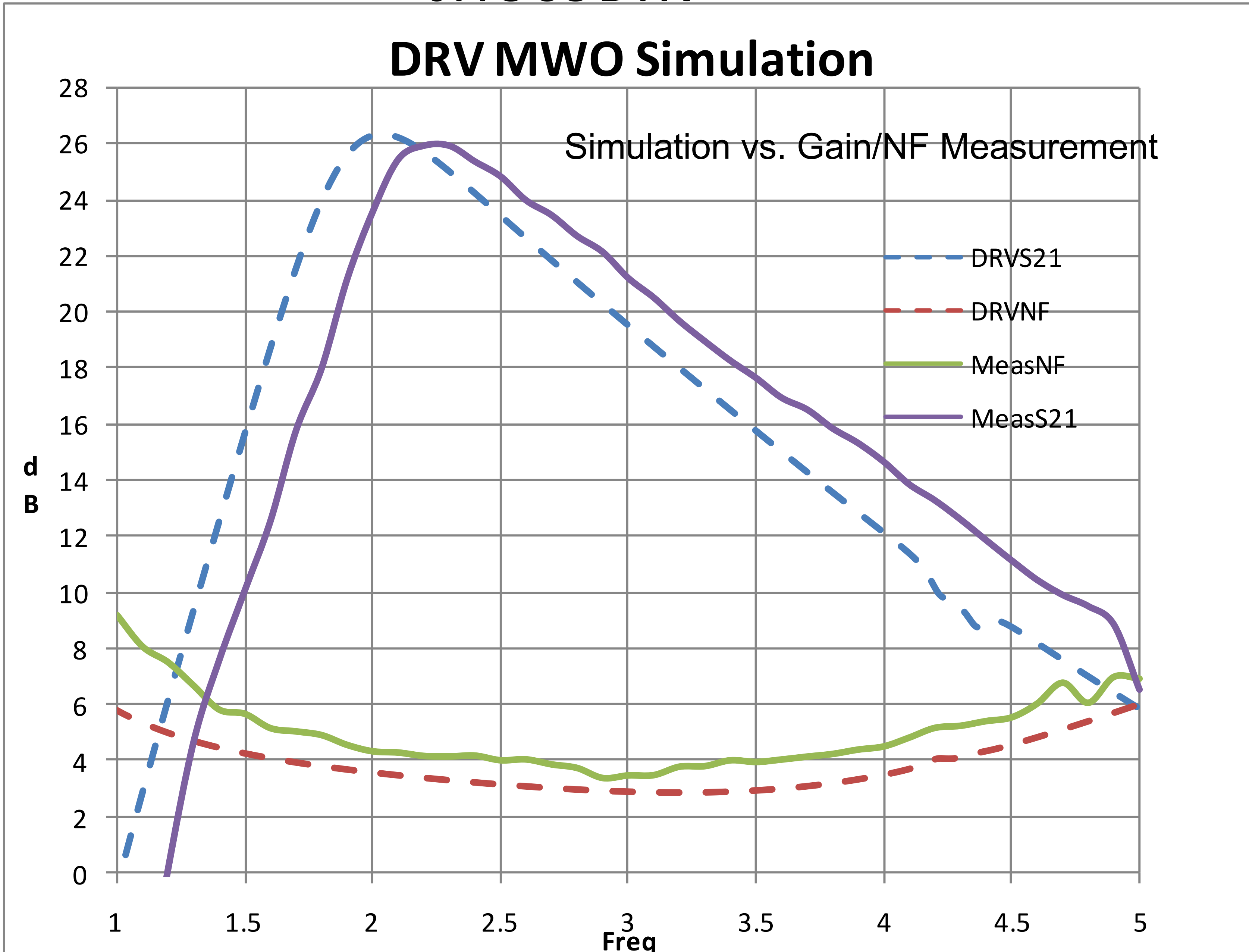
TEST PHEMT Emode 300 um

VG	VDD	Name
+0.52V	3V 10 mA	E300V3I10
+0.66V	4V 31 mA	E300V4I31

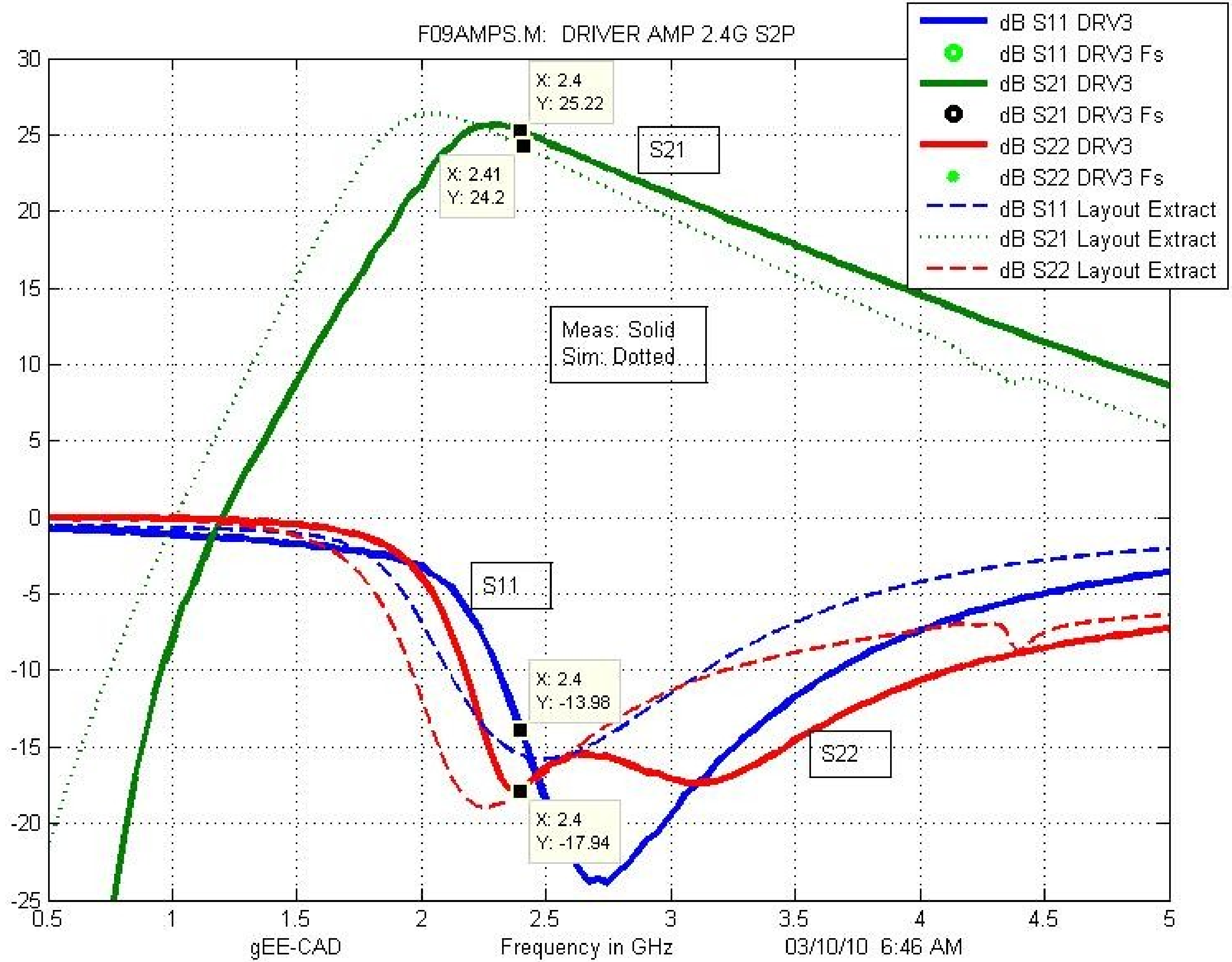
JHU09DRV


Corrected Gain/NF Measurement
DRV 3V
dB
Freq
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1
2
3
4
5
NFRaw
GainRaw
NFCorr
GainCorr

JHU09DRV

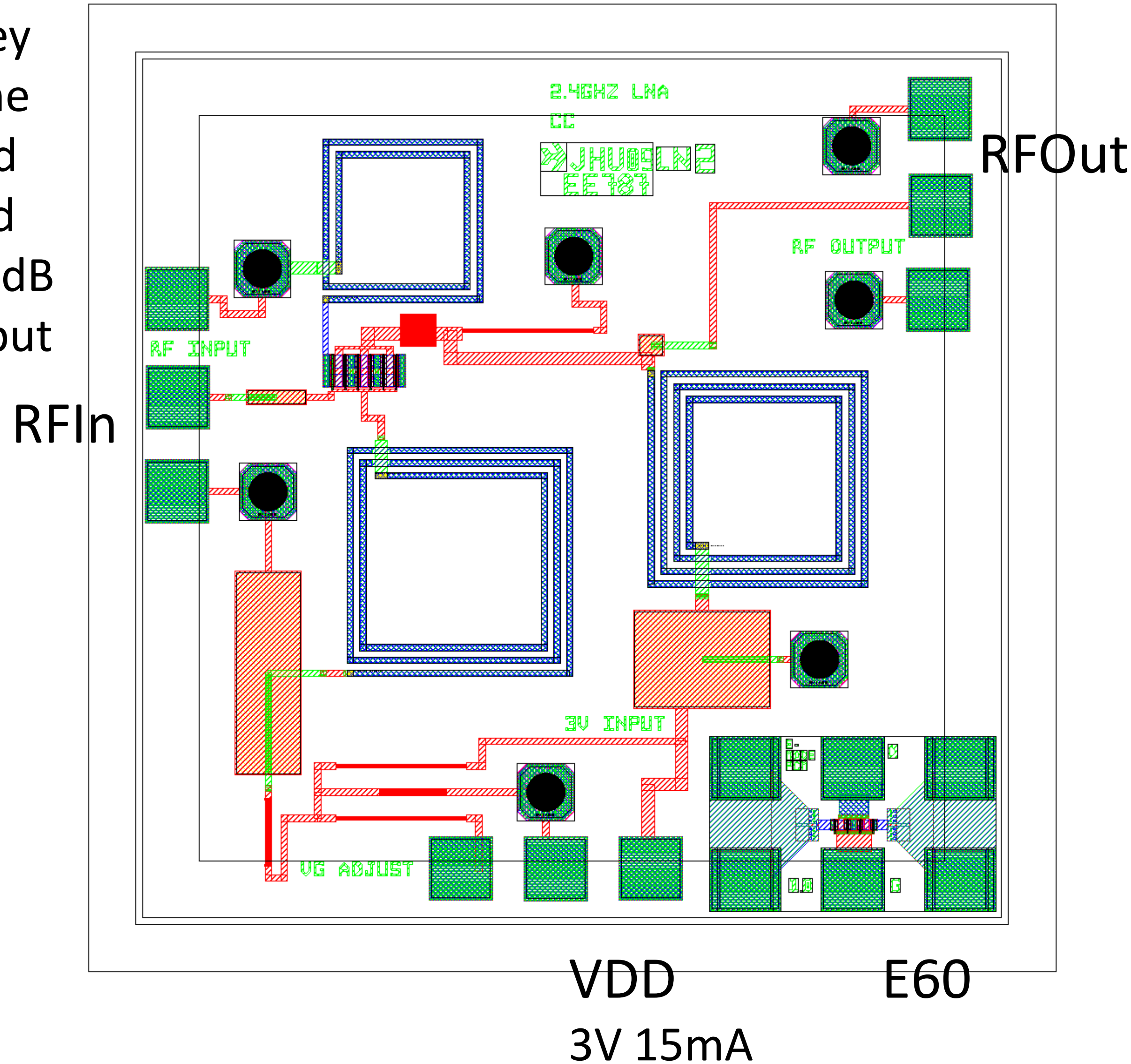

DRV MWO Simulation
Simulation vs. Gain/NF Measurement
DRVS21
DRVNF
MeasNF
MeasS21
dB
Freq
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
1
1.5
2
2.5
3
3.5
4
4.5
5

S-Parameters Measurement JHU09DRV



JHU09LN2 Clay Couey

Summary: This 2.4 GHz LNA was a backup circuit for Clay Couey who also designed a VCO. The one stage amplifier compared well with simulations and had about 1 to 1.5 dB NF with 11 dB gain and good input and output return loss.



Test:

Power up LNA

Measure RFIn to RFOut

LNA: VG -0.5V VD 3V at 15mA

VDD	Name
3V 19 mA	LN2V3
3.3V 26 mA	LN2V33

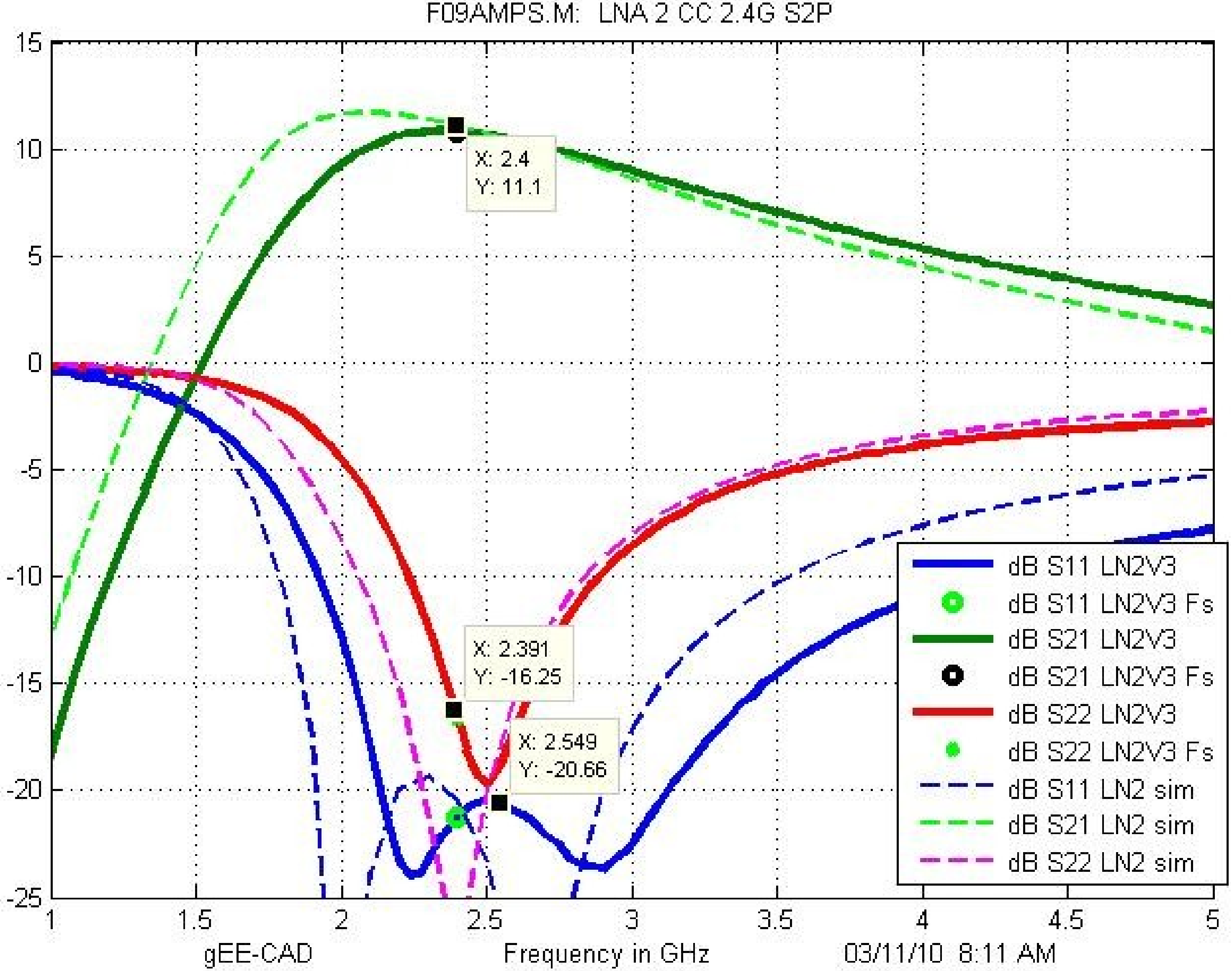
Good NF, worked as expected!

TEST PHEMT Emode 60 um

VG	VDD	Name
+0.57V	3V 3 mA	E60V3I3
+0.57V	4V 4 mA	E60V4I4

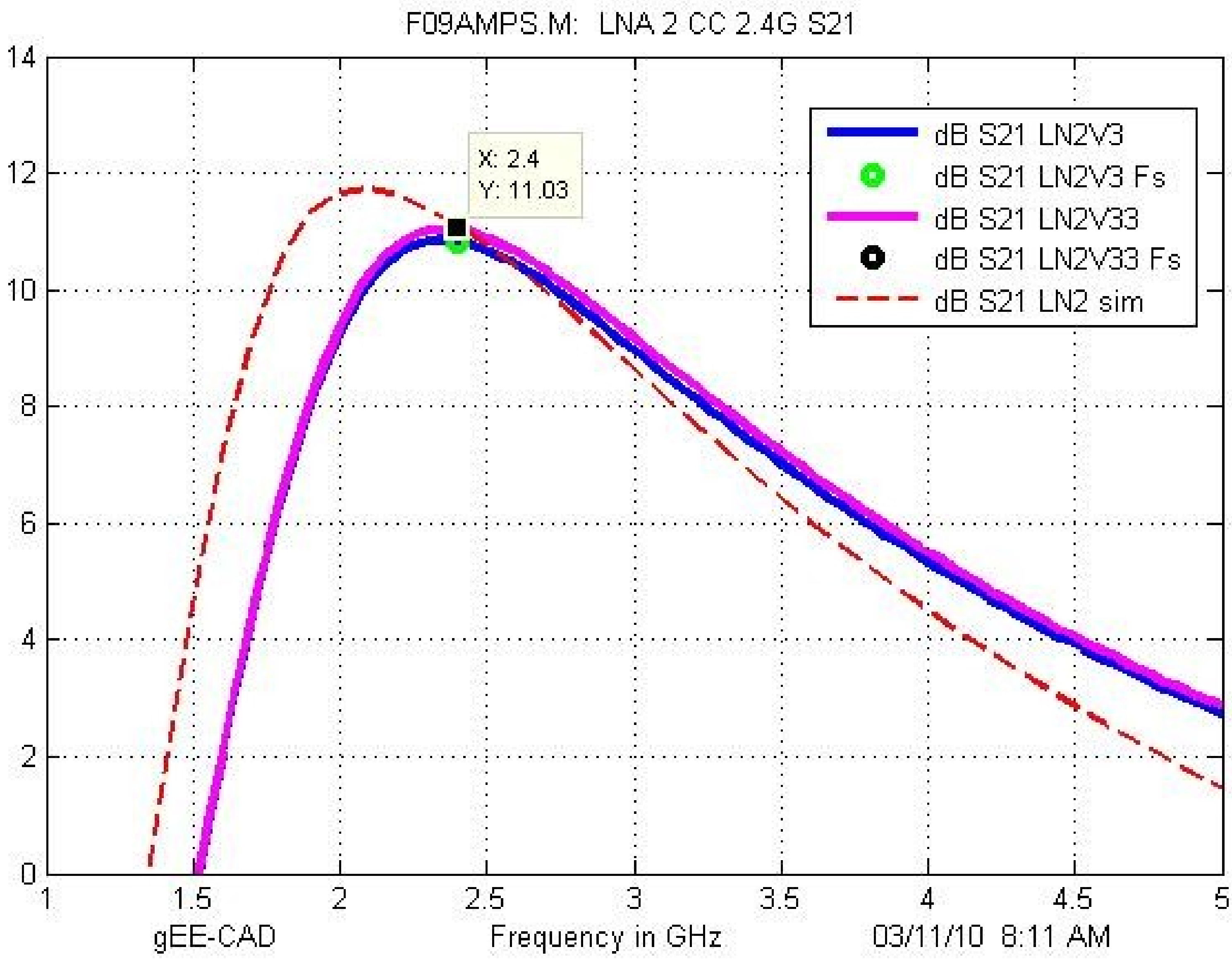
JHU09LN2

S-Parameters Measurement (Solid) vs. Simulation (Dotted)



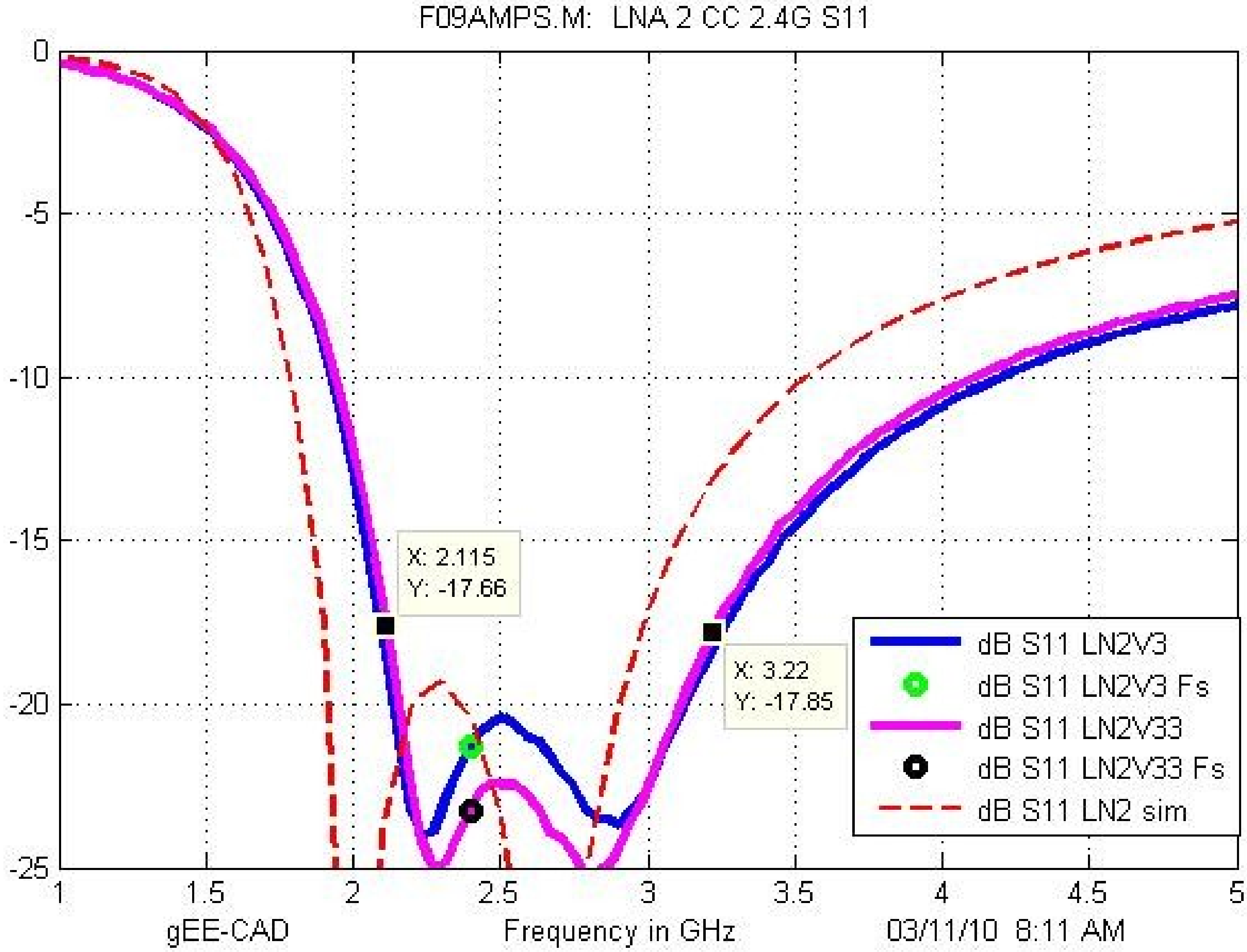
JHU09LN2

Gain Measurement (Solid) vs. Simulation (Dotted)



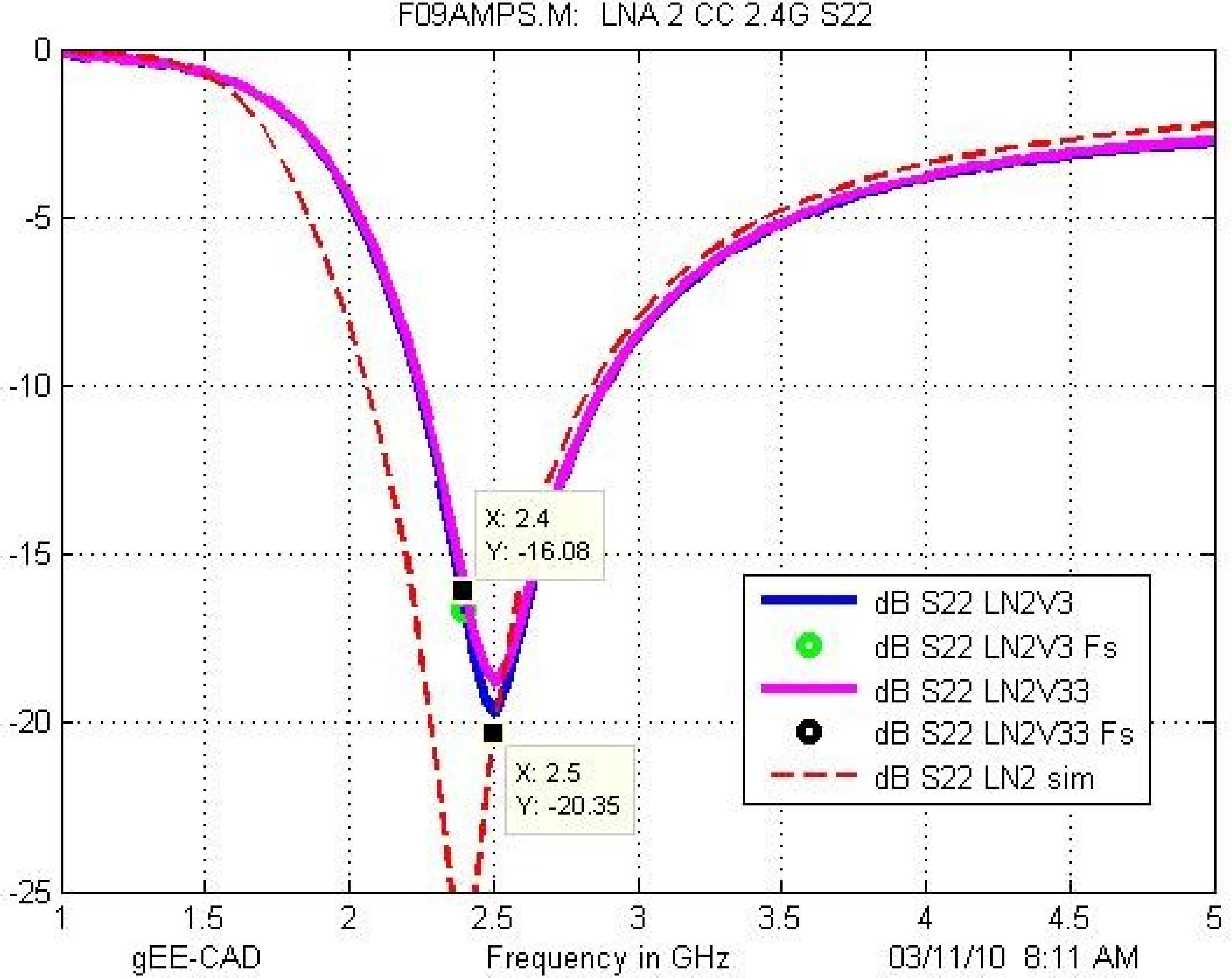
JHU09LN2

Return Loss S11 (Solid) vs. Simulation (Dotted)



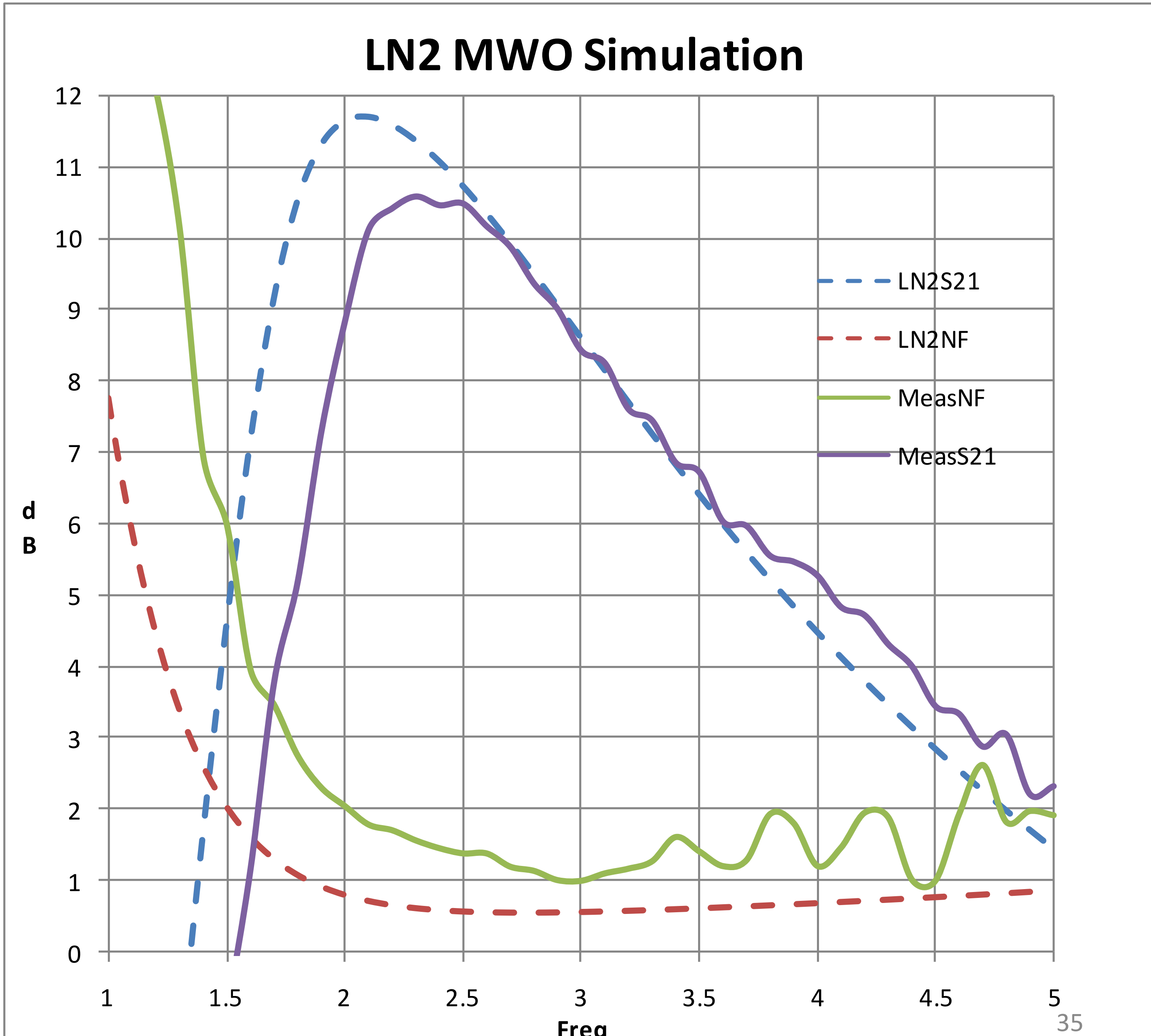
JHU09LN2

Return Loss S22 (Solid) vs. Simulation (Dotted)



JHU09LN2 Measured NF vs. Simulation

Freq(GHz)	Gaincorr	NFCorr2
1.20	-10.12	12.09
1.30	-5.82	10.16
1.40	-3.08	6.96
1.50	-0.89	6.00
1.60	1.16	3.97
1.70	3.78	3.48
1.80	5.19	2.76
1.90	7.29	2.31
2.00	**8.83**	**2.05**
2.10	**10.11**	**1.79**
2.20	**10.41**	**1.72**
2.30	**10.58**	**1.57**
2.40	**10.46**	**1.46**
2.50	**10.48**	**1.39**
2.60	**10.16**	**1.39**
2.70	**9.87**	**1.20**
2.80	**9.36**	**1.15**
2.90	**9.00**	**1.02**
3.00	**8.42**	**1.01**
3.10	8.25	1.11
3.20	7.60	1.18



JHU09PA2 Ken McKnight

Summary: This 2.4 GHz Doherty one stage power amplifier (PA) that DC biased OK but had stability issues. Some measurements were made with just the Class A amplifier portion biased at low DC/low gain before oscillations started.

Test:

Power up PA

Measure RFIn to RFOut

PA: VG1 -0.8V VD1 3V at ?? mA

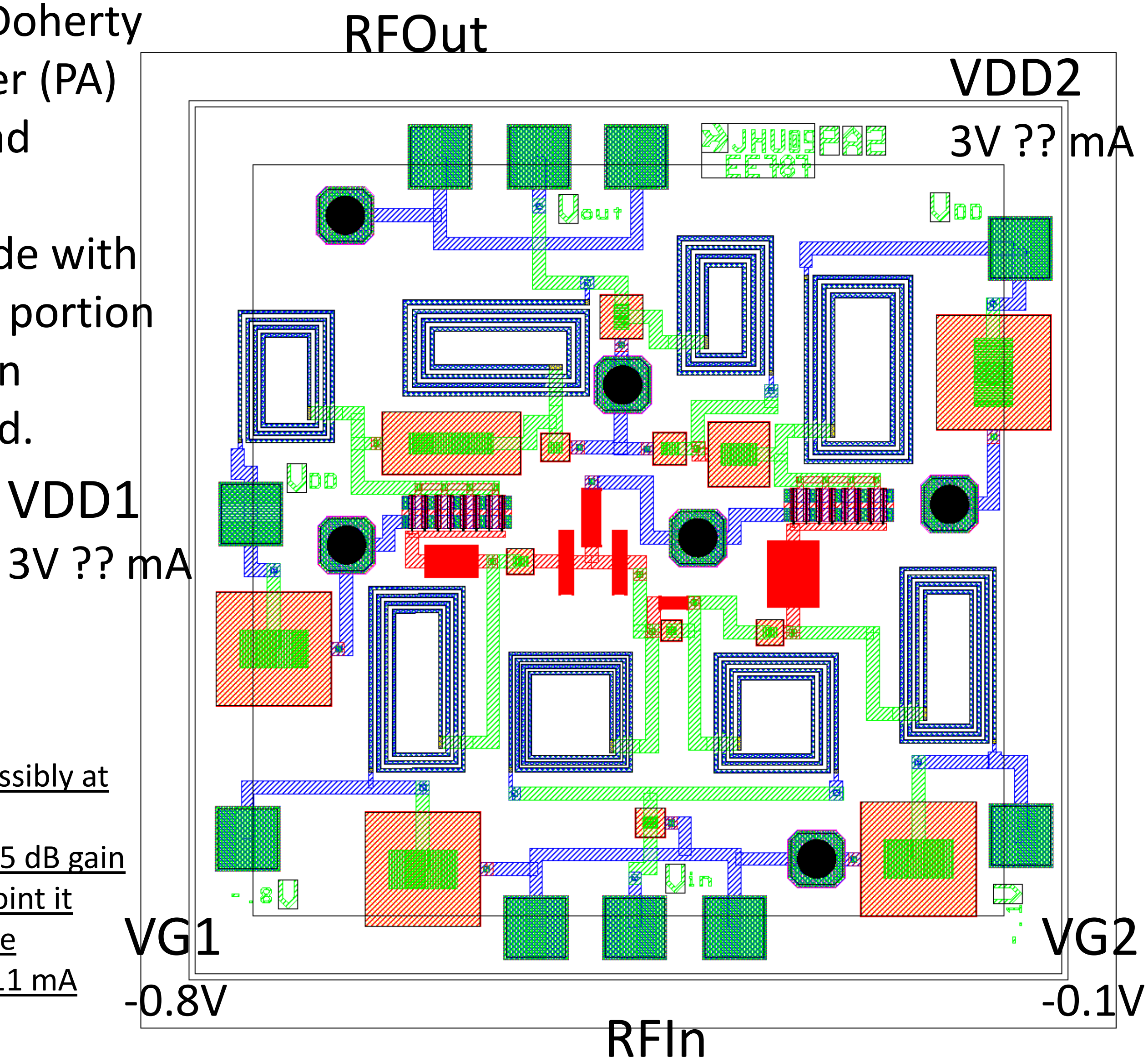
VG2 -0.2V VD2 3V at ?? mA

VG1	VG2	VD1	VD2	Name
				PA2V3

Class C side had no gate control, possibly at IDSS? But no gain either??

Class A side biased OK, but beyond 5 dB gain it broke into oscillations at which point it had gate current of a few mA. Made measurements at low DC bias. 3V 11 mA and 2 V 39 mA (-0.1V VGS)

Check Layout on Class C side.

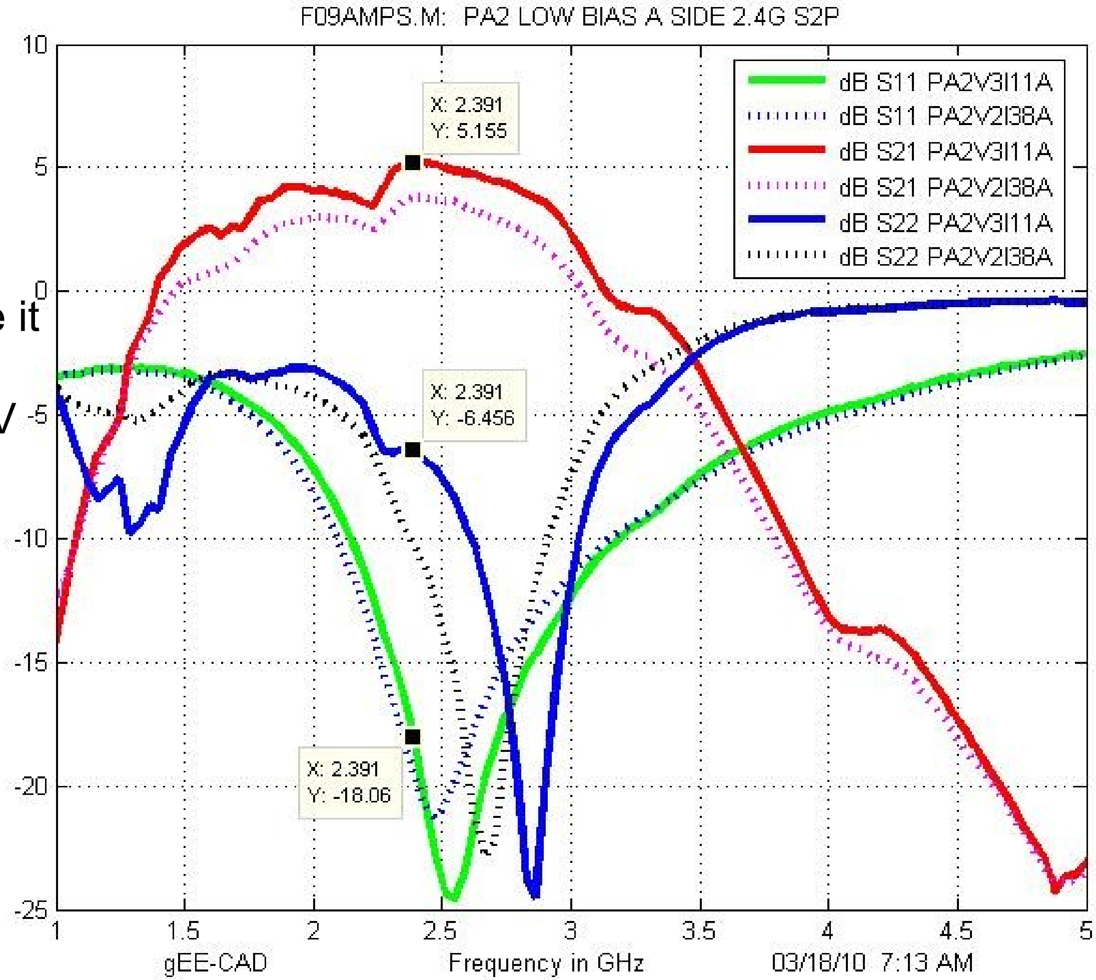


JHU09PA2

PA2: 3/17/10 Class A amp biased, but Class C side appeared to have no gate control. May be running at IDSS? Look for short in layout. When A side had more than 5 dB gain it wanted to oscillate. Saw 35 MHz oscillations on spec amp but large caps did not seem to quell it. Also gate current was evident once it started to oscillate. Made partial measurements at 2V 38 mA and 3V 11 mA.

PA2 4/13/10 Re-Measured MMIC. Had gate control and proper bias on both Class C and Class A portions of the design. But the spectrum analyzer showed a lot of oscillation! Tried to drive a 2.4 GHz signal to quell oscillations but only saw a few dB of gain when 13 dbm was input!

S-Parameters at Low DC Bias (A side only)



JHU09VC1 Clay Couey

Summary: This 2.4 GHz VCO worked very well. See attached plots of the tuning range and output power. Even the phase noise measured with a spectrum analyzer looked good.

Test:

Power up VCO

Measure RFOut over Vtune Range

VG Vtune VD FO PO

Oscillated! See Plots

PA24: VD 3V at 10mA

VDD	Name
NA	PA24EV3

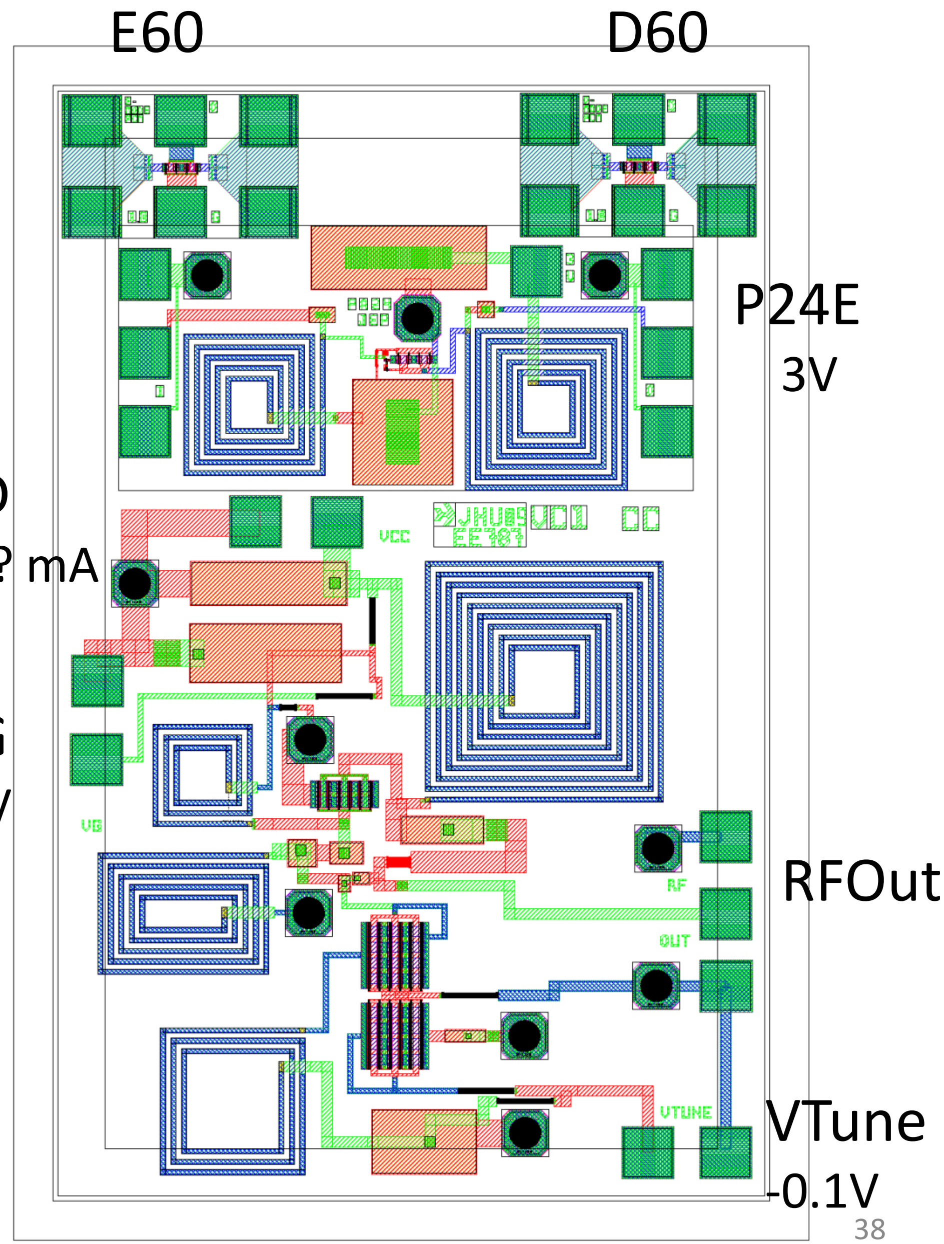
No current, no gain—missing connection in current mirror!

TEST PHEMT Dmode 60 um

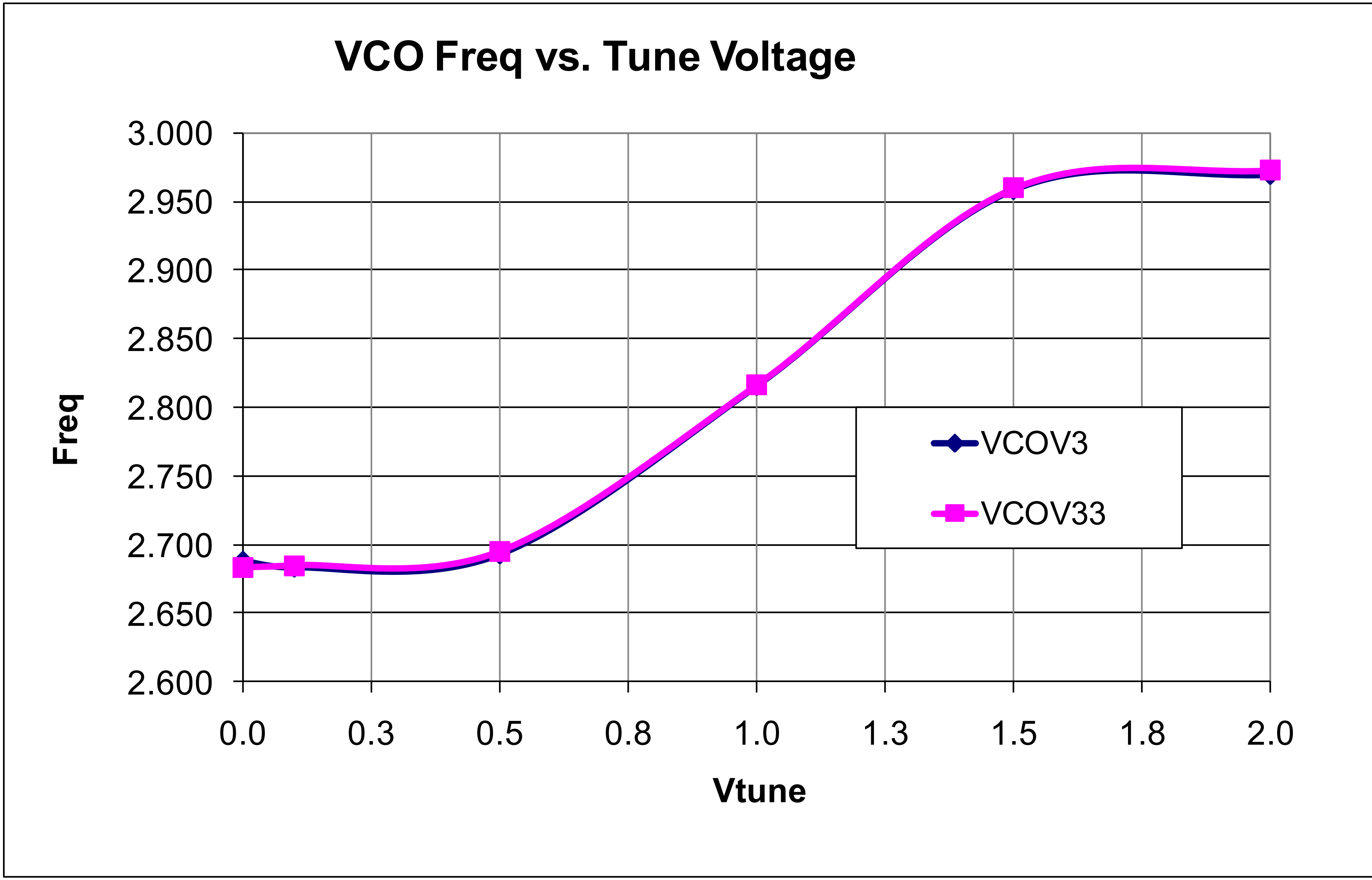
VG	VDD	Name
-0.54V	3V 3 mA	D60V3I3
-0.5V	4V 4 mA	D60V4I4

TEST PHEMT Emode 60 um

VG	VDD	Name
+0.57V	3V 3 mA	E60V3I3



JHU09VC1



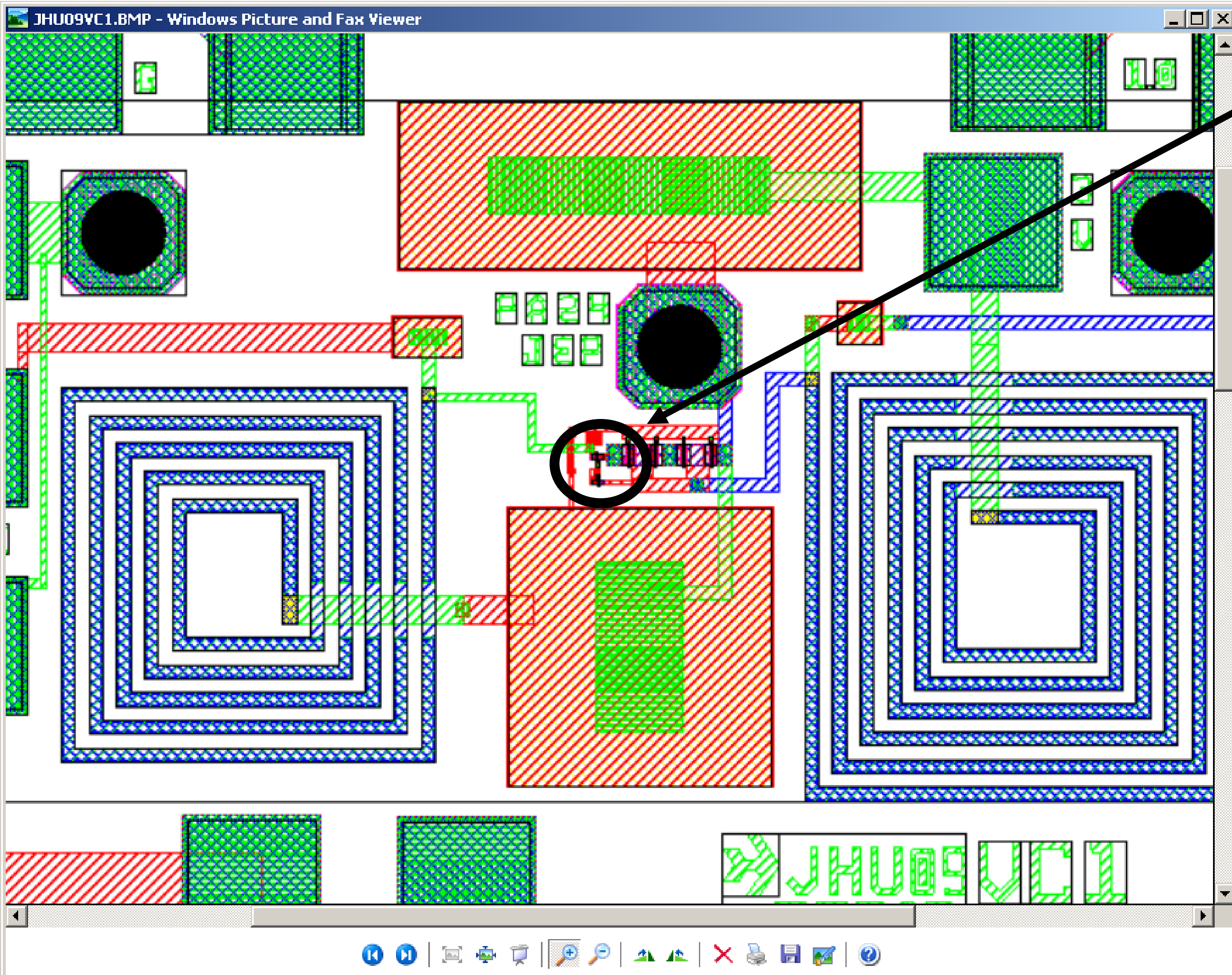
VCO Freq vs. Tune Voltage
3.000
2.950
2.900
2.850
2.800
2.750
2.700
2.650
2.600
Freq
0.0
0.3
0.5
0.8
1.0
1.3
1.5
1.8
2.0
Vtune
VCOV3
VCOV33

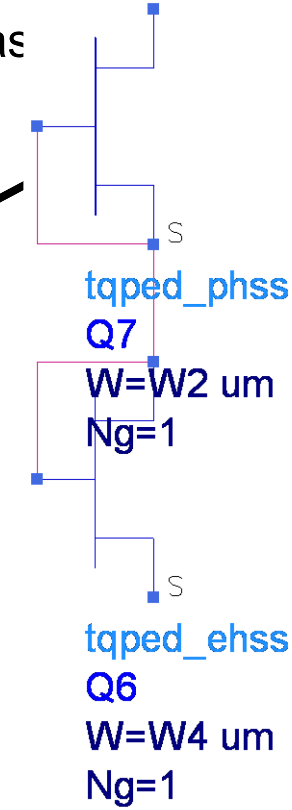
JHU09VC1

MWO VCO	3V at 25mA		Die #1		ADS VCO	3.3V at 28mA		Die #1
VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)		VBias (V)	Freq (GHz)	Pout(ms)	Pout(corr)
0.0	2.688	8.3	**9.2**		0.0	2.683	9.3	**10.2**
0.1	2.683	8.3	**9.2**		0.1	2.685	9.3	**10.2**
0.5	2.693	8.2	**9.1**		0.5	2.695	9.0	**9.9**
1.0	2.816	7.5	**8.4**		1.0	2.816	8.3	**9.2**
1.5	2.959	5.7	**6.6**		1.5	2.960	6.3	**7.2**
2.0	2.970	5.5	**6.4**		2.0	2.973	6.3	**7.2**
2.5	2.975	5.0	**5.9**		2.5	2.978	6.3	**7.2**
3.0	2.979	5.5	**6.4**		3.0	2.983	6.2	**7.1**
3.5	2.984	5.3	**6.2**		3.5	2.987	6.2	**7.1**
4.0	2.988	5.5	**6.4**		4.0	2.991	6.2	**7.1**
4.5	2.991	5.3	**6.2**		4.5	2.994	6.2	**7.1**
5.0	2.994	5.3	**6.2**		5.0	2.9975	6.17	**7.1**

JHU09VC1—PA Test Circuit

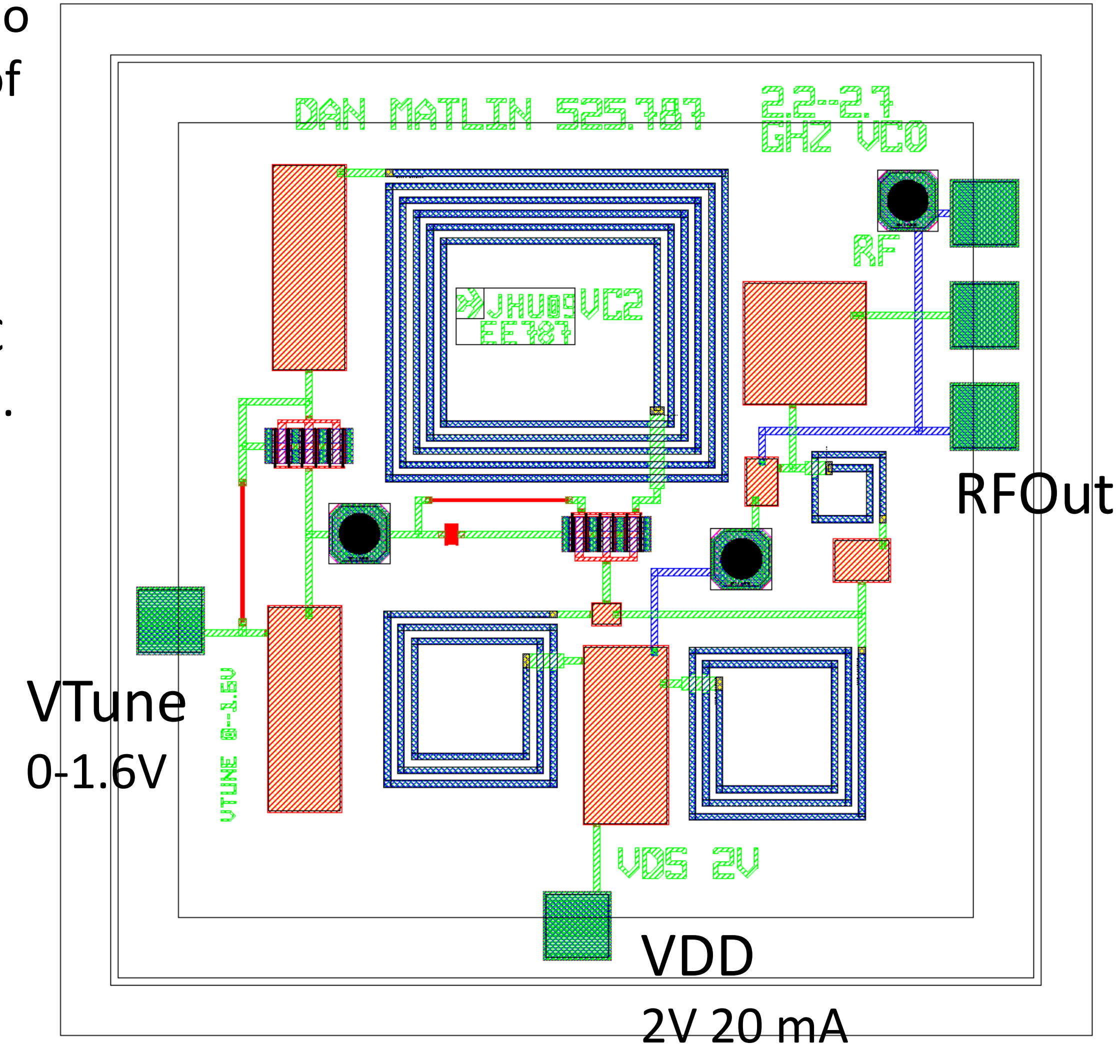
PA24E test cell failed to bias. Missing connection in current mirror bias





JHU09VC2 Dan Matlin

Summary: This 2.4 GHz VCO also oscillated. See attached plots of the tuning range and output power. The tuning range and oscillation conditions were measured at a slightly lower DC bias than intended (1.6, 1.8V vs. 2V as designed).



Test:

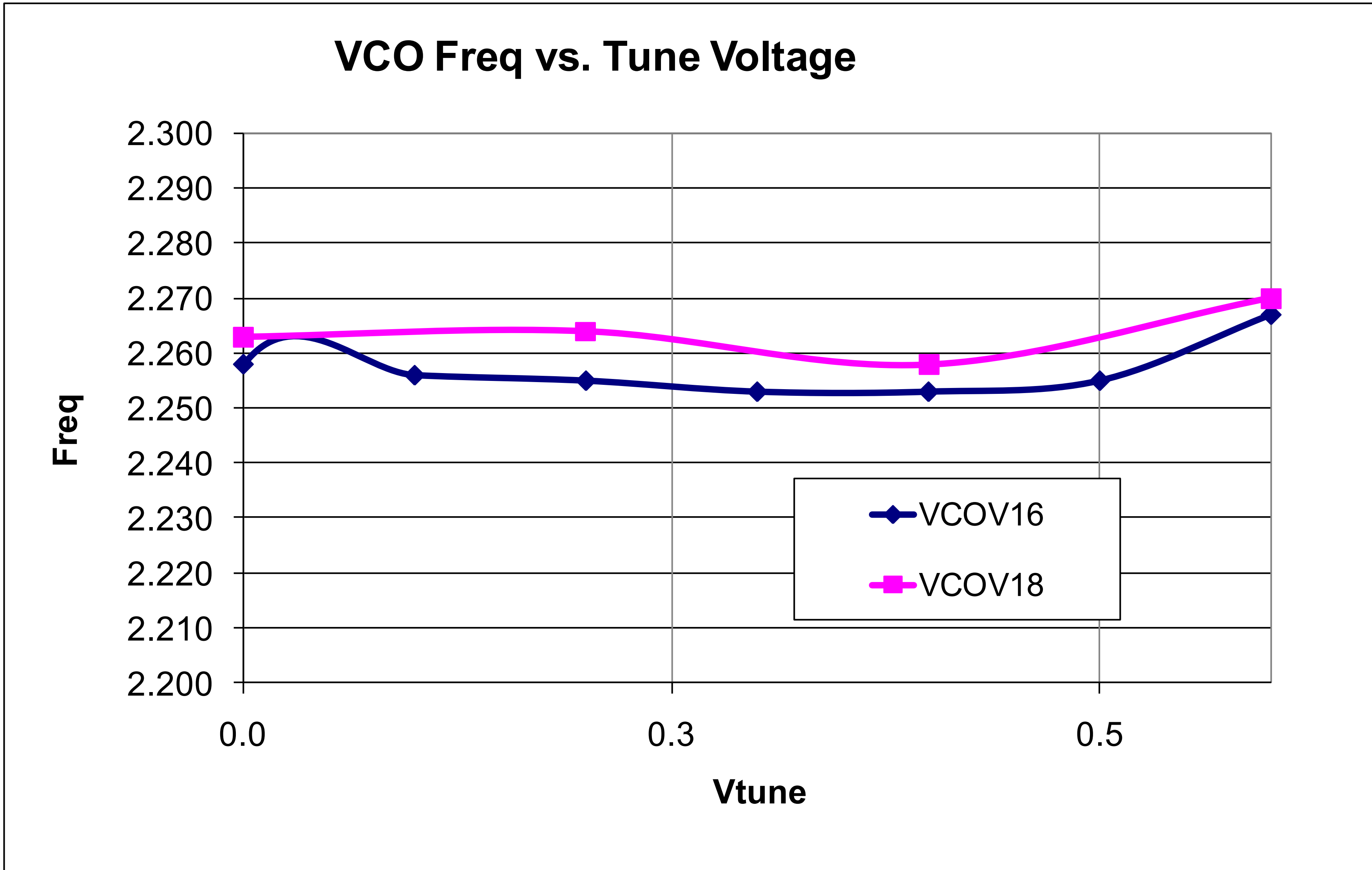
Power up VCO

Measure RFOut over Vtune Range

Vtune VD FO PO

Oscillated Well! See Plots!

JHU09VC2



VCO Freq vs. Tune Voltage
2.300
2.290
2.280
2.270
2.260
2.250
2.240
2.230
2.220
2.210
2.200
Freq
0.0
0.3
0.5
Vtune
VCOV16
VCOV18

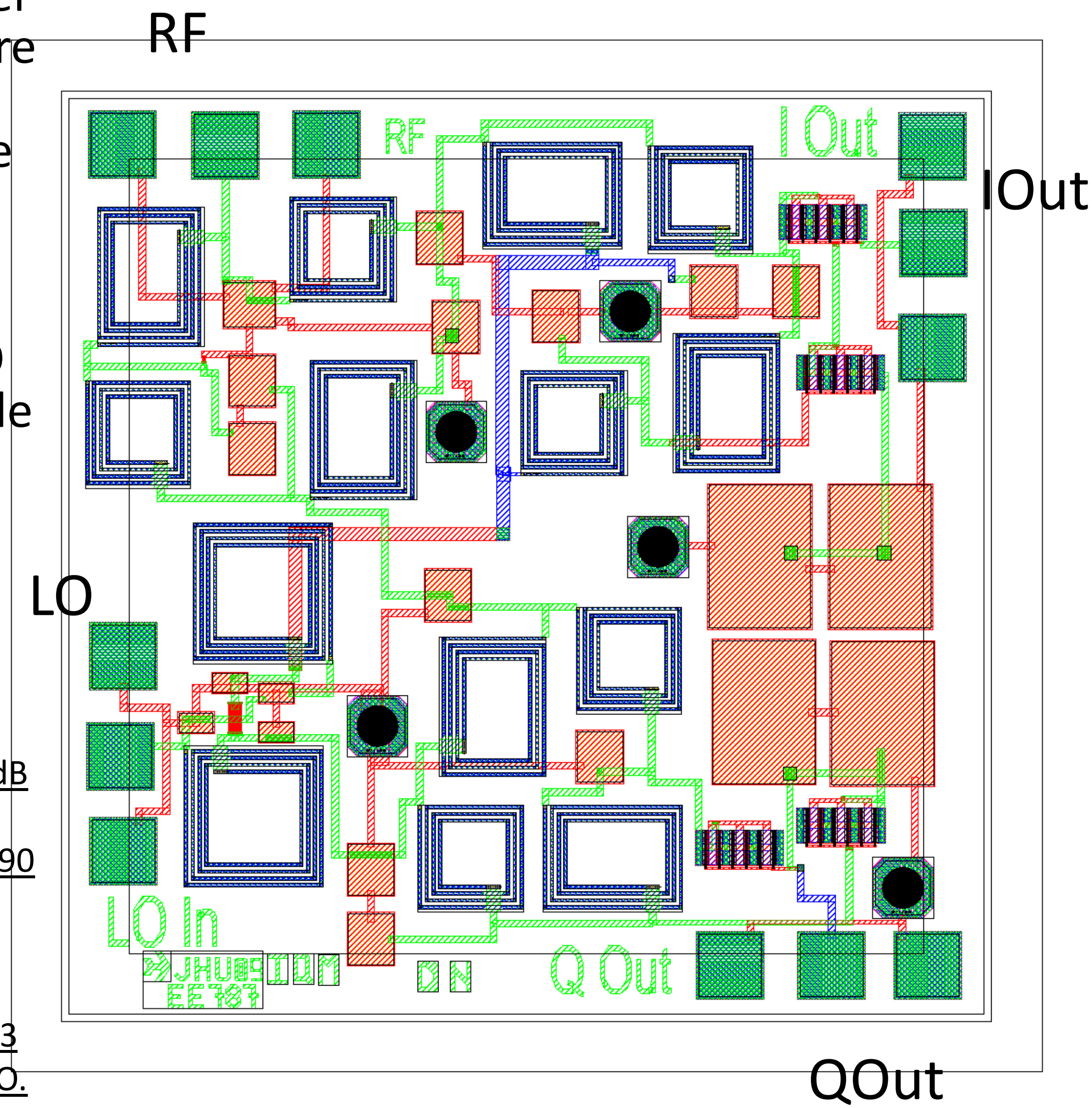
JHU09VC2

MWO VCO	1.6V at 20 mA		Die #1		ADS VCO	1.8V at 20mA		Die #1
VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)		VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)
-0.4	2.252	-8.2	**-7.3**		0.0	2.263	-1.3	**-0.4**
-0.3	2.252	-5.7	**-4.8**		0.2	2.264	-0.2	**0.7**
-0.2	2.173	-1.5	**-0.6**		0.4	2.258	0.3	**1.2**
-0.1	2.175	-1.7	**-0.8**		0.6	2.270	1.7	**2.6**
0.0	2.258	-1.8	**-0.9**		0.7	NA	NA	NA
0.1	2.256	-1.3	**-0.4**					
0.2	2.255	-0.8	**0.1**					
0.3	2.253	-0.7	**0.2**					
0.4	2.253	0.0	**0.9**					
0.5	2.255	0.3	**1.2**					
0.6	2.267	1.3	**2.2**					
0.7	NA	NA	NA					

MWO VCO	1.6V at 20 mA		Die #2		ADS VCO	1.8V at 20mA		Die #1
VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)		VBias (V)	Freq (GHz	Pout(ms)	Pout(corr)
0.0	2.250	1.0	**1.9**		0.0	2.269	2.2	**3.1**
0.2	2.252	1.3	**2.2**		0.2	2.270	2.5	**3.4**
0.4	2.256	1.8	**2.7**		0.4	2.274	3.2	**4.1**
0.6	2.282	2.5	**3.4**		0.5	NA	NA	NA
0.7	2.365	0.3	**1.2**					
0.8	2.380	1.2	**2.1**					

JHU09IQM David Nelson

Summary: This 2.4 GHz I/Q Mixer worked, but the I/Q outputs were measured on a spectrum analyzer, so the 90 degree phase difference could not be verified. Also, the initial measurements were under-driven so later measurements used a higher LO drive. Conversion loss was a little worse than expected.



Test:

2.4 GHz IQ Mixer

Not able to drive LO as high as needed. Conversion loss was low, but was also low on later test mixer circuits on JHU09MSC. Noted that a 2 dB backoff of LO drive resulted in 12 dB more conversion loss. Mixed OK but had difficulty measuring all 4 ports at once to see 90 degree difference between I and Q measurements.

2.45 GHz LO at 12.8 dBm (SG)

2.4/2.5 GHz RF at 12.8 dBm also yielded -17.33 dBm at Q and -15.83 dBm at I. Underdriven LO.

JHU09IQM

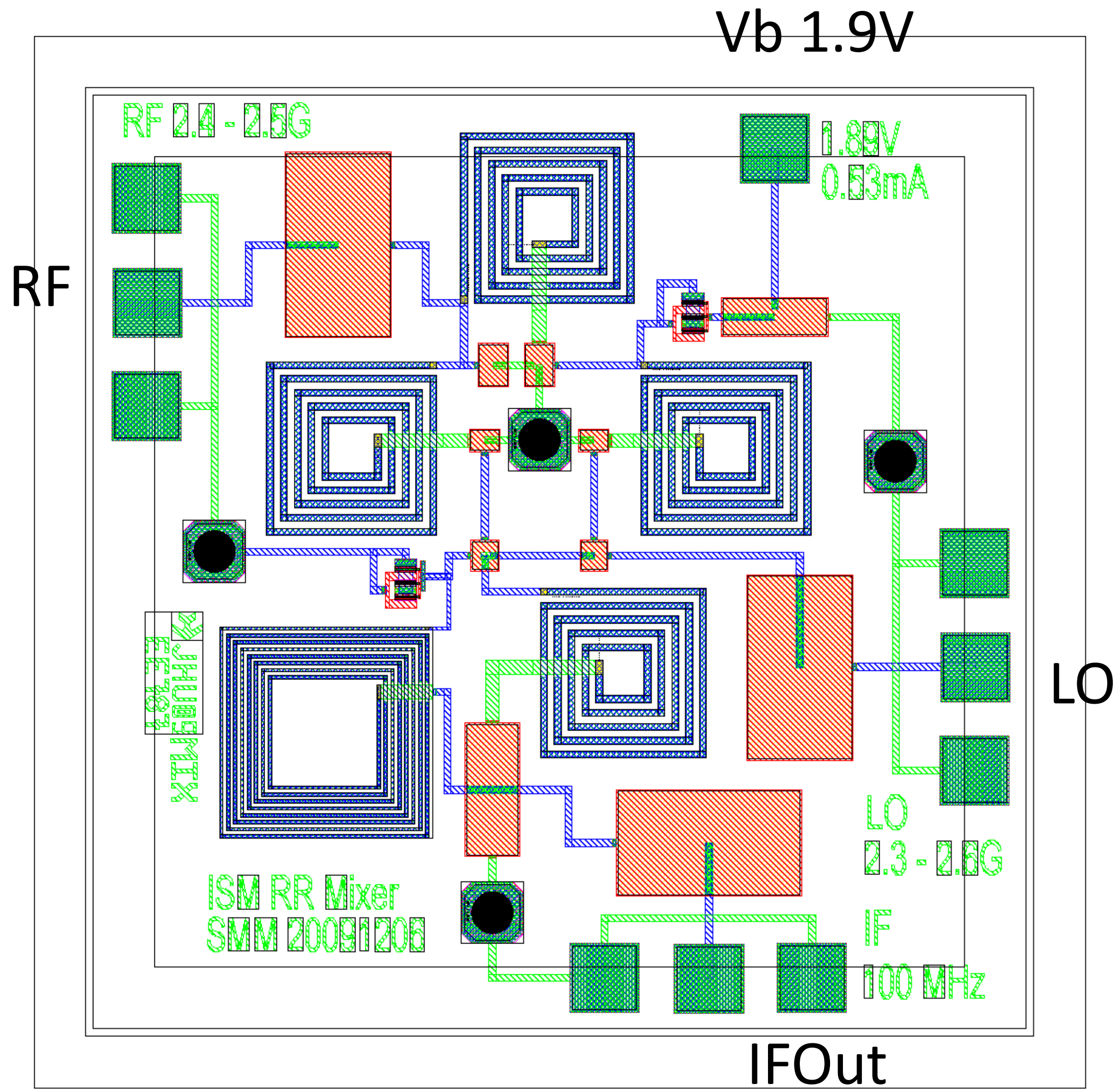
Measured Mixer									
DNelson Mixer 2.4 GHz LO									
				RF 2.4/2.5 GHz and IF 50 MHz 12.8 dBm setting					
	LO = 2.45 GHz 12.8 dBm => ~11.8			Measured 5.8 GHz LO					
1) RF 2.4/2.5 GHz									
Down Conversion IRM	**Q**		**IF=50 MHz**				**I**		
RF 2.4G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.4G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain**
12.8	11.8	-17.3	-17.1	**-28.9**	12.8	11.8	-15.8	-15.6	**-27.4**
RF 2.5G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.5G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain**
12.8	11.8	-17.3	-17.1	**-28.9**	12.8	11.8	-15.8	-15.6	**-27.4**

IQM: Re-Measured with higher LO drive, still high conversion loss but consistent with previous measurements.

4/13/2010									
Down Conversion IRM	**I Out/2.4G**	**IF=50 MHz**		RF = -11 dBM		**I Out/2.5G**			
LO 2.45G	**LO (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**LO 2.45G**	**LO (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain**
13	12	-41.3	-41.1	**-30.1**	13	12	-41.9	-41.6	**-30.6**
14	13	-39.0	-38.8	**-27.8**	14	13	-39.3	-39.1	**-28.1**
15	14	-37.5	-37.3	**-26.3**	15	14	-37.7	-37.4	**-26.4**
16	15	-35.8	-35.6	**-24.6**	16	15	-36.2	-35.9	**-24.9**

JHU09MIX Steve Moeglein

Summary: This 2.4 GHz Up/Down Mixer worked well. A DC bias was provided to the diodes so that the LO drive could be lowered considerably. The design was re-measured with about 12-13 dB conversion loss for up or down mixing.



Test:

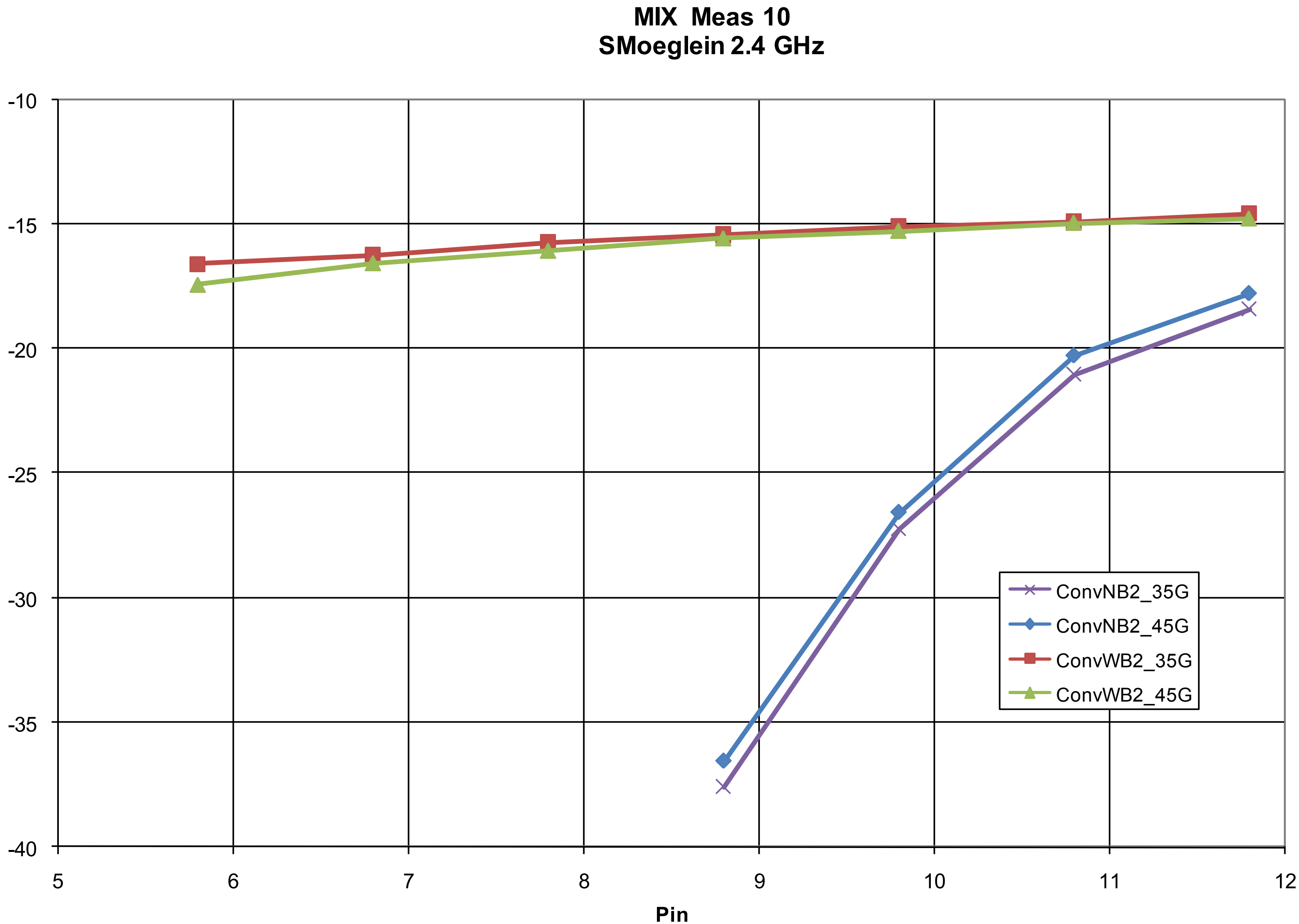
2.4 GHz Up/Down Mixer
1.89V at 0.53 mA (Diode Bias)

JHU09MIX

Measured Mixer										**Freq (GHz)**
SMoeglein Mixer 2.4 GHz LO										2.40
				RF 2.35/2.45 GHz and IF 50 MHz 12.8 dBm setting						
	LO = 2.4 GHz -10 dBm => -11 dBm									
1) RF 2.35/2.45 GHz										
Down Conversion IRM		**Q**	**IF=50 MHz**	No Bias			**I**			
RF 2.35G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.45G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	
12.8	11.8	-29.7	-29.4	**-18.4**	12.8	11.8	-29.0	-28.8	**-17.8**	
11.8	10.8	-32.3	-32.1	**-21.1**	11.8	10.8	-31.5	-31.3	**-20.3**	
10.8	9.8	-38.5	-38.3	**-27.3**	10.8	9.8	-37.8	-37.6	**-26.6**	
9.8	8.8	-48.8	-48.6	**-37.6**	9.8	8.8	-47.8	-47.6	**-36.6**	
RF 2.35G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.45G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gair**	**with 1.2V a**
12.8	11.8	-25.8	-25.6	**-14.6**	12.8	11.8	-26.0	-25.8	**-14.8**	
11.8	10.8	-26.2	-25.9	**-14.9**	11.8	10.8	-26.2	-25.9	**-14.9**	
10.8	9.8	-26.3	-26.1	**-15.1**	10.8	9.8	-26.5	-26.3	**-15.3**	
9.8	8.8	-26.7	-26.4	**-15.4**	9.8	8.8	-26.8	-26.6	**-15.6**	
8.8	7.8	-27.0	-26.8	**-15.8**	9.8	8.8	-27.3	-27.1	**-16.1**	
7.8	6.8	-27.5	-27.3	**-16.3**	9.8	8.8	-27.8	-27.6	**-16.6**	
6.8	5.8	-27.8	-27.6	**-16.6**	9.8	8.8	-28.7	-28.4	**-17.4**	

Measured w/ and w/o DC bias to Diodes. DC Current seemed higher than expected but the conversion loss did get better and was less sensitive to lower LO drive levels.

JHU09MIX



Note Lower conversion loss w/ 1.2V 7m A DC bias.

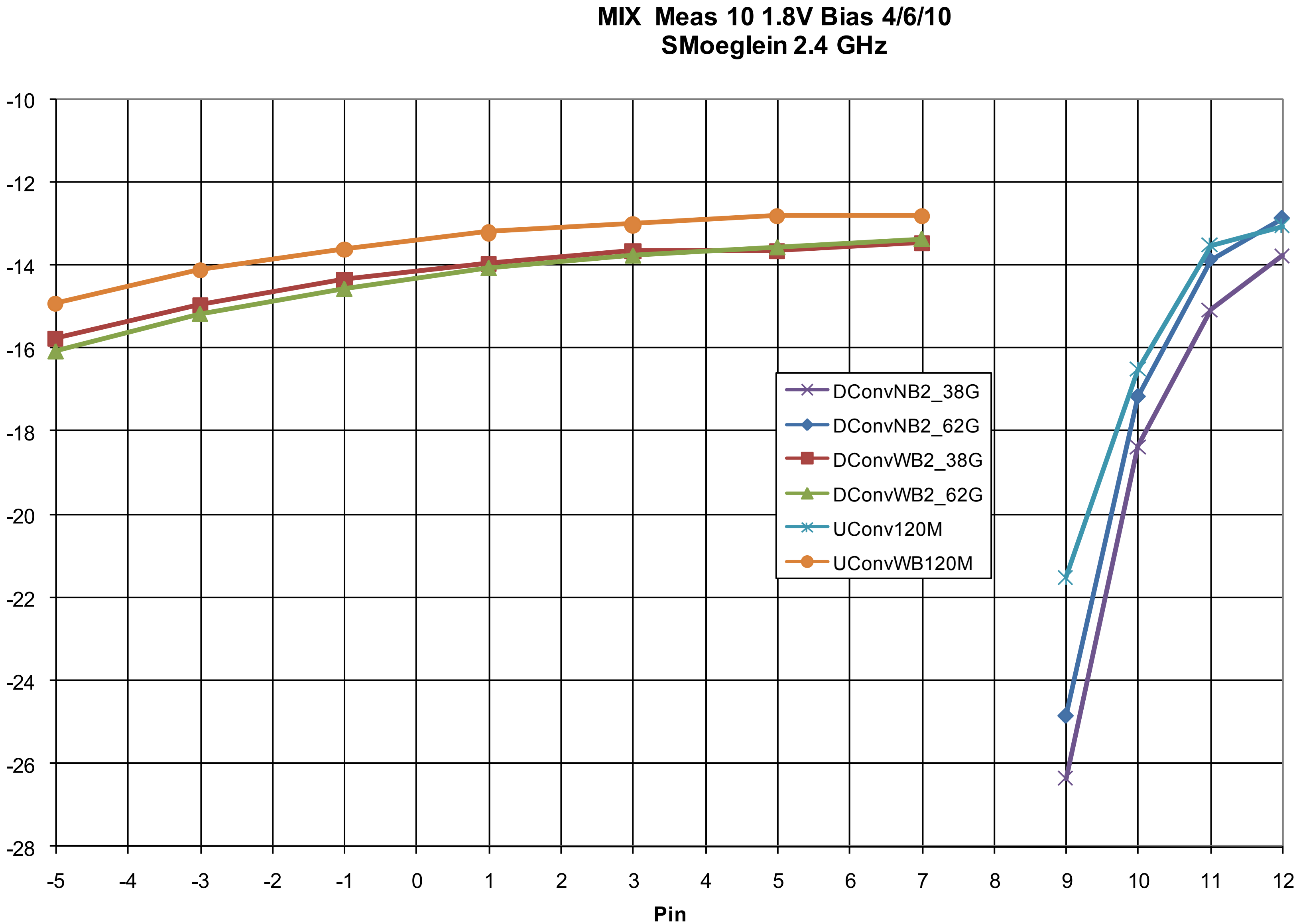
JHU09MIX

4/6/2010	LO = 2.5 GHz									
1) RF 2.38/2.62 GHz -10 dBm => -11 dBm										
UP Conversion IRM		**Q**	**IF=120 MHz**	No Bias			**I**			
RF 2.38G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.62G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	
13	12	-25.0	-24.8	**-13.8**	12.8	11.8	-24.1	-23.9	**-12.9**	
12	11	-26.3	-26.1	**-15.1**	11.8	10.8	-25.1	-24.9	**-13.9**	
11	10	-29.6	-29.4	**-18.4**	10.8	9.8	-28.4	-28.2	**-17.2**	
10	9	-37.6	-37.4	**-26.4**	9.8	8.8	-36.1	-35.9	**-24.9**	
RF 2.38G	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gain)**	**RF 2.62G**	**RF (corr)**	**IF (meas)**	**IF (corr)**	**Loss (gair**	**with 1.8V a**
8	7	-24.7	-24.5	**-13.5**	12.8	11.8	-24.6	-24.4	**-13.4**	
6	5	-24.9	-24.7	**-13.7**	11.8	10.8	-24.8	-24.6	**-13.6**	
4	3	-24.9	-24.7	**-13.7**	10.8	9.8	-25.0	-24.8	**-13.8**	
2	1	-25.2	-25.0	**-14.0**	9.8	8.8	-25.3	-25.1	**-14.1**	
0	-1	-25.6	-25.4	**-14.4**	9.8	8.8	-26.8	-26.6	**-15.6**	
-2	-3	-26.2	-26.0	**-15.0**	9.8	8.8	-26.4	-26.2	**-15.2**	
-4	-5	-27.0	-26.8	**-15.8**	9.8	8.8	-27.3	-27.1	**-16.1**	

Down Conversion IRM	**Q**		**IF=120 MHz**	No Bias
IF 120M	**RF (corr)**	**RF (meas)**	**RF (corr)**	**Loss (gain)**
13	12	-24.3	-23.3	**-13.1**
12	11	-25.5	-24.5	**-13.5**
11	10	-28.5	-27.5	**-16.5**
10	9	-33.5	-32.5	**-21.5**
IF 120M	**RF (corr)**	**RF (meas)**	**RF (corr)**	**Loss (gain)**
8	7	-24.8	-23.8	**-12.8**
6	5	-24.8	-23.8	**-12.8**
4	3	-25.0	-24.0	**-13.0**
2	1	-25.2	-24.2	**-13.2**
0	-1	-25.6	-24.6	**-13.6**
-2	-3	-26.1	-25.1	**-14.1**
-4	-5	-26.9	-25.9	**-14.9**

Re-Measured 4/6/2010 w/ and w/o 1.8V DC bias to Diodes. DC Current increased with LO drive. DC bias to diodes enabled good conversion loss at much lower LO levels. Up/Down conversion with 2.5 GHz LO and 120 MHz IF.

JHU09MIX



Note good up/down conversion loss w/ 1.8V 1-4 m A DC bias and lower LO.

JHU09PA5 Ken McKnight

Summary: This Doherty PA at 5 GHz was a last minute addition. It did not get the LVS checking of the other student designs. Does not seem to DC bias correctly.

Test:

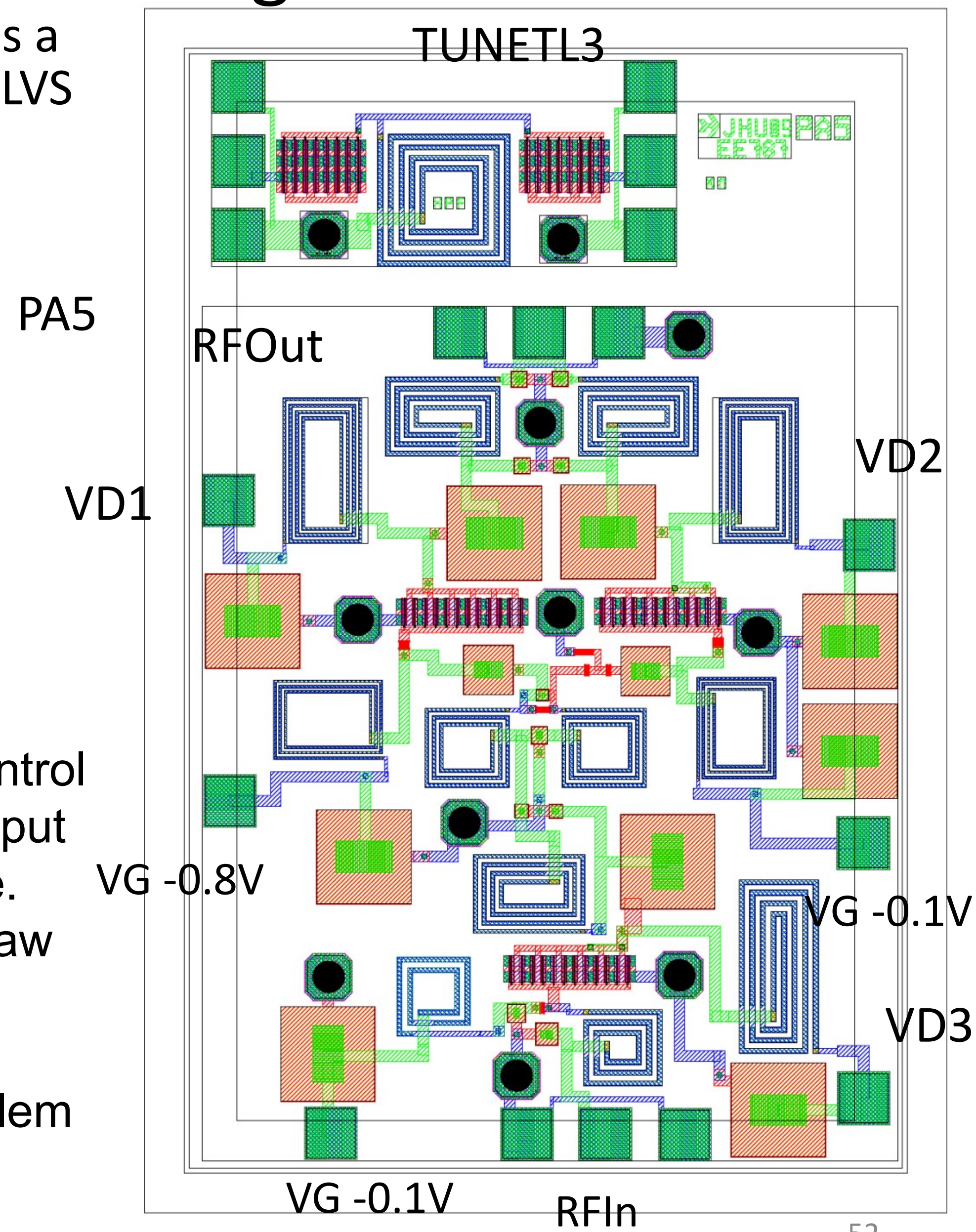
Varactor Filter TUNETL3

PA5 High DC Power! 5 GHz

6 DC Probes!?

VG1	VG2	VDD(P)	Name
			PA5V3
0V			TL3V0
			TL3V
			TL3V
			TL3V
			TL3V

PA5 4/13/10 Previously checked gate control and bias with good checks at the two output devices but no control at the input device. Repeated the measurement and again saw no drain current or gate control on input stage. Output stages appeared to work correctly. Need to find out what the problem might be.



JHU09PRJ Class Project 2--John Penn

Summary: This test circuit contains a 2.4 GHz front end as well as a VCO designed by the instructor. The front end includes a T/R switch, BPSK modulator, LNA, medium PA, and driver circuits to generate complementary switch logic control, plus a robust current mirror bias for 2-5V operation.

Test:

Power up LNA Measure Ant to RFOut

Set TS to 0,3V

LNA: VG -0.5V VD 3V at 30 mA

TS	VDD(L)	VDD(P)	Name
0	3V 3mA	3V 7mA	PRJLON
3	3V 3mA	3V 8mA	PRJLOFF

LNA Works Well! PA?

Power up PA Measure RFIn to Ant

Set TS to 0,3V

Set BP to 0,3V

PA: VG -0.25V VD 3V at 300 mA

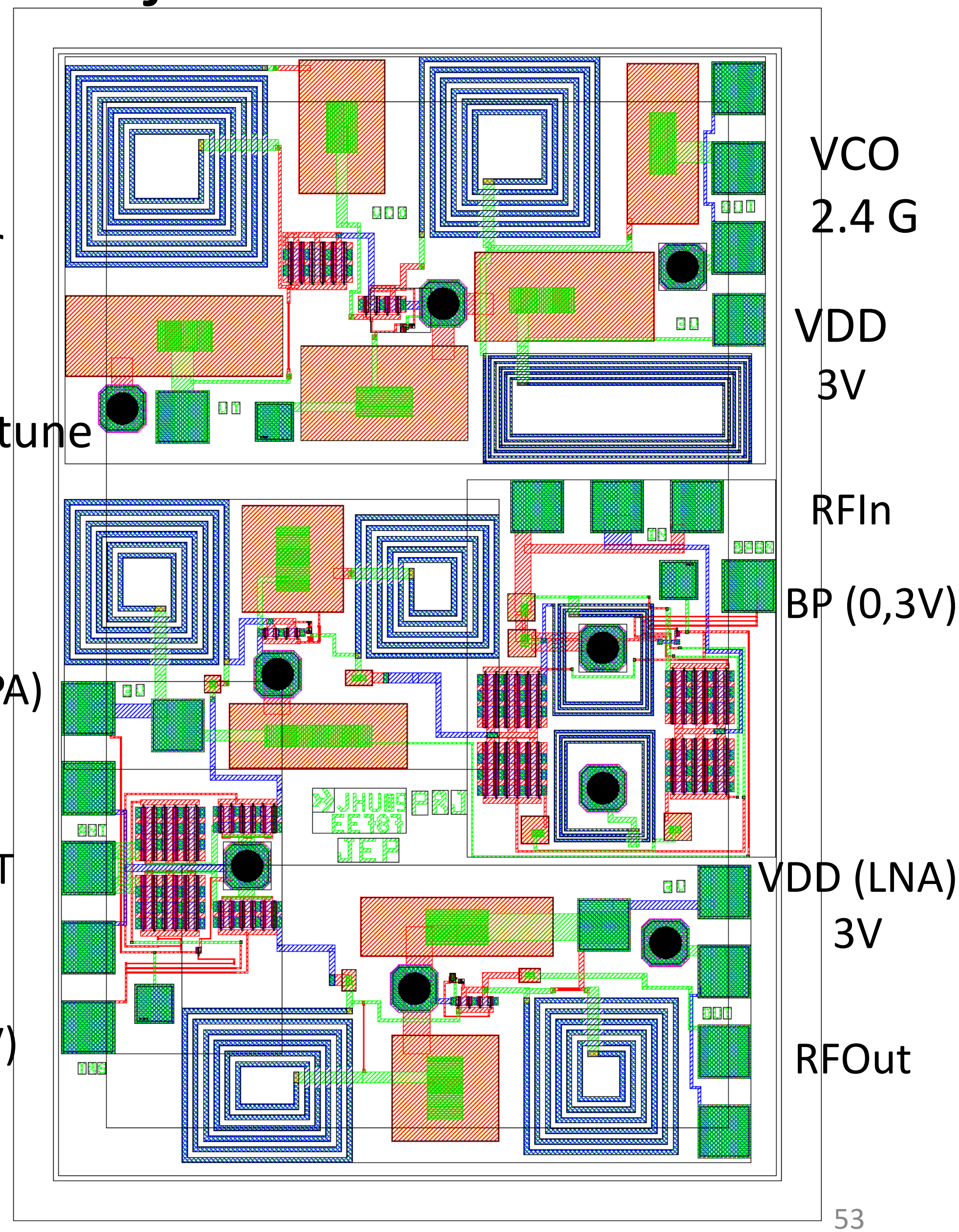
TS	BP	VDD(L)	VDD(P)	Name
0				PRJPOFF
3	0			PRJPONA
3	3			PRJPONB

Power up VCO

Measure RFOut over Vtune Range

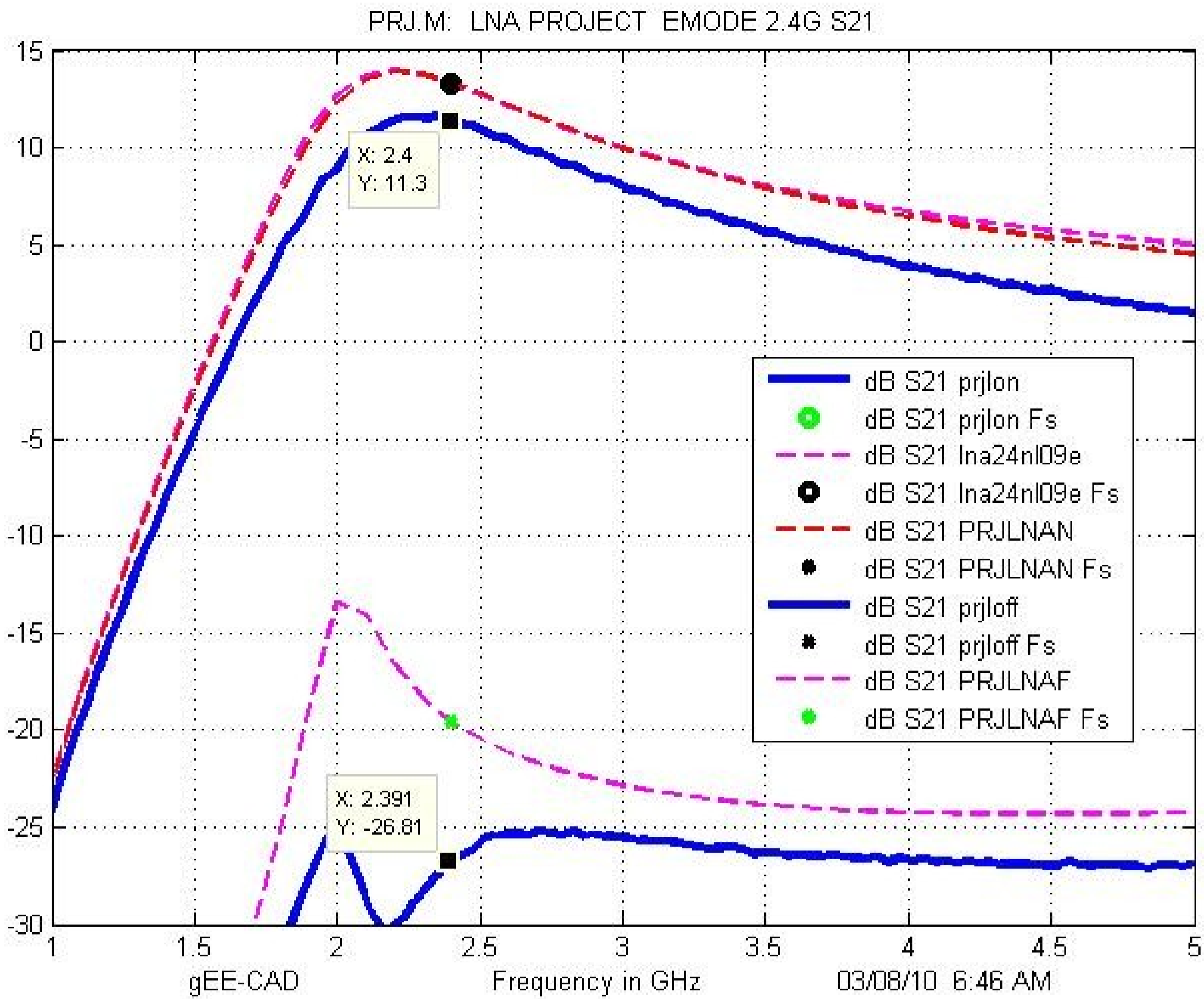
Vtune	VD	FO	PO

Did Not Oscillate!? DC Bias OK .



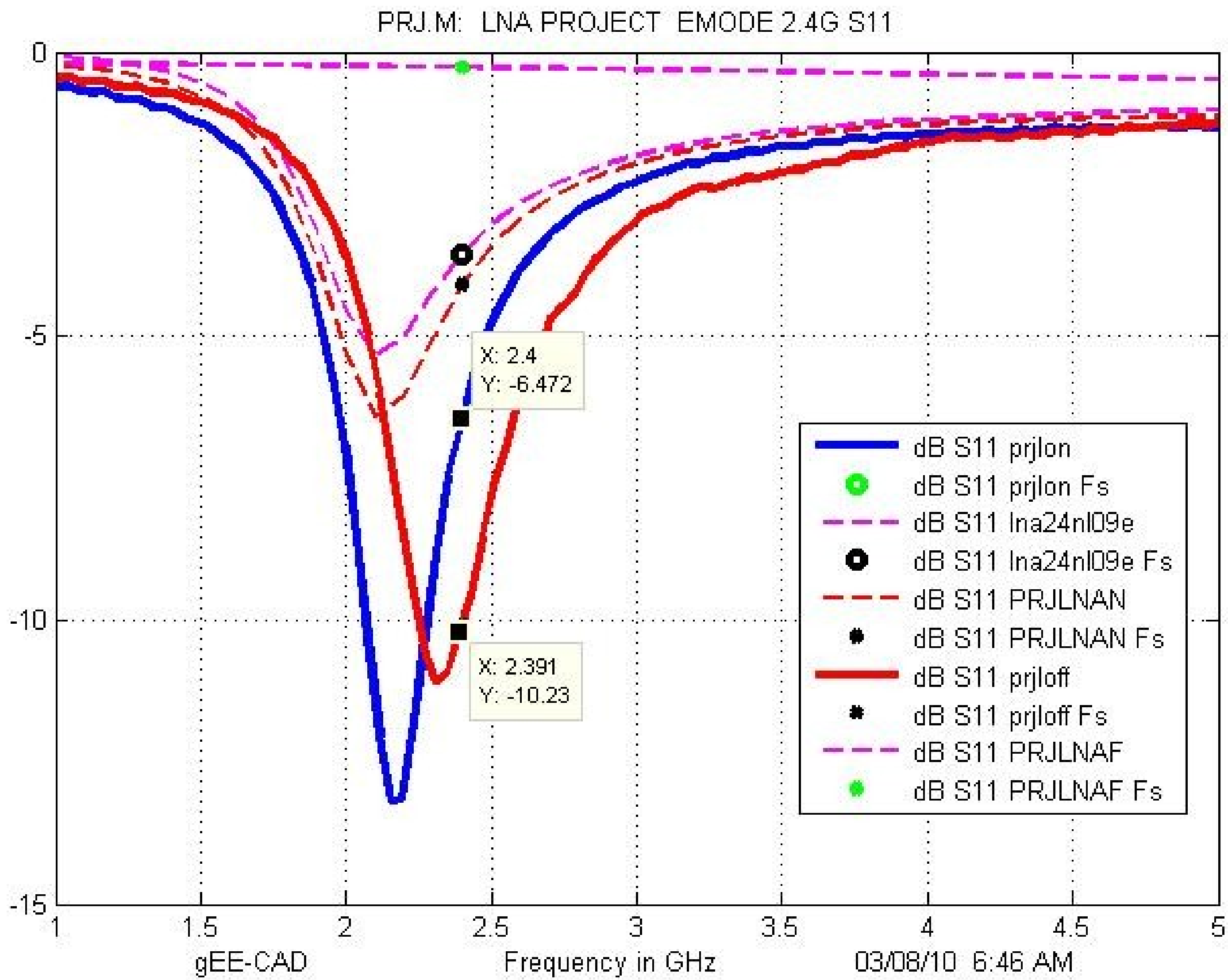
JHU09PRJ

LNA Measured Ant to RFOut



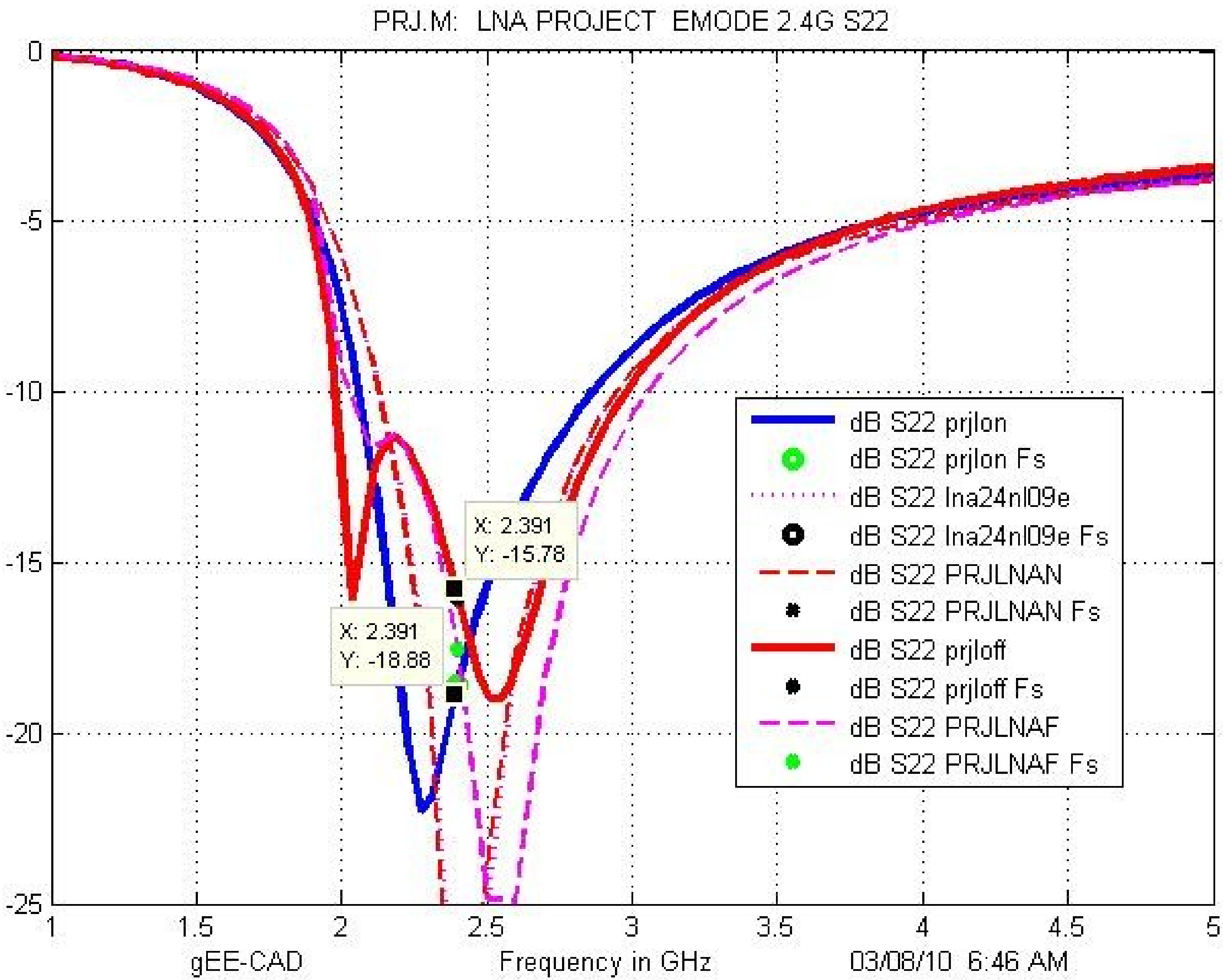
JHU09PRJ

LNA Measured Ant to RFOut



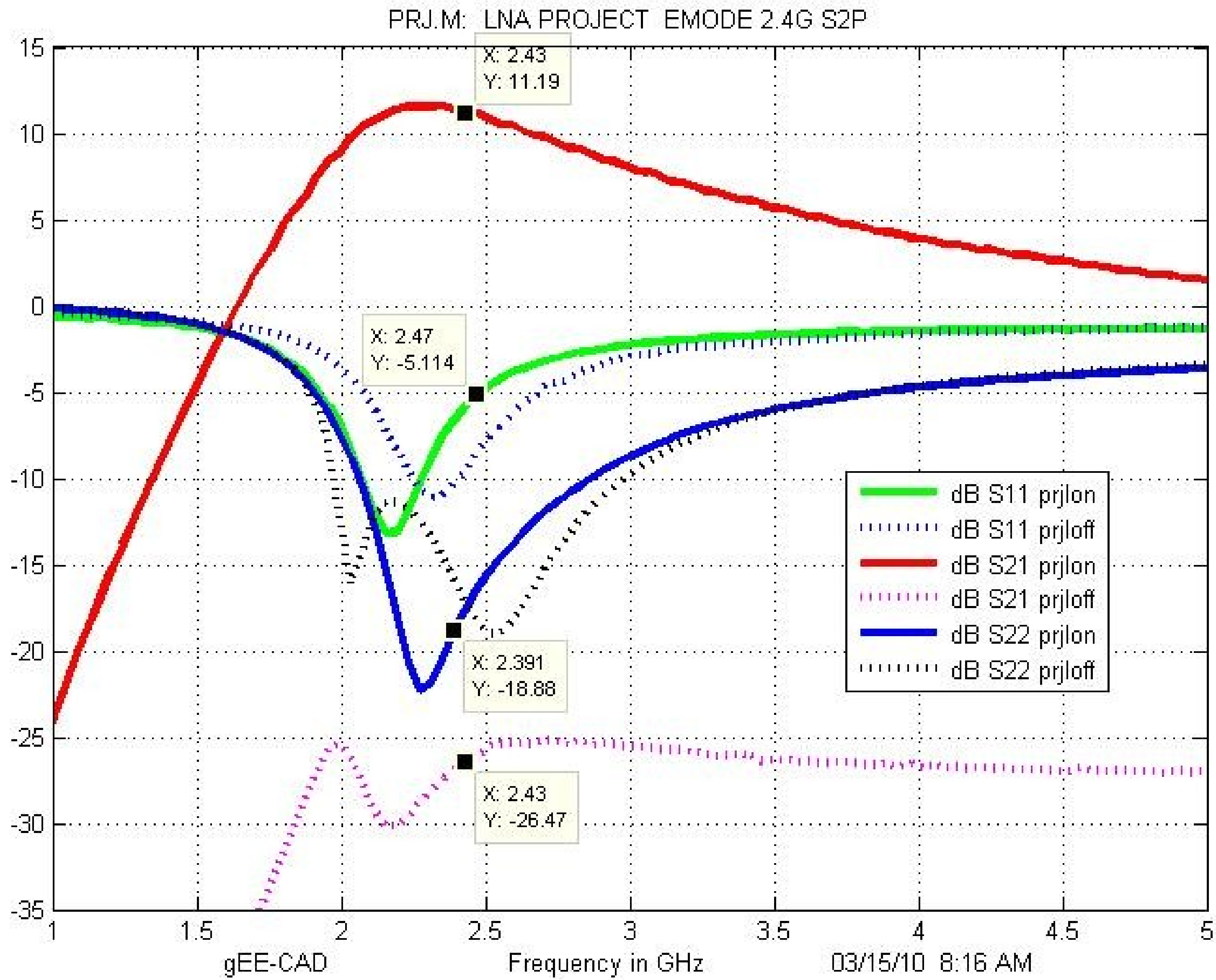
JHU09PRJ

LNA Measured Ant to RFOut



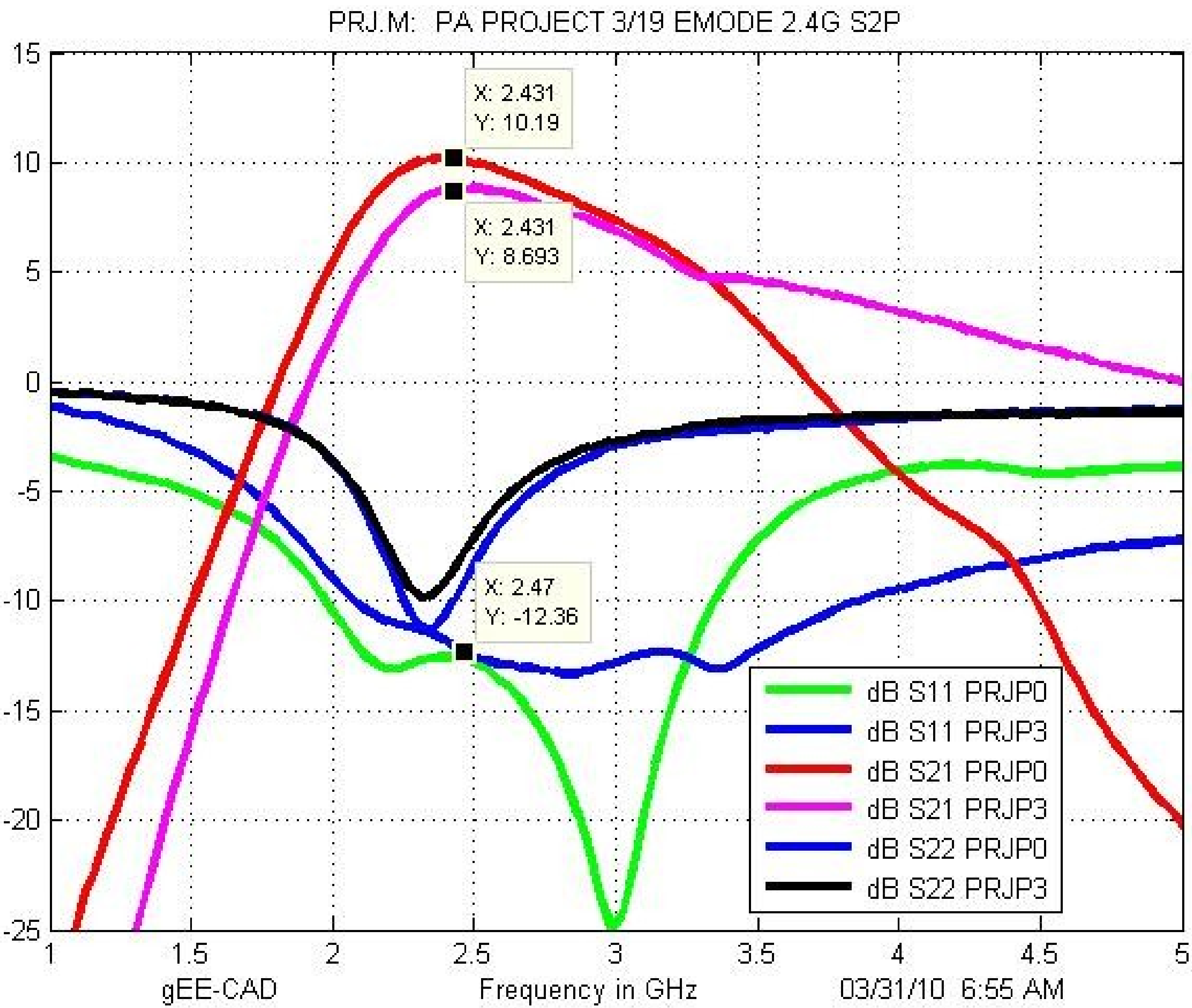
JHU09PRJ

LNA on/off—good T/R switch isolation of 37 dB!



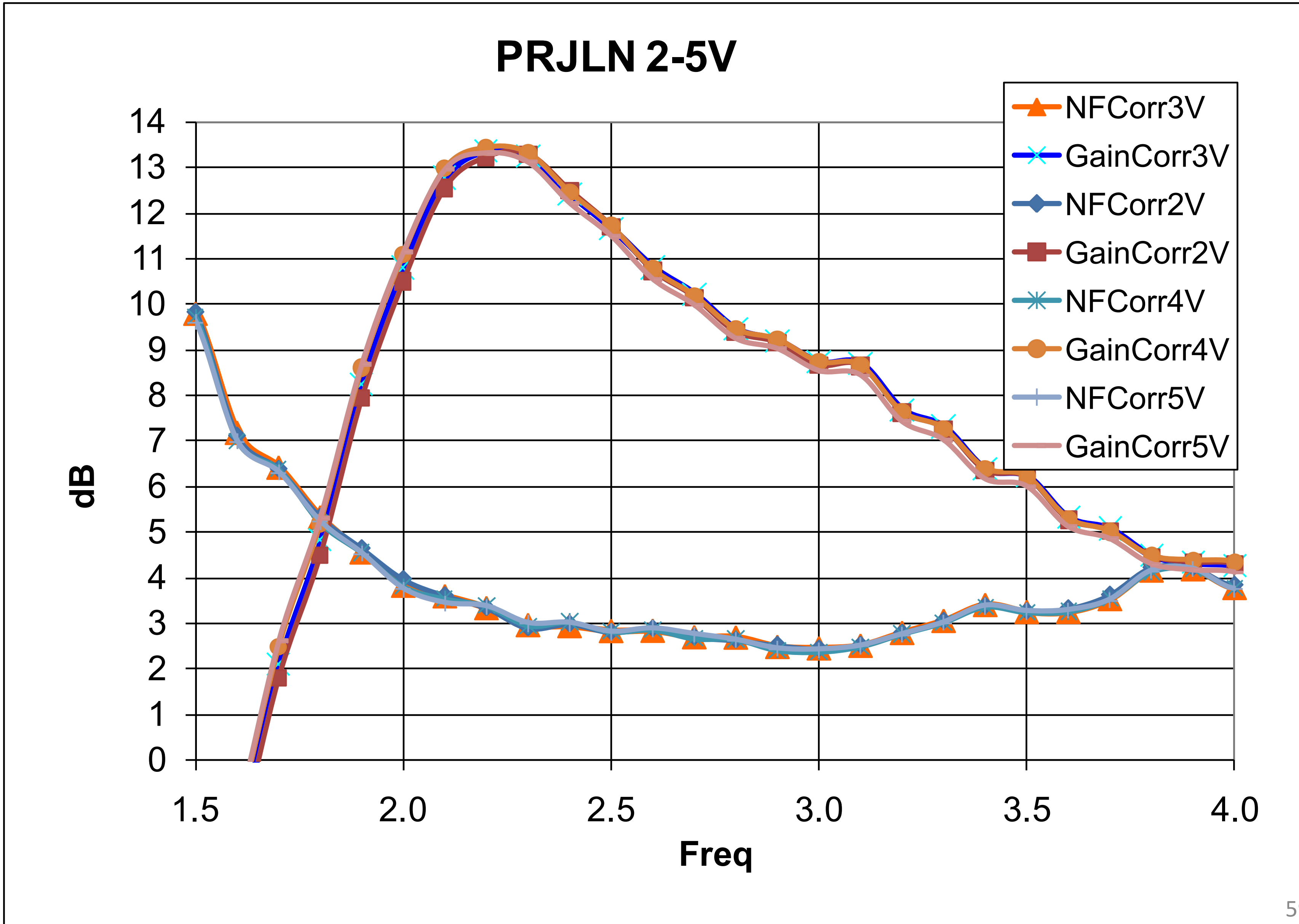
JHU09PRJ

PA A/B Re-Measured 3/19 OK Results but Gain is low.



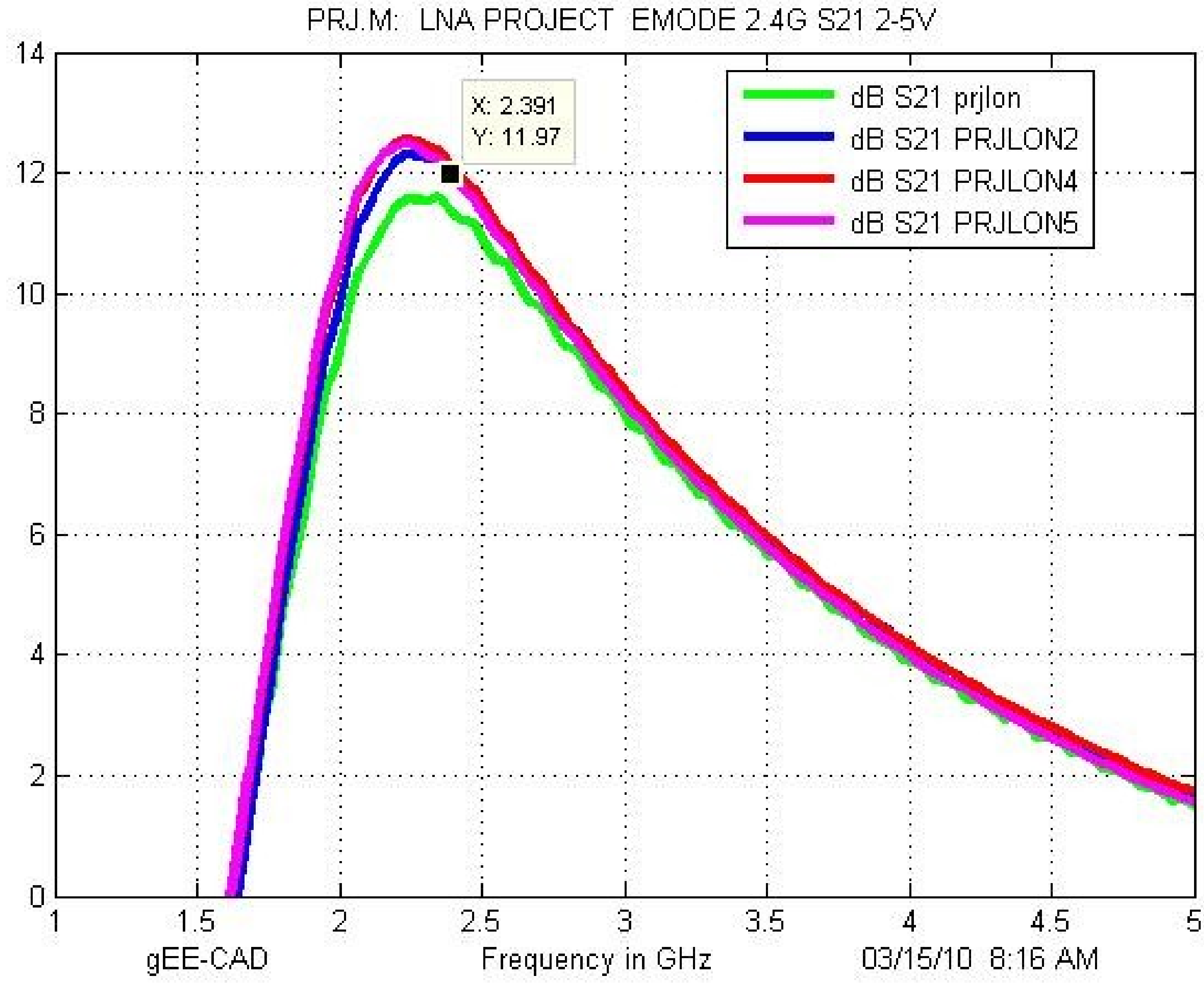
JHU09PRJ

LNA NF from 2-5V! 10 to 12 mA total, very robust!



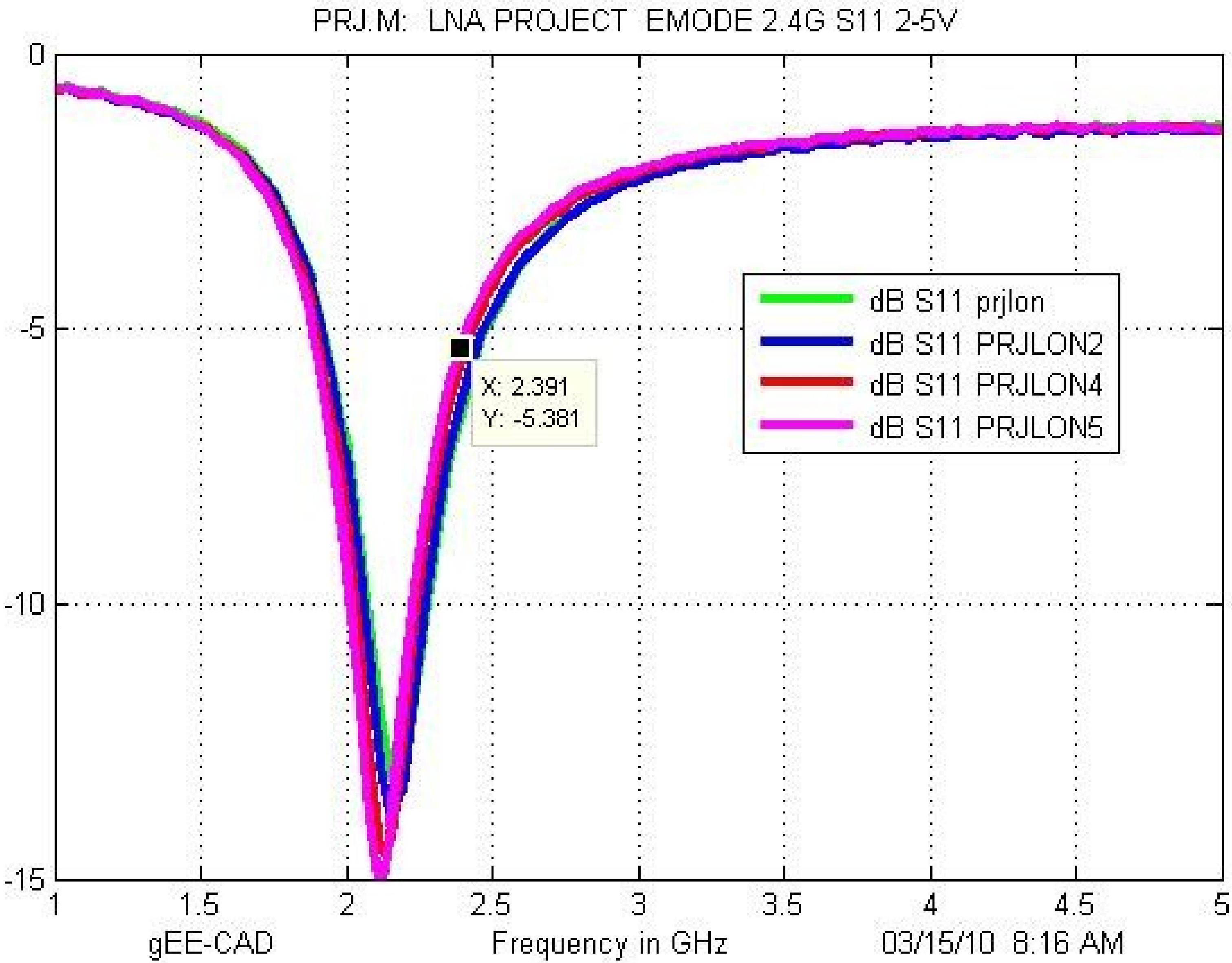
JHU09PRJ

LNA S21 from 2-5V! 10 to 12 mA total, very robust S21!



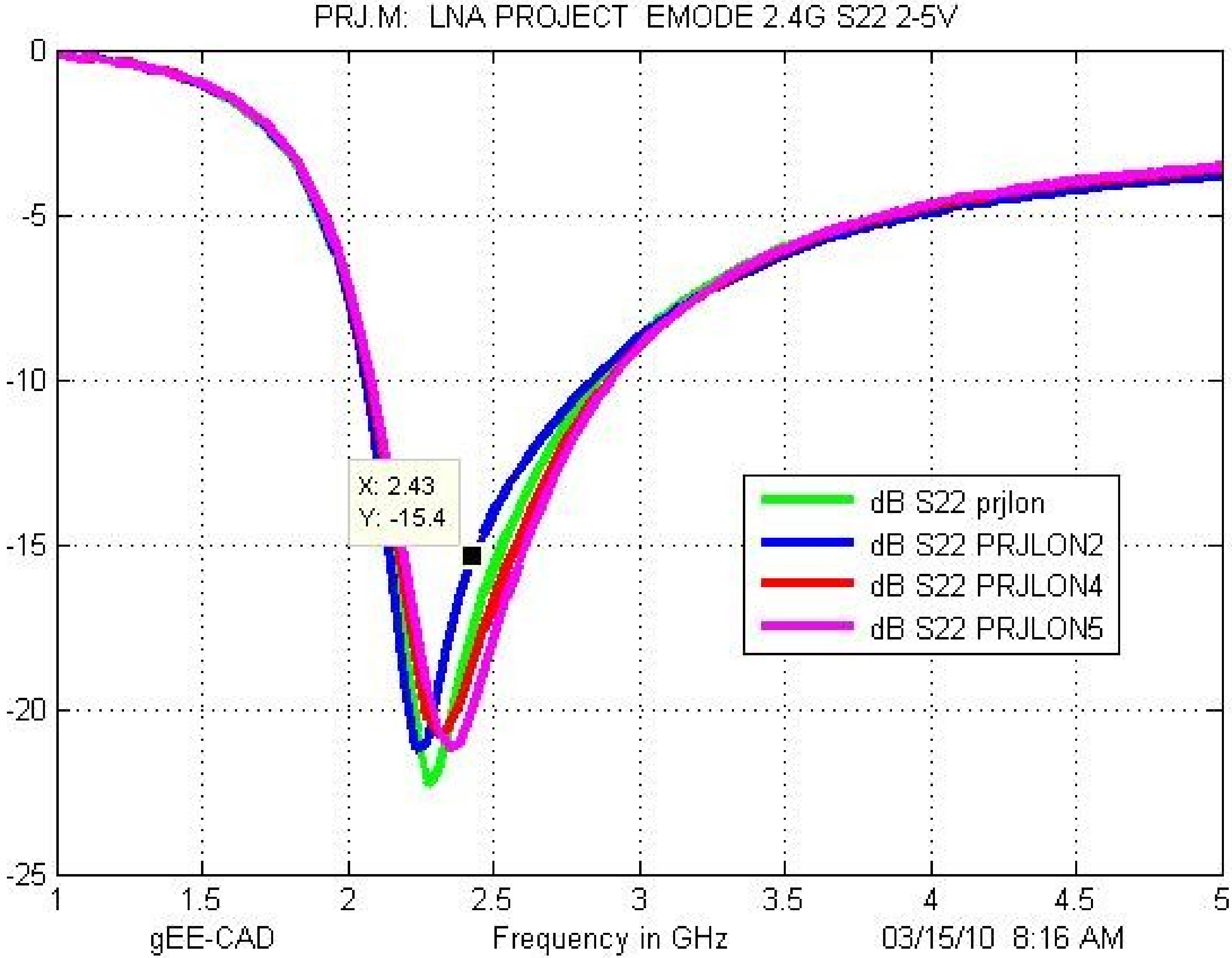
JHU09PRJ

LNA S11 from 2-5V! 10 to 12 mA total, very robust S11!



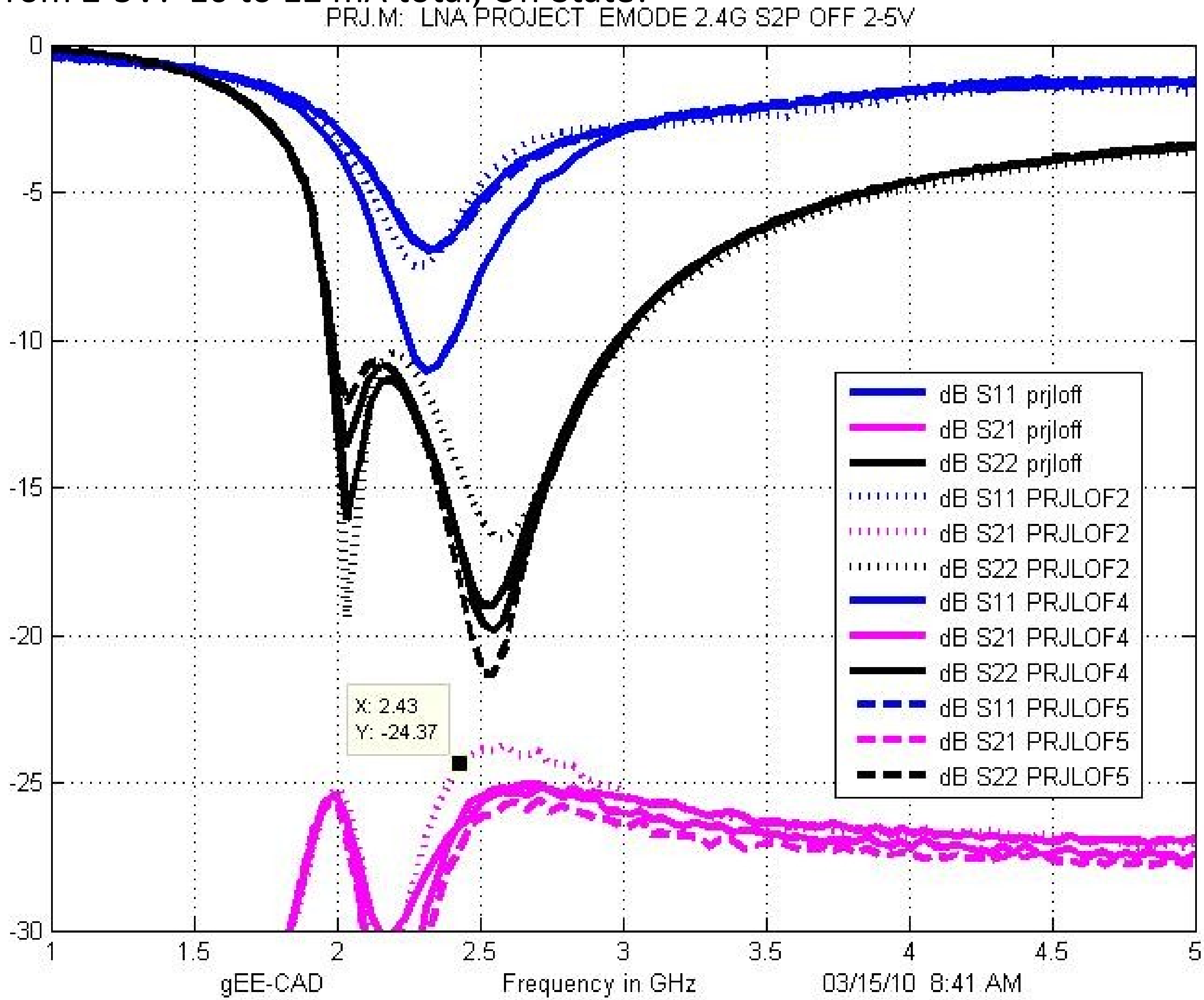
JHU09PRJ

LNA S22 from 2-5V! 10 to 12 mA total, very robust S22!



JHU09PRJ

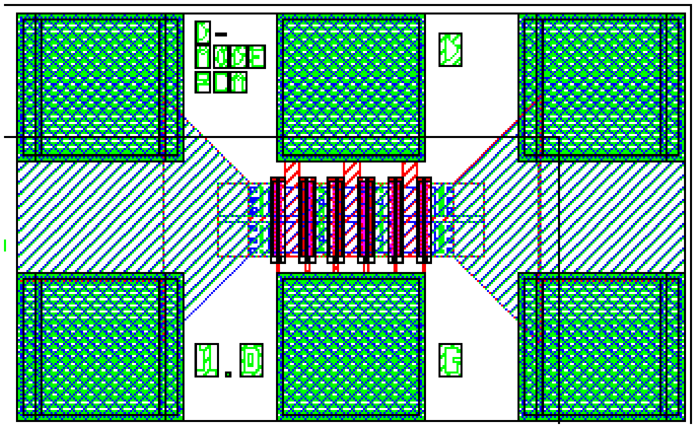
LNA S2P from 2-5V! 10 to 12 mA total, Off State!



PHEMT Measurements--Fall JHU MMIC Designs 2009

Emode and Dmode PHEMTs were included in the JHU tile for comparison to typical devices and for possible re-simulations to compare the students designs to their measurements using S2P files for PHEMTs from the same wafer fabrication. The device sizes were 4x15 um and the typical 6x50 um size for the Emode and Dmode PHEMTs. Data was measured at 3V and 4V at typical current bias conditions. The measured data looks very similar to the simulations of both the TOM3 and TOM4 models, so with only one sample it is hard to draw any conclusions. Following are comparisons between simulations and actual measured data. ADS and MWO have both TOM3 and TOM4 models.

3/12/10
PHEMT s2p measurements
E60303 3V 3mA 60 um Emode vg = +0.57V
E60303B 3V 3mA 60 um Emode Die #2
E60404 4V 4mA 60 um Emode vg = +0.57V
D60303 3V 3mA 60 um Dmode vg = -0.54V
D60404 4V 4mA 60 um Dmode vg = -0.5V
E300310 3V 10mA 300 um Emode vg = +0.52V
E300431 4V 31mA 300 um Emode vg = +0.66V
D300315 3V 15mA 300 um Dmode vg = -0.5V
D300442 4V 42mA 300 um Dmode vg = -0.25V

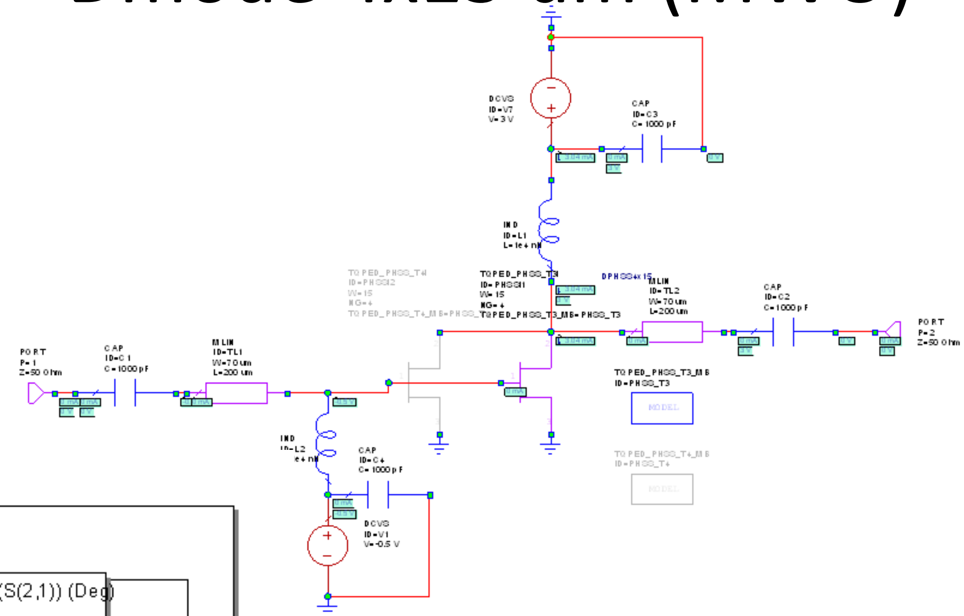


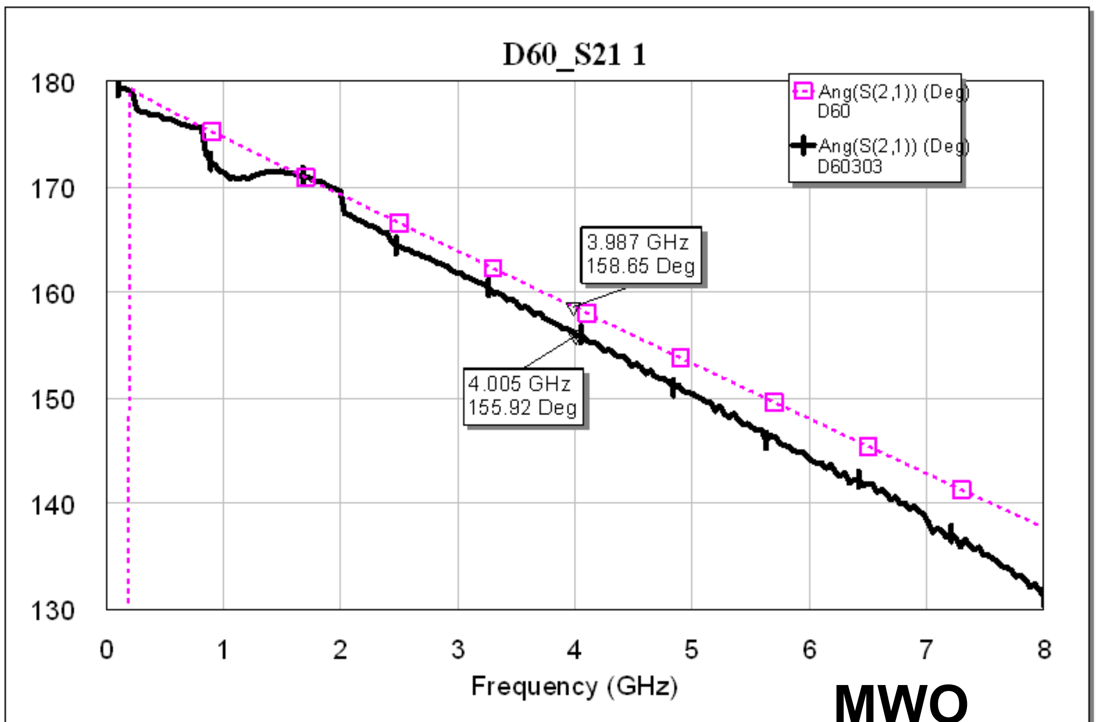
MWO

PHEMT Measurements—Dmode 4x15 um (MWO)

<u>Dmode 4x15 um PHEMT</u>

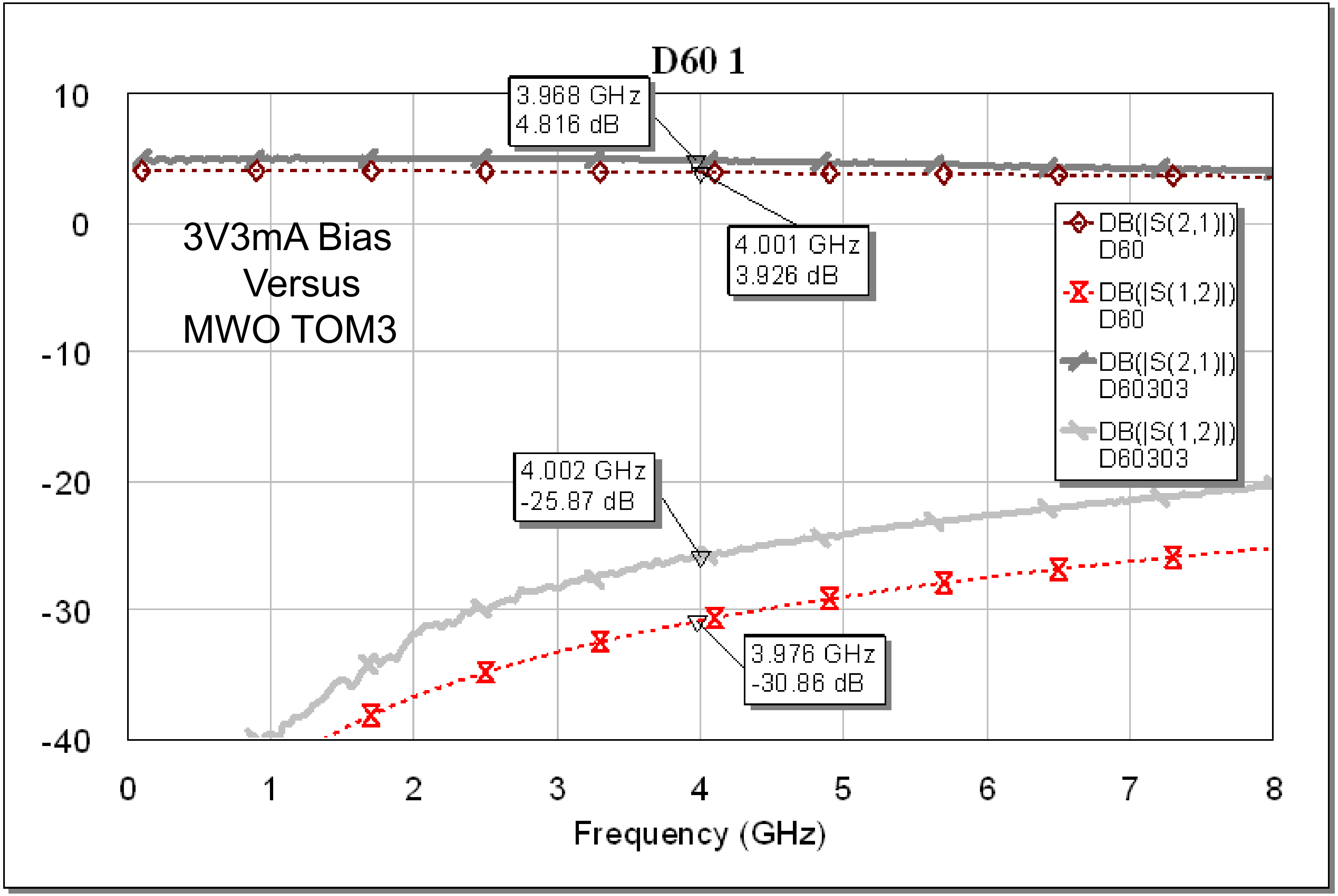
D60303 3V 3mA 60 um vg = -0.54V
Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model). Compare to non-linear model using ADS and MWO.





3V3mA Bias
Versus
MWO TOM3

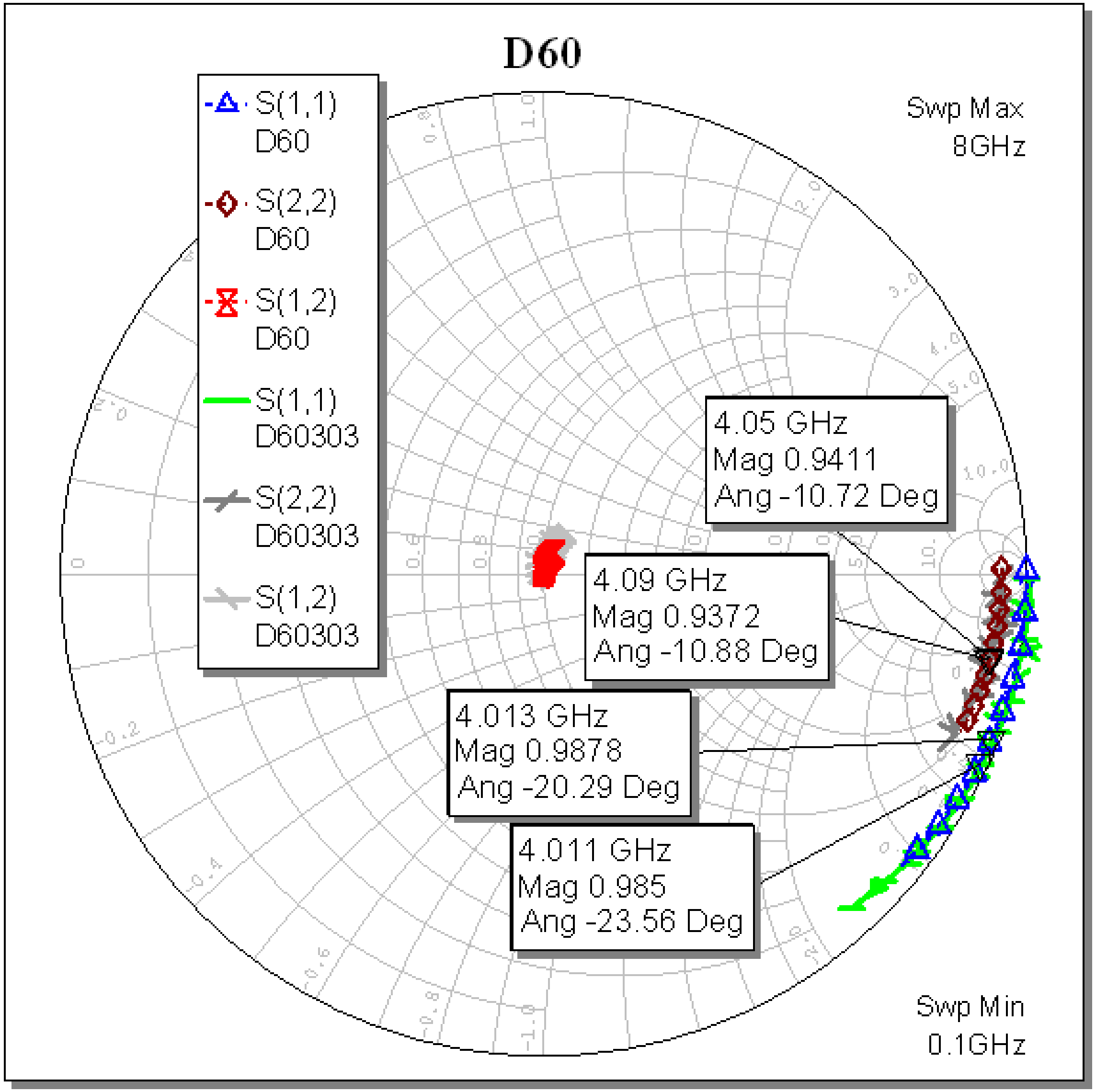
PHEMT Measurements—Dmode 4x15 um (MWO)



MWO

PHEMT Measurements—Dmode 4x15 um (MWO)

3V3mA Bias
Versus
MWO TOM3



MWO

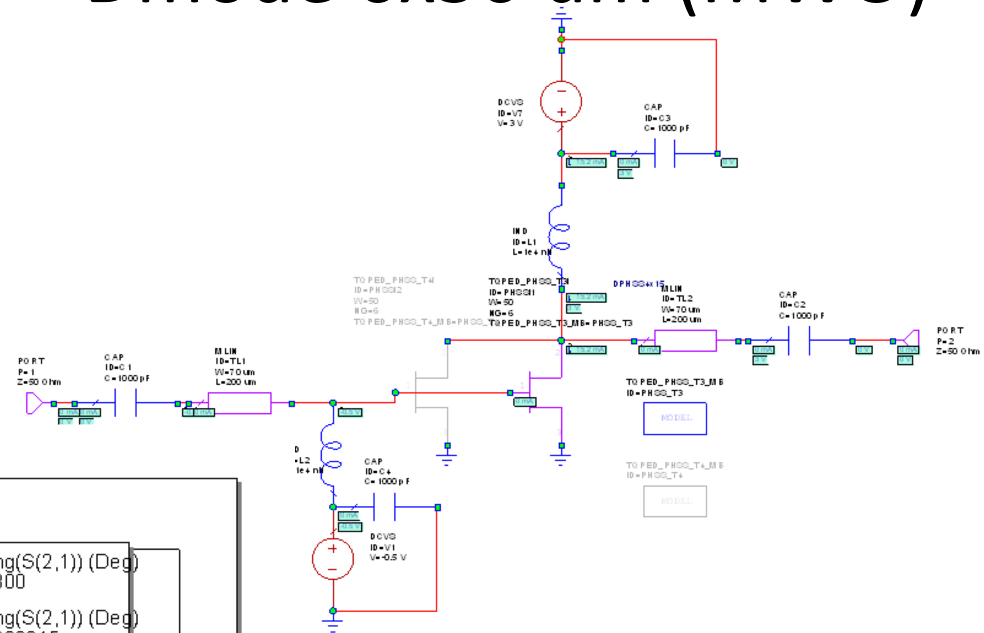
PHEMT Measurements—Dmode 6x50 um (MWO)

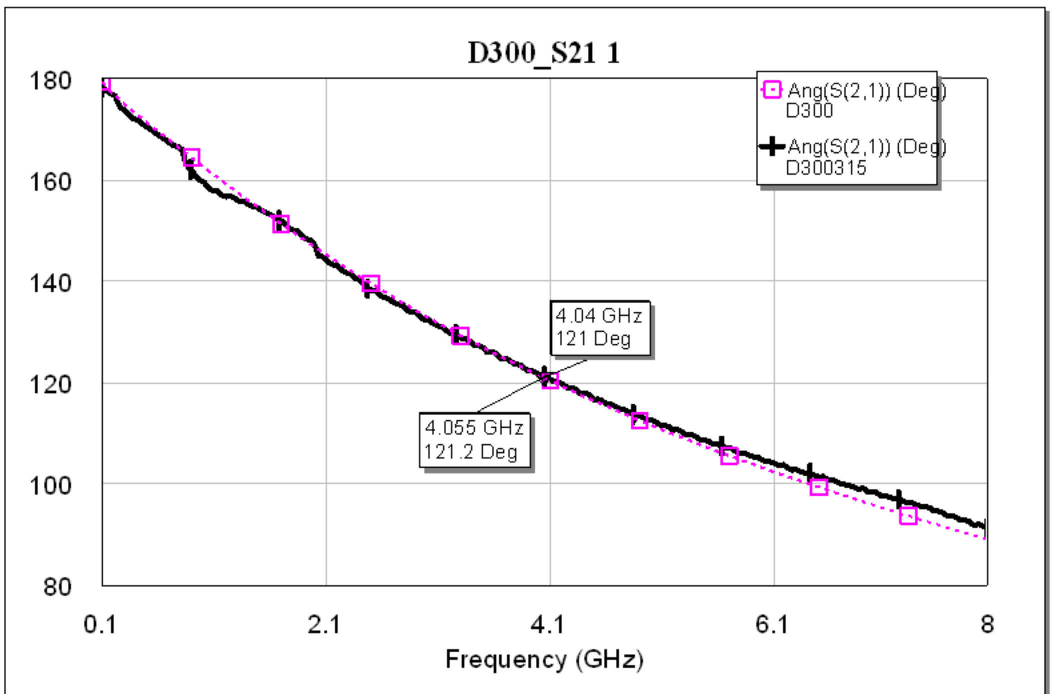
Dmode 6x50 um PHEMT

D300315 3V 15mA 300 um vg = -0.5V

Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model).

Compare to non-linear model using ADS and MWO.

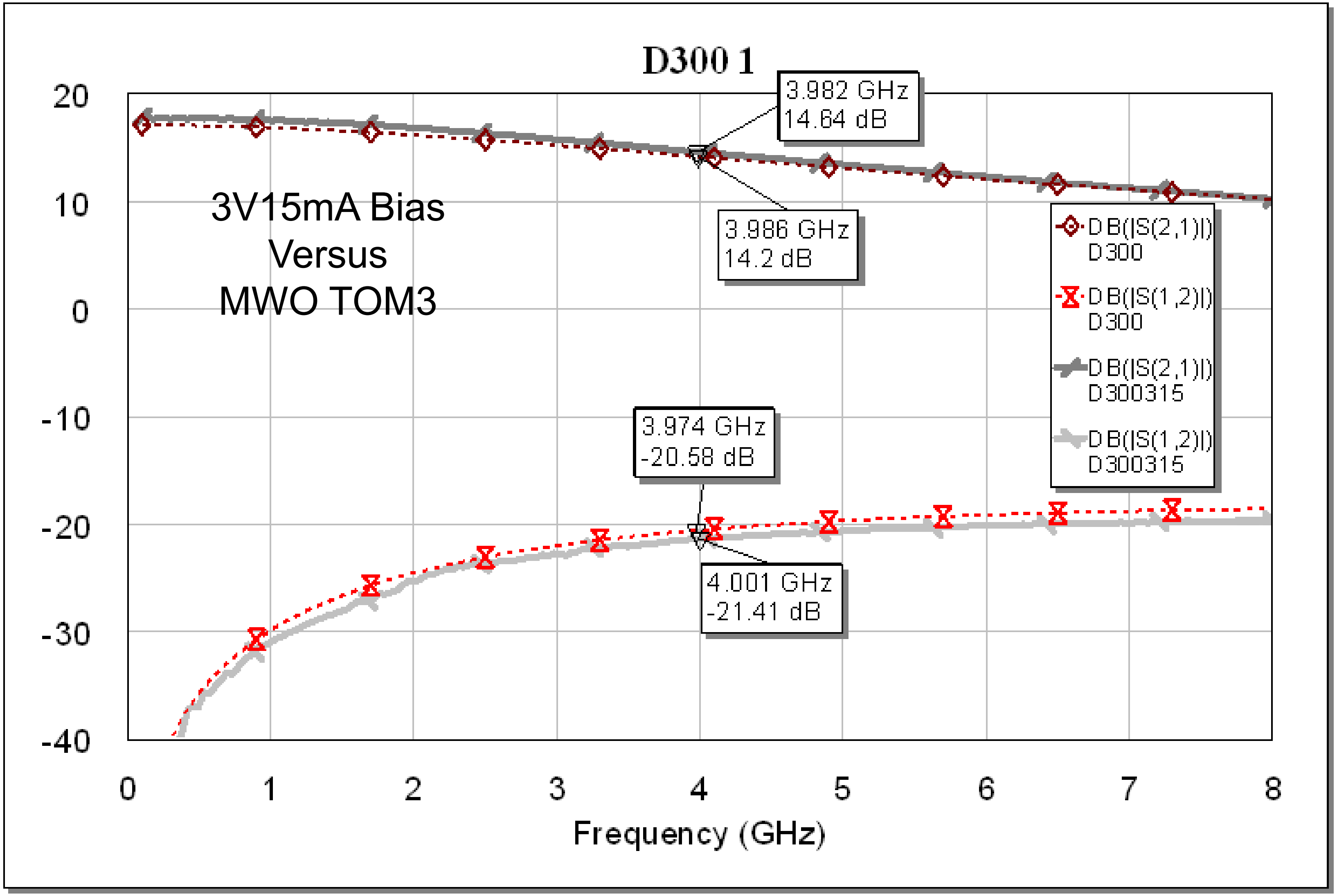




3V15mA Bias
Versus
MWO TOM3

MWO

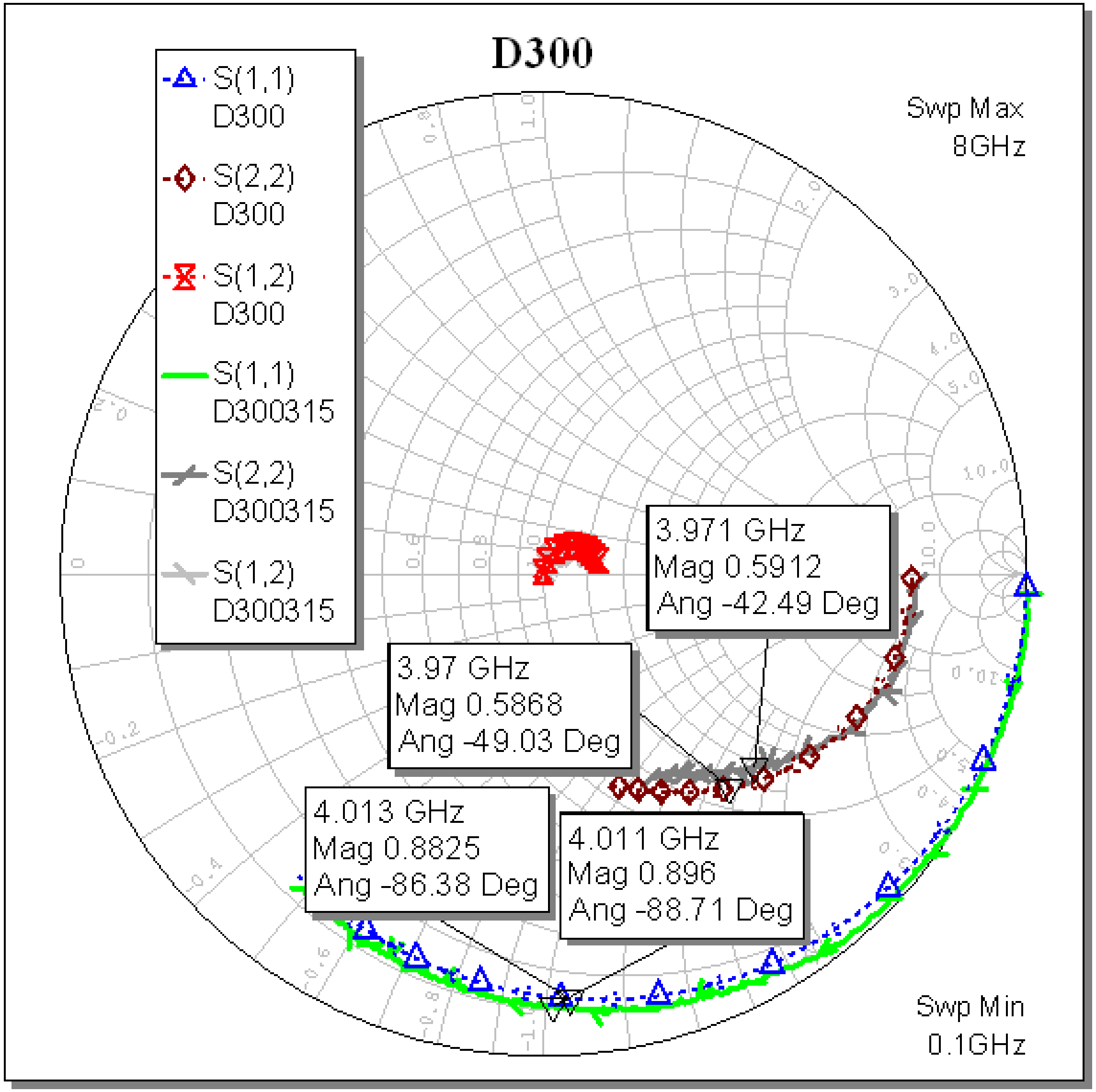
PHEMT Measurements—Dmode 6x50 um (MWO)



MWO

PHEMT Measurements—Dmode 6x50 um (MWO)

3V15mA Bias
Versus
MWO TOM3

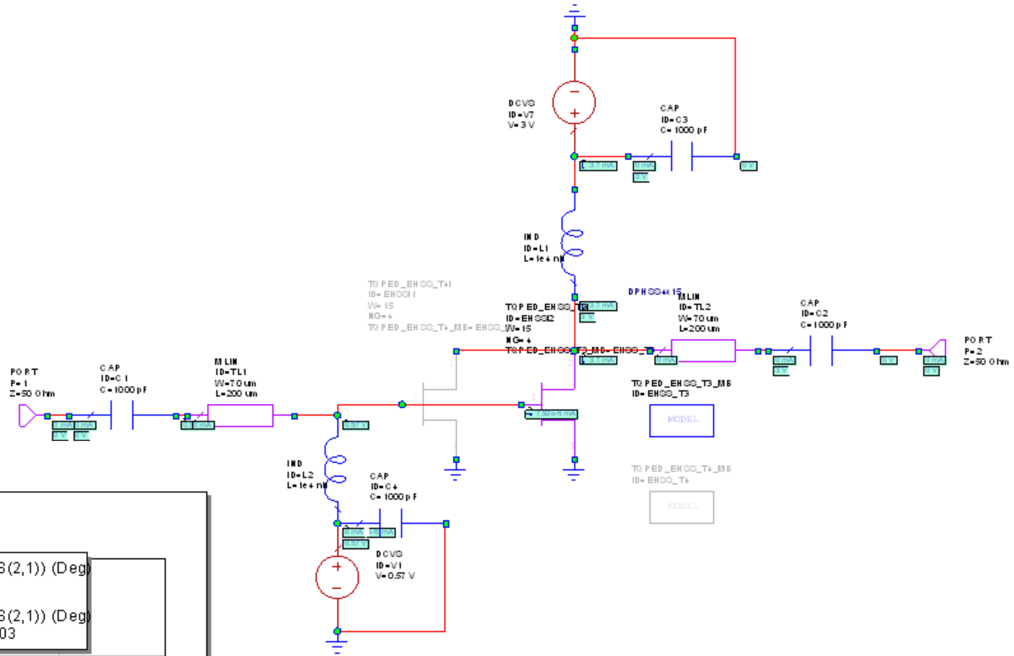


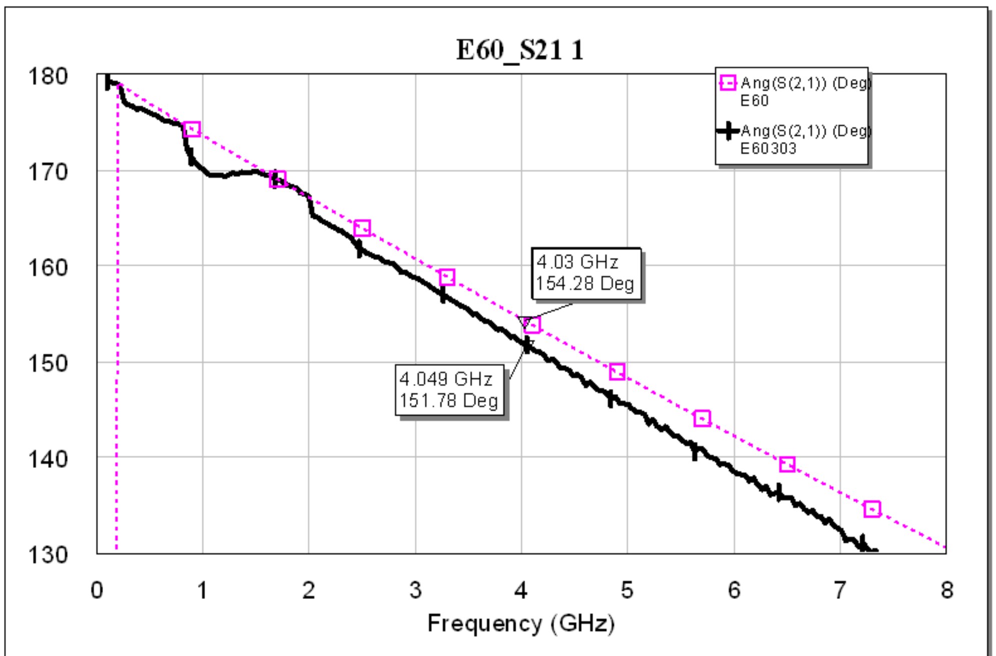
MWO

PHEMT Measurements—Emode 4x15 um (MWO)

Emode 4x15 um PHEMT

E60303 3V 3mA 60 um vg = +0.57V
Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model). Compare to non-linear model using ADS and MWO.

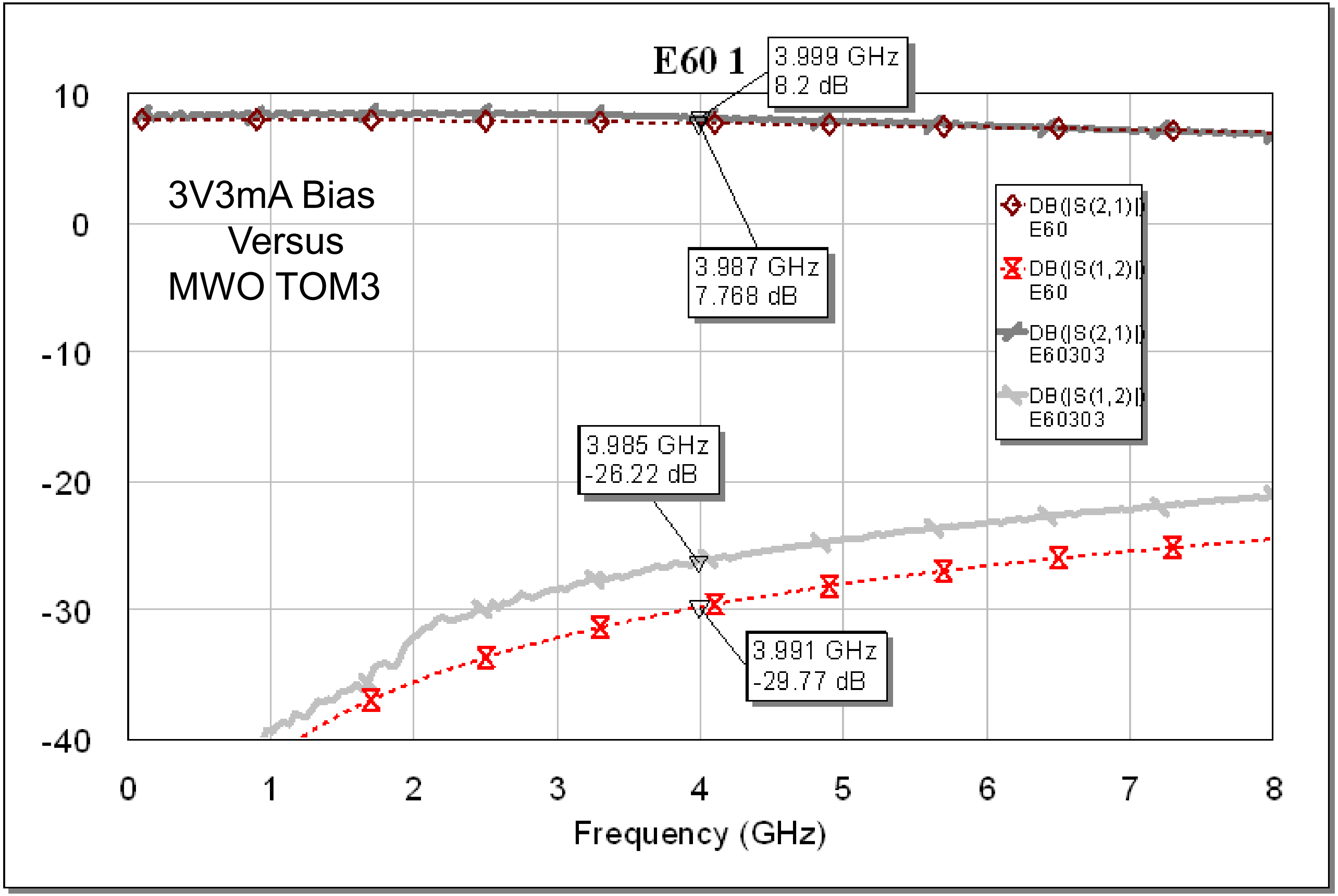




MWO

3V3mA Bias
Versus
MWO TOM3

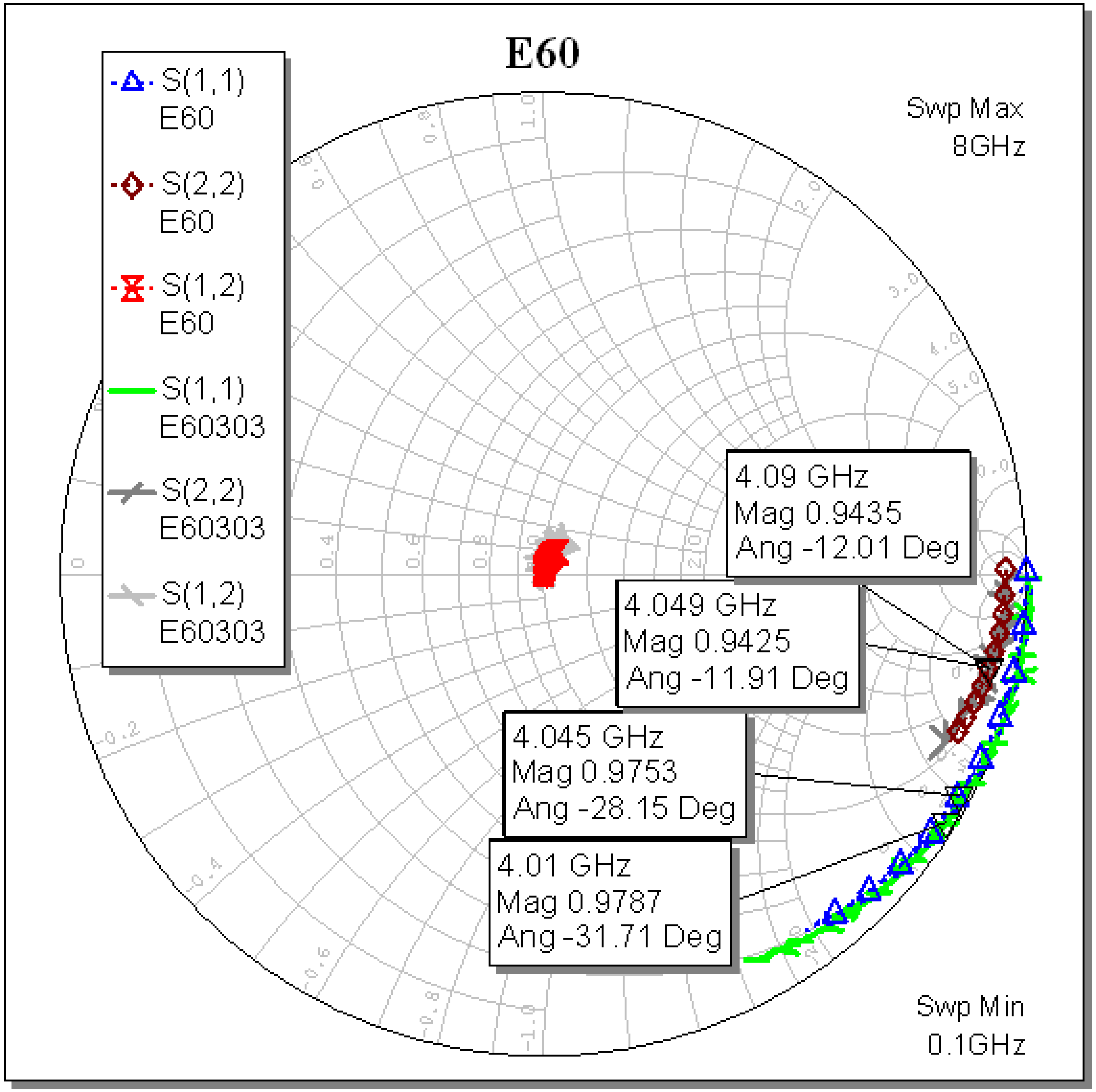
PHEMT Measurements—Emode 4x15 um (MWO)



MWO

PHEMT Measurements—Emode 4x15 um (MWO)

3V3mA Bias
Versus
MWO TOM3

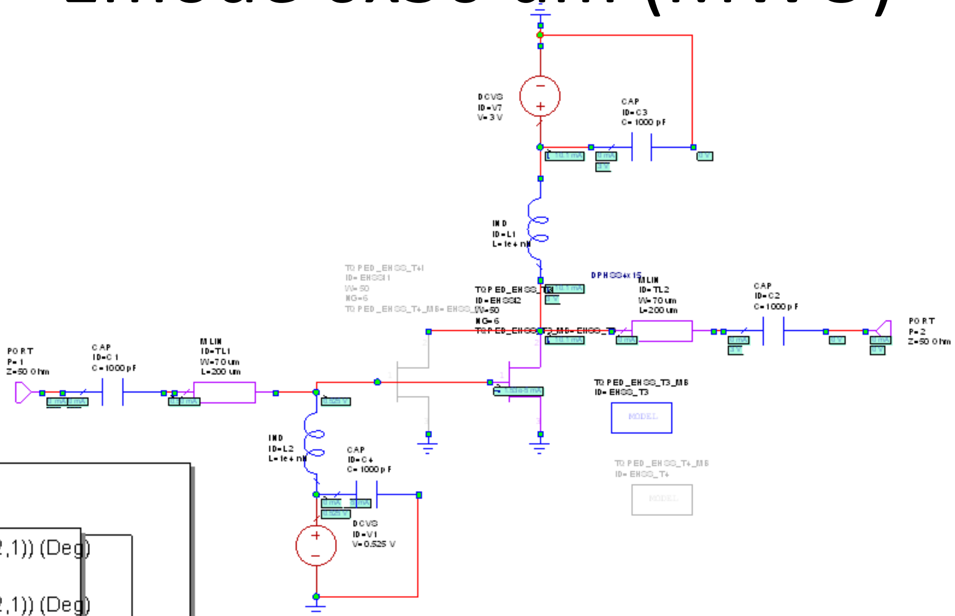


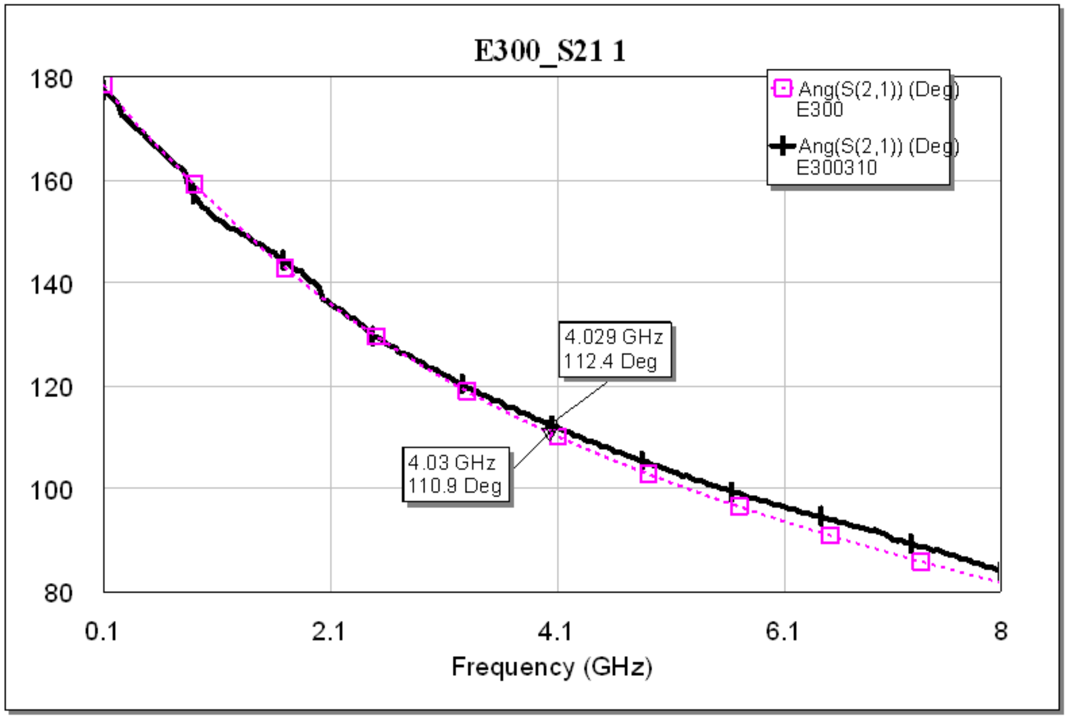
MWO

PHEMT Measurements—Emode 6x50 um (MWO)

<u>Emode 6x50 um PHEMT</u>

E300310 3V 10mA 300 um vg = +0.52V
Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model).
Compare to non-linear model using ADS and MWO.

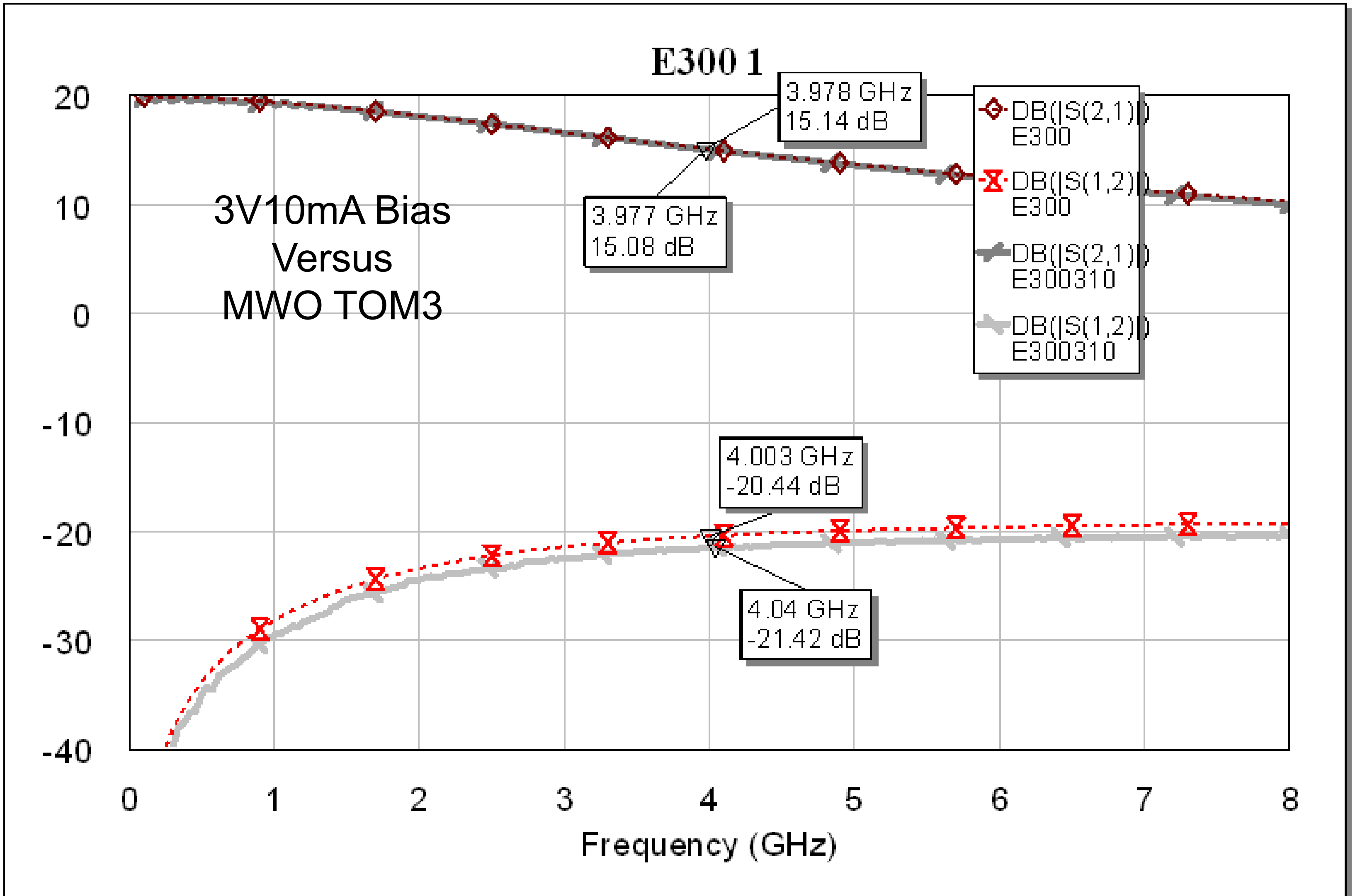




MWO

3V10mA Bias
Versus
MWO TOM3

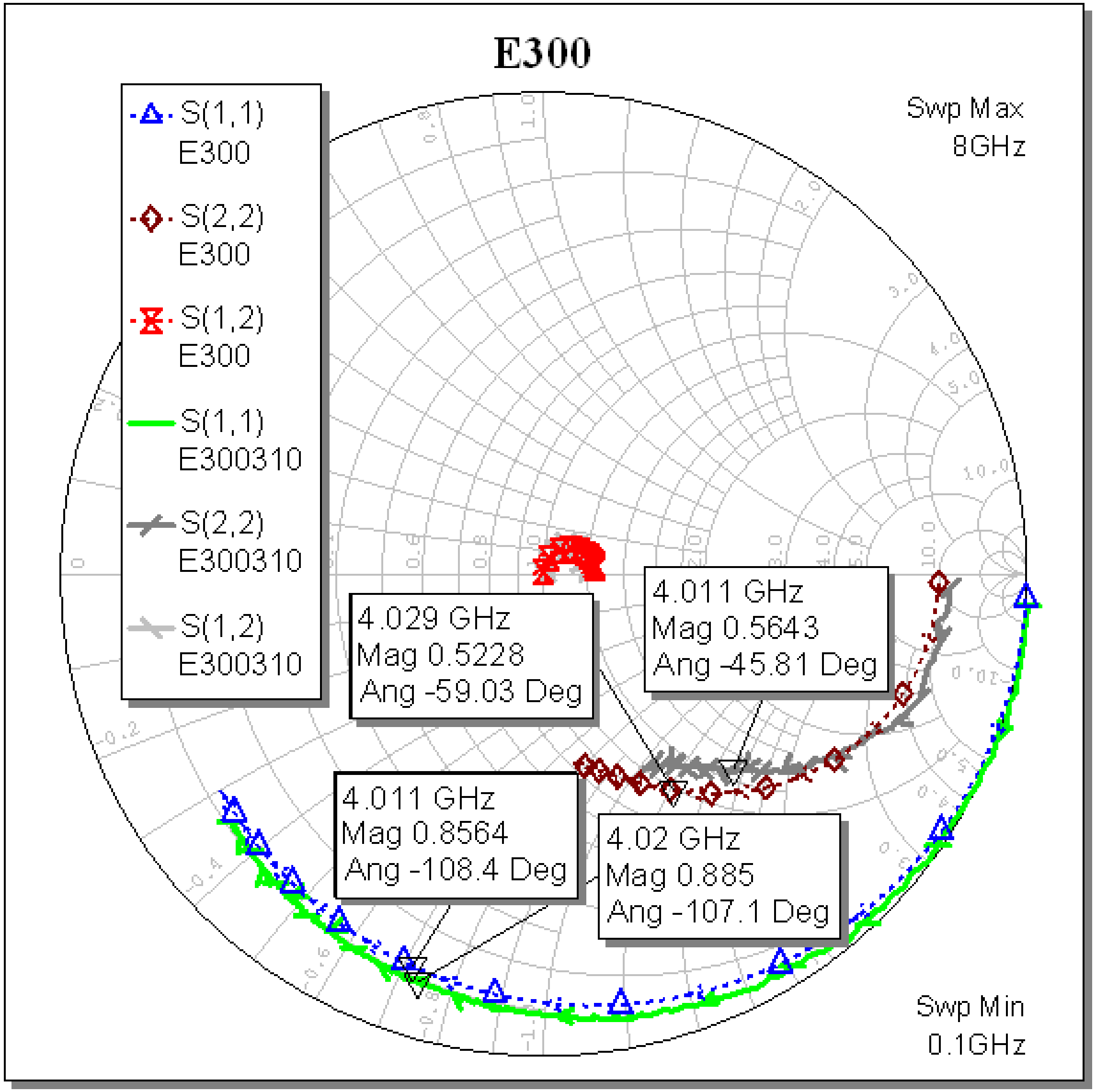
PHEMT Measurements—Emode 6x50 um (MWO)



MWO

PHEMT Measurements—Emode 6x50 um (MWO)

3V10mA Bias
Versus
MWO TOM3



MWO

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3/12/10
PHEMT s2p measurements
E60303 3V 3mA 60 um Emode vg = +0.57V
E60303B 3V 3mA 60 um Emode Die #2
E60404 4V 4mA 60 um Emode vg = +0.57V
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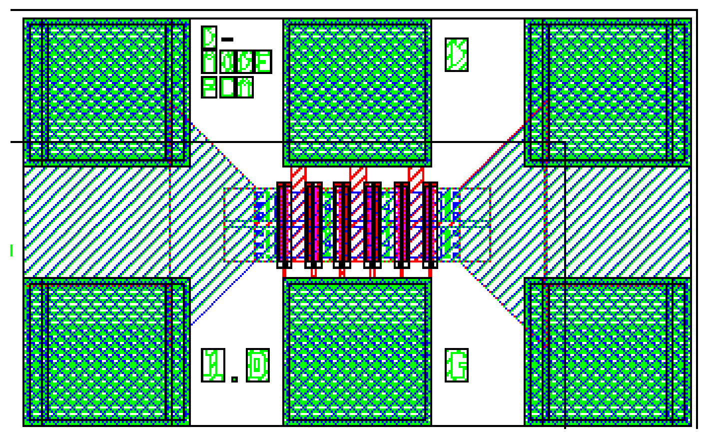
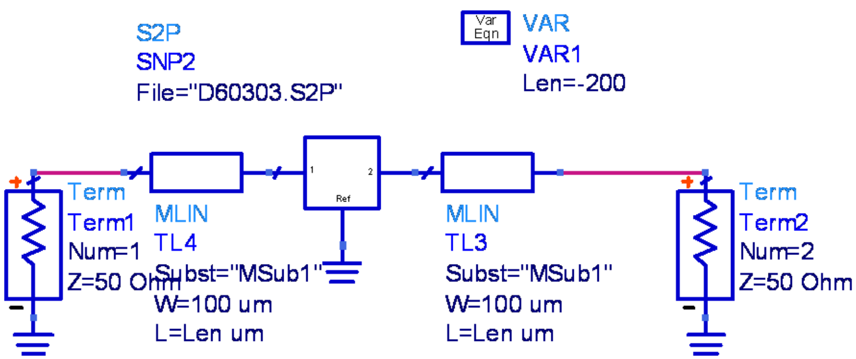
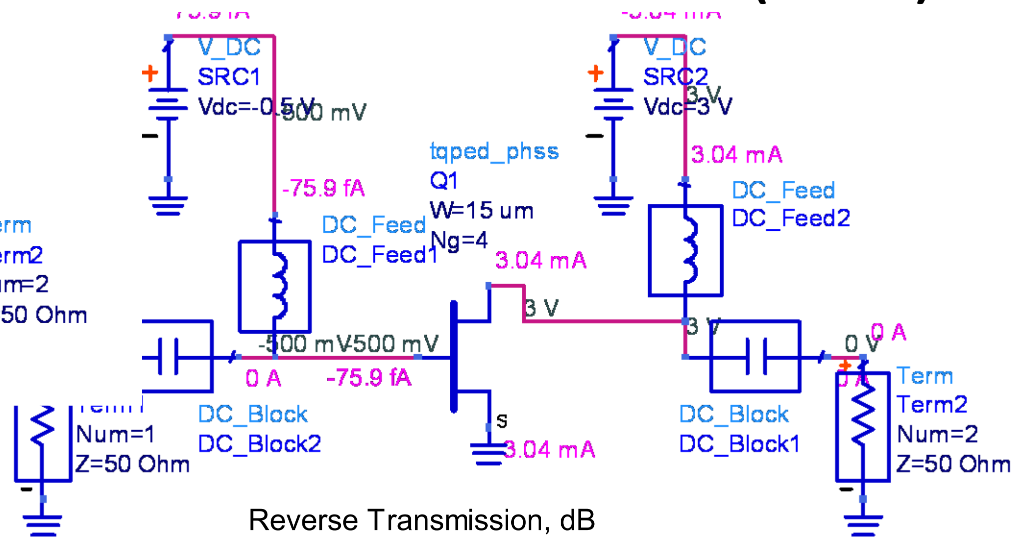
E300310 3V 10mA 300 um Emode vg = +0.52V
E300431 4V 31mA 300 um Emode vg = +0.66V
D300315 3V 15mA 300 um Dmode vg = -0.5V
D300442 4V 42mA 300 um Dmode vg = -0.25V



ADS

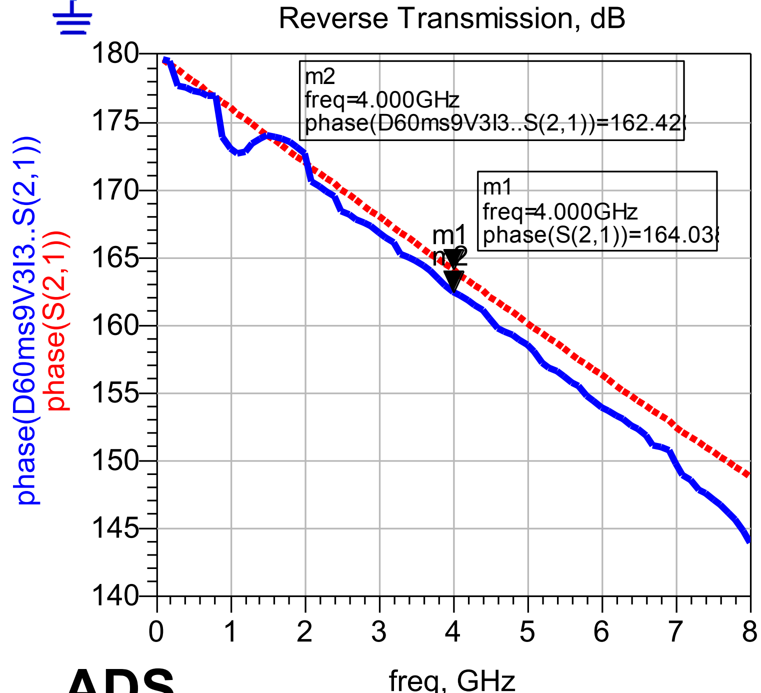
PHEMT Measurements—Dmode 4x15 um (ADS)





Dmode 4x15 um PHEMT

D60303 3V 3mA 60 um vg = -0.54V
Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model). Compare to non-linear model using ADS and MWO.

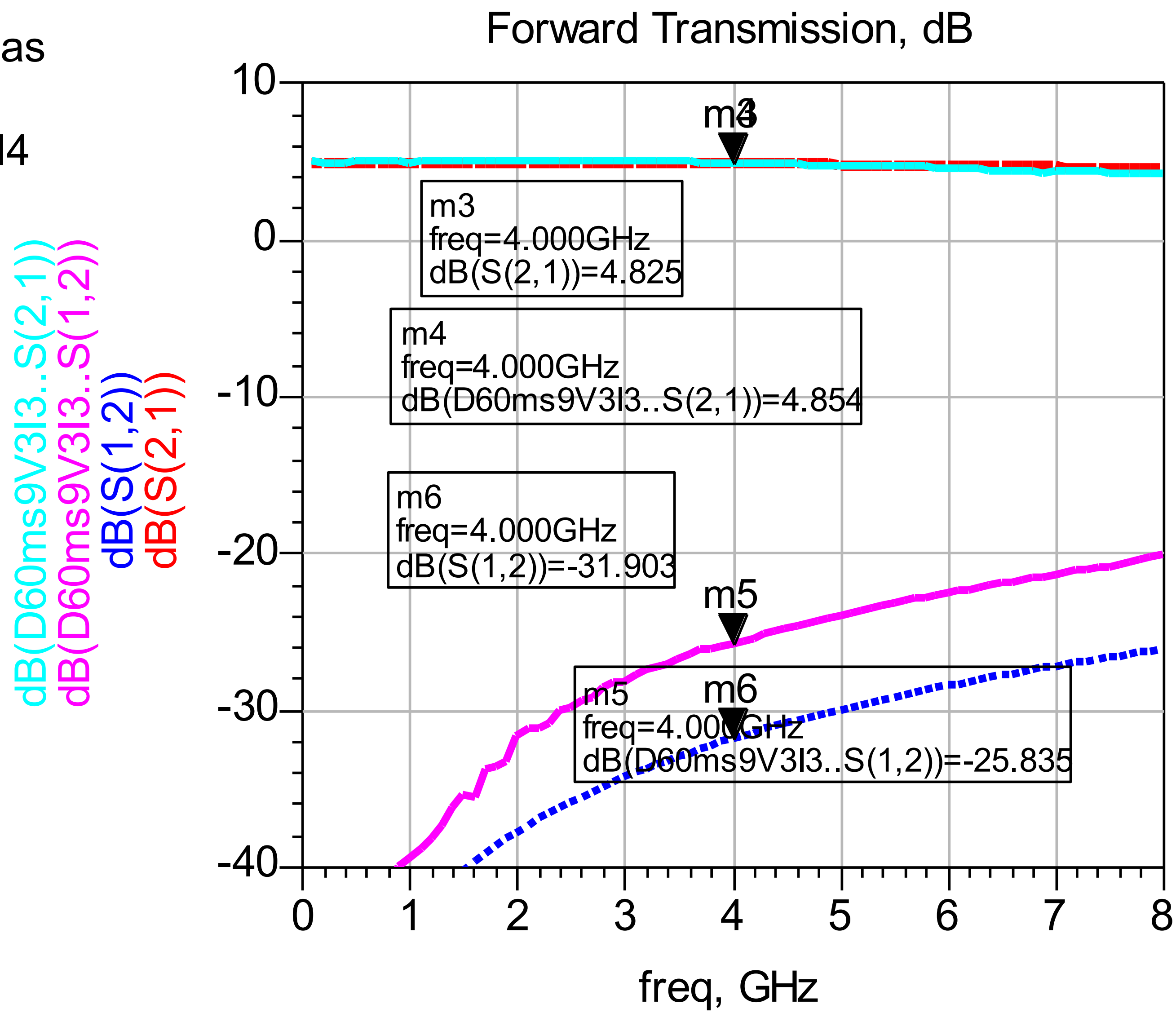


ADS

3V3mA Bias
Versus
ADS TOM3

PHEMT Measurements—Dmode 4x15 um (ADS)

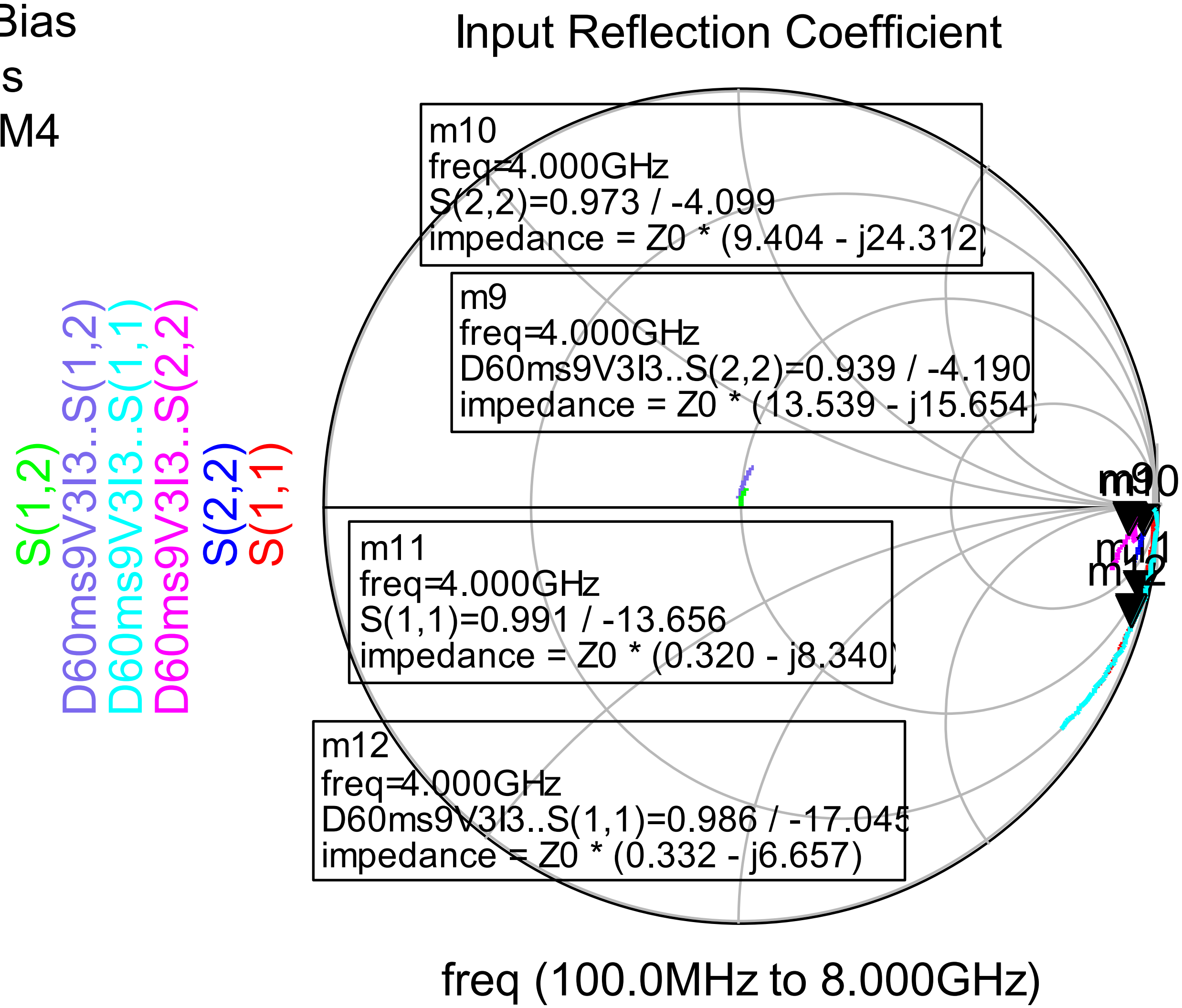
3V3mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Dmode 4x15 um (ADS)

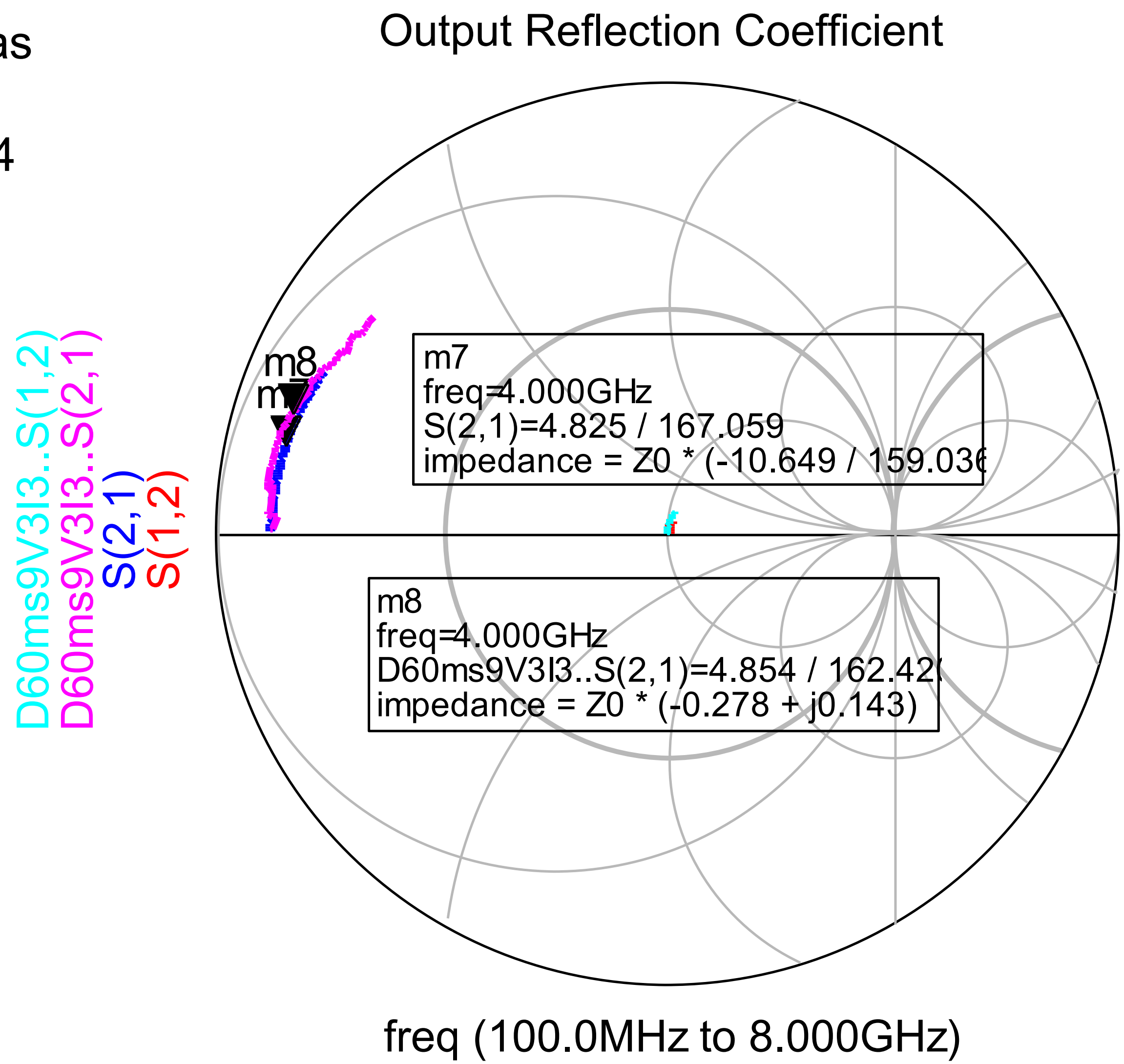
3V3mA Bias
Versus
ADS TOM4



ADS

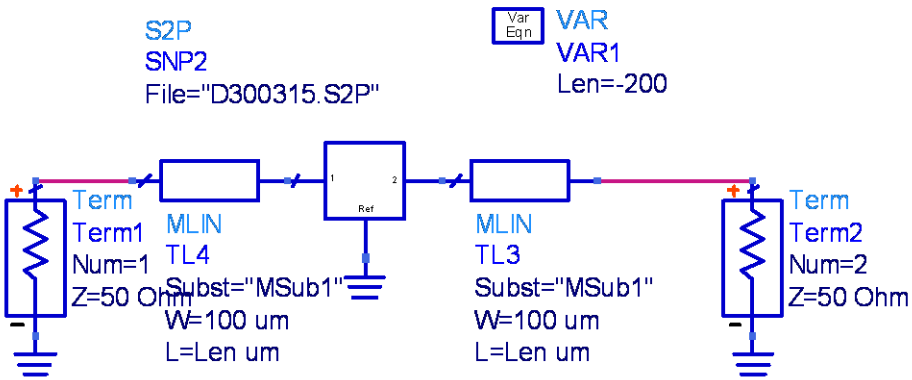
PHEMT Measurements—Dmode 4x15 um (ADS)

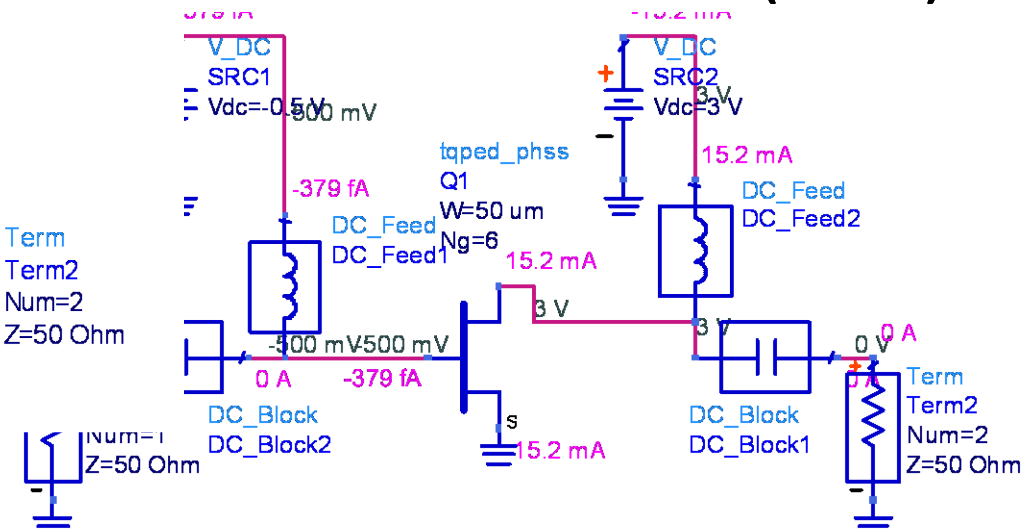
3V3mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Dmode 6x50 um (ADS)



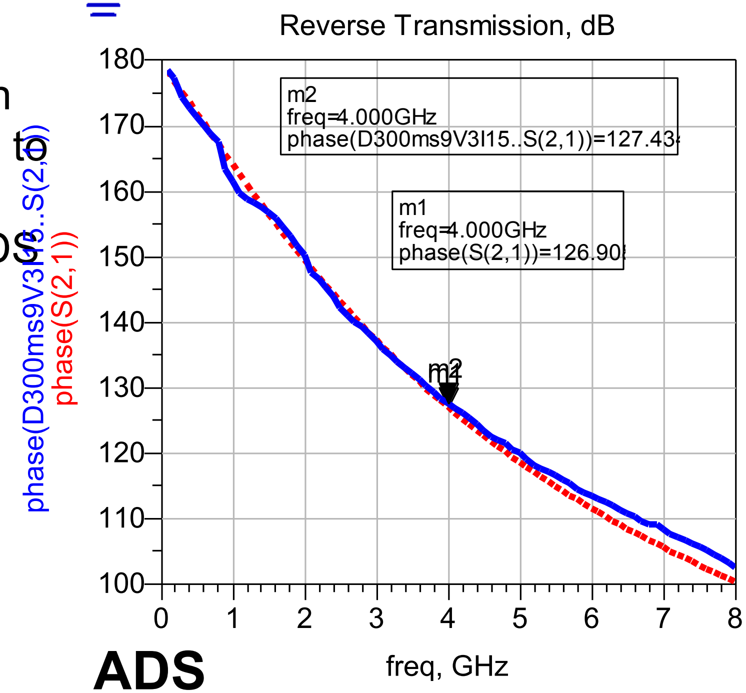


Dmode 6x50 um PHEMT

D300315 3V 15mA 300 um vg = -0.5V

Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model).

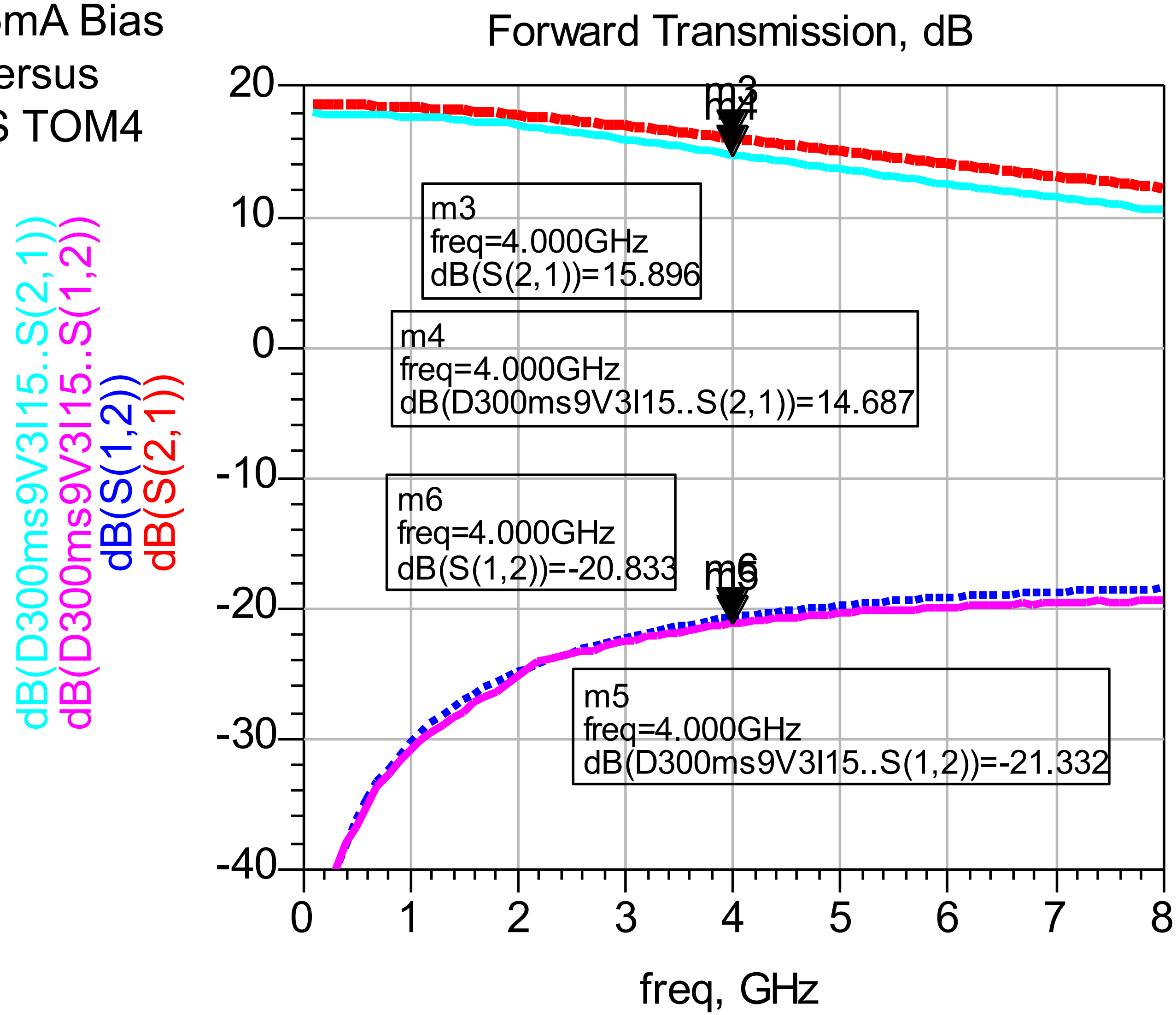
Compare to non-linear model using ADS and MWO.



3V15mA Bias
Versus
ADS TOM3

PHEMT Measurements—Dmode 6x50 um (ADS)

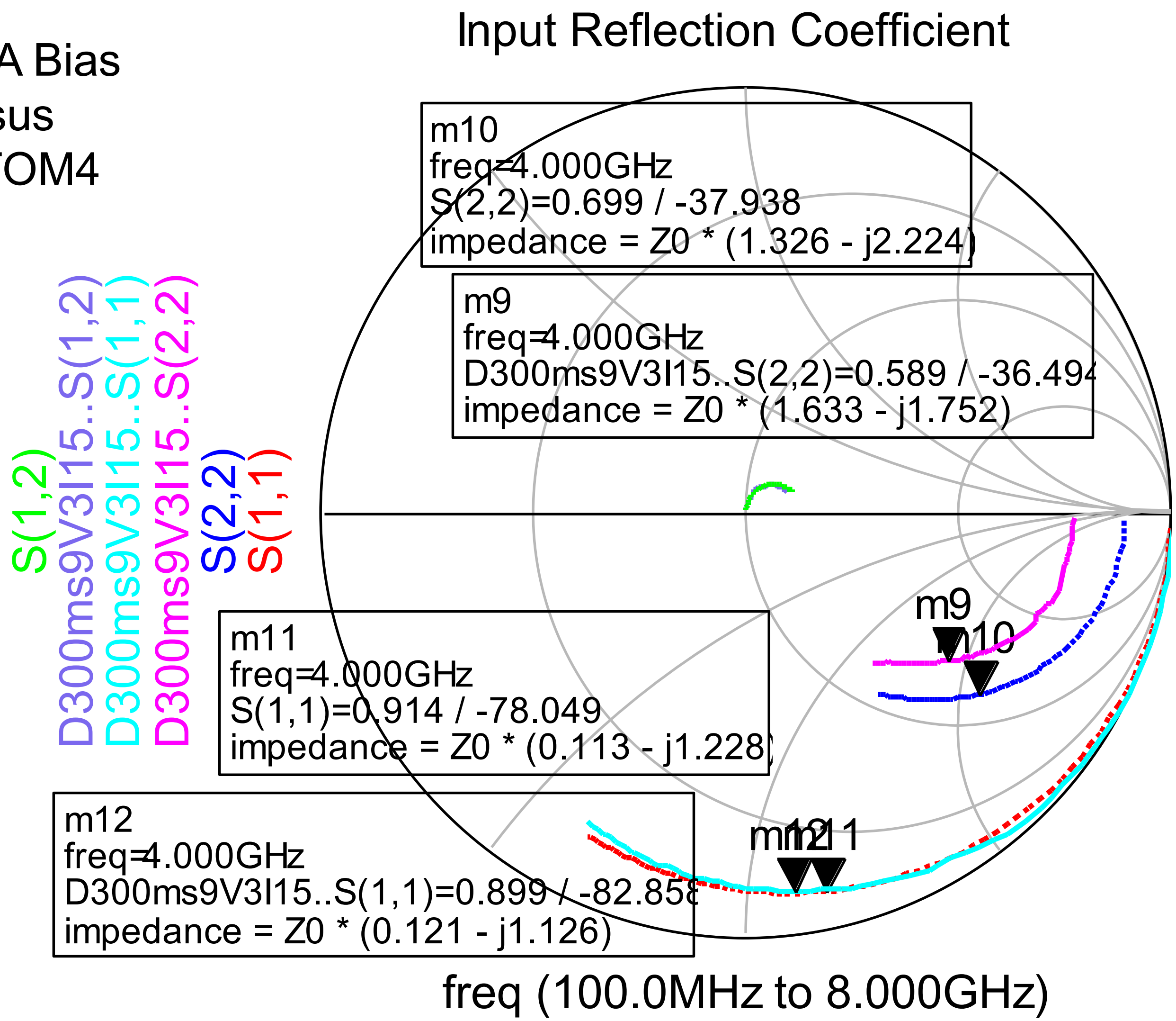
3V15mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Dmode 6x50 um (ADS)

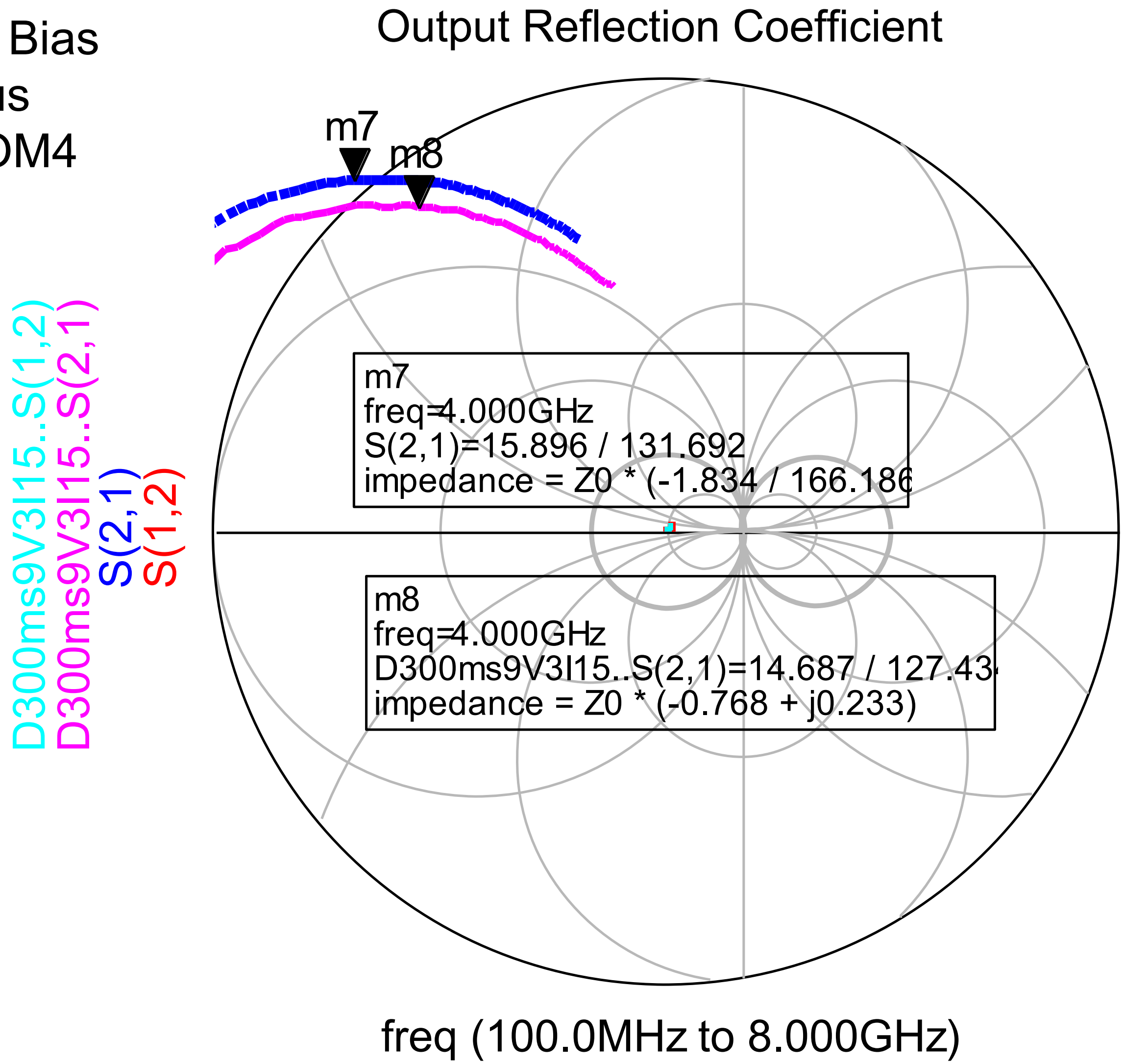
3V15mA Bias
Versus
ADS TOM4



ADS

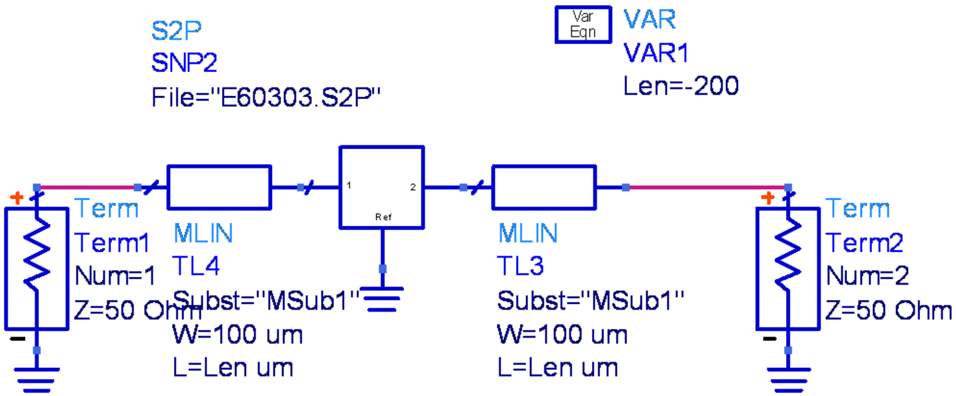
PHEMT Measurements—Dmode 6x50 um (ADS)

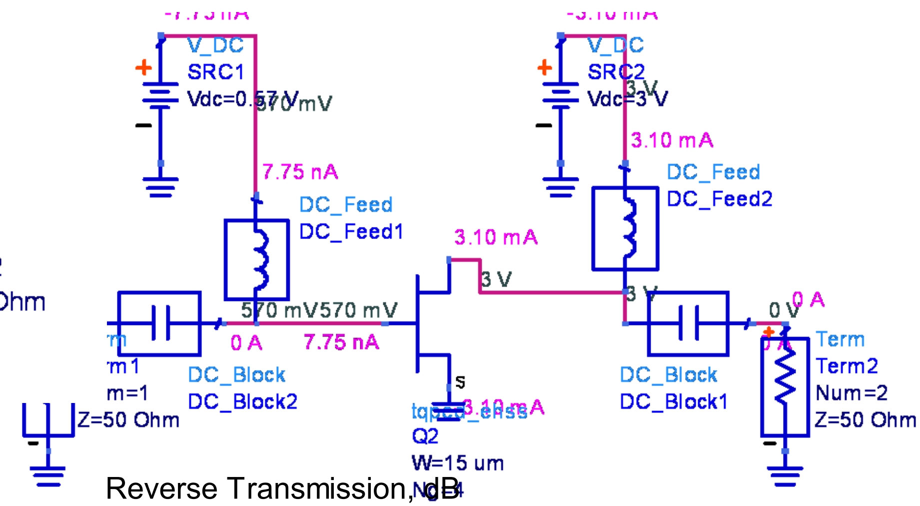
3V15mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Emode 4x15 um (ADS)

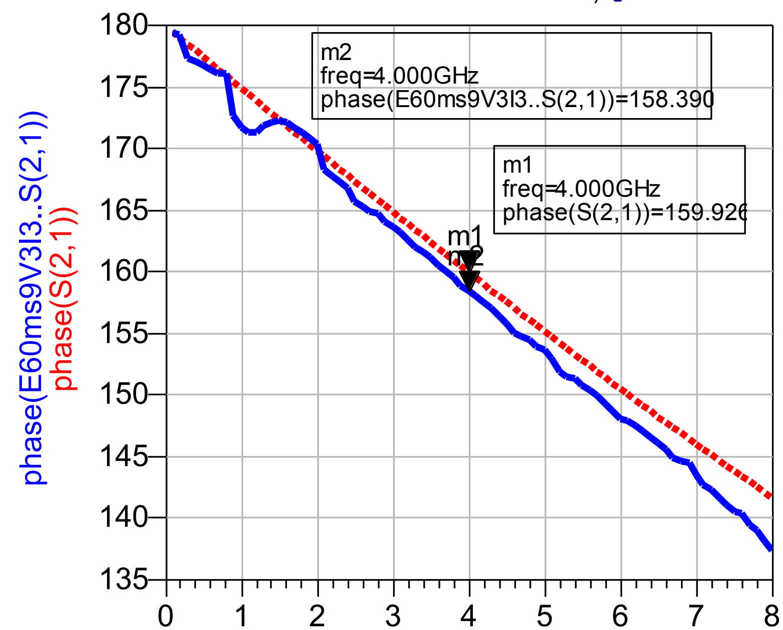




Emode 4x15 um PHEMT

E60303 3V 3mA 60 um vg = +0.57V

Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model). Compare to non-linear model using ADS and MWO.

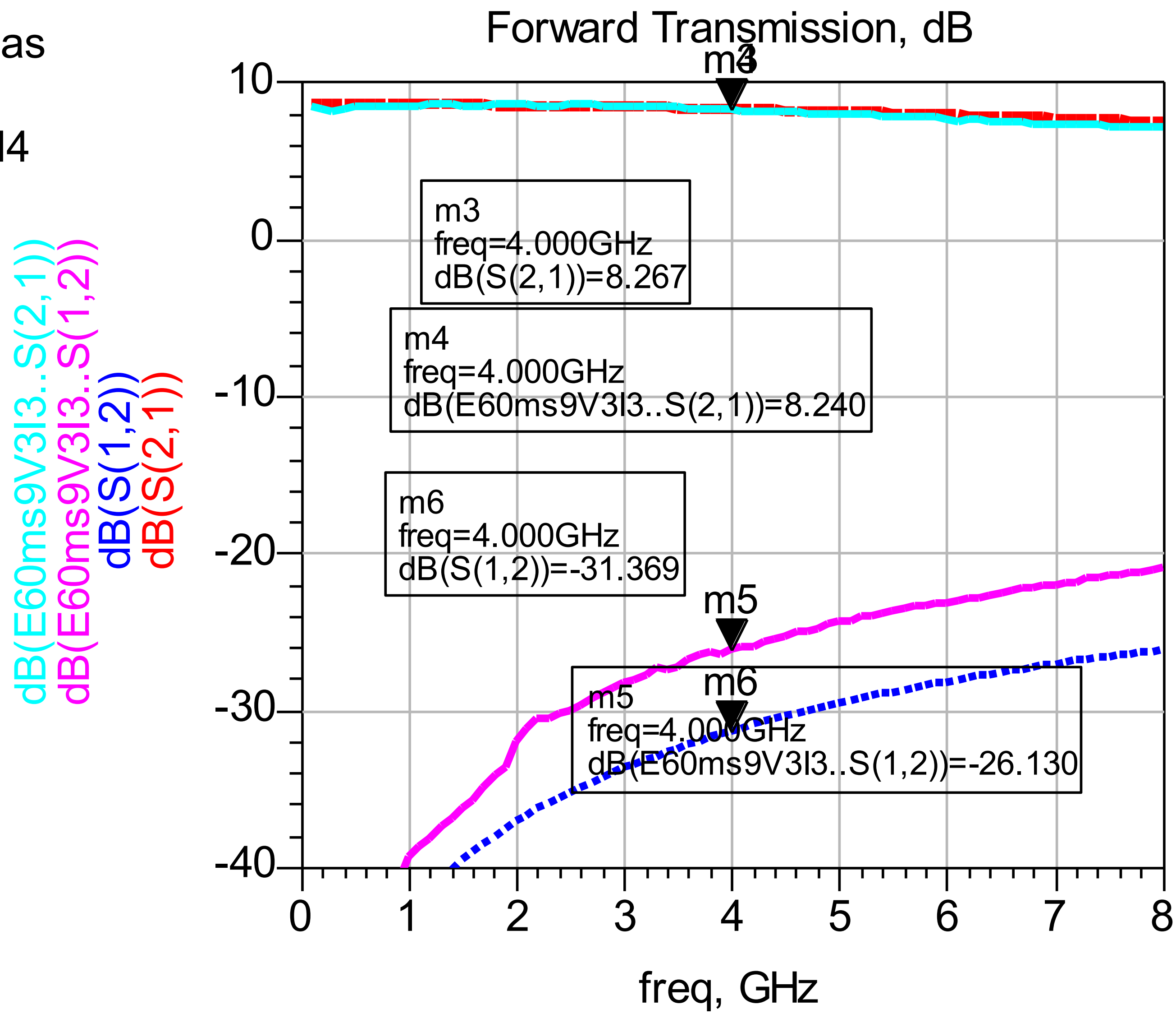


ADS

3V3mA Bias
Versus
ADS TOM3

PHEMT Measurements—Emode 4x15 um (ADS)

3V3mA Bias
Versus
ADS TOM4

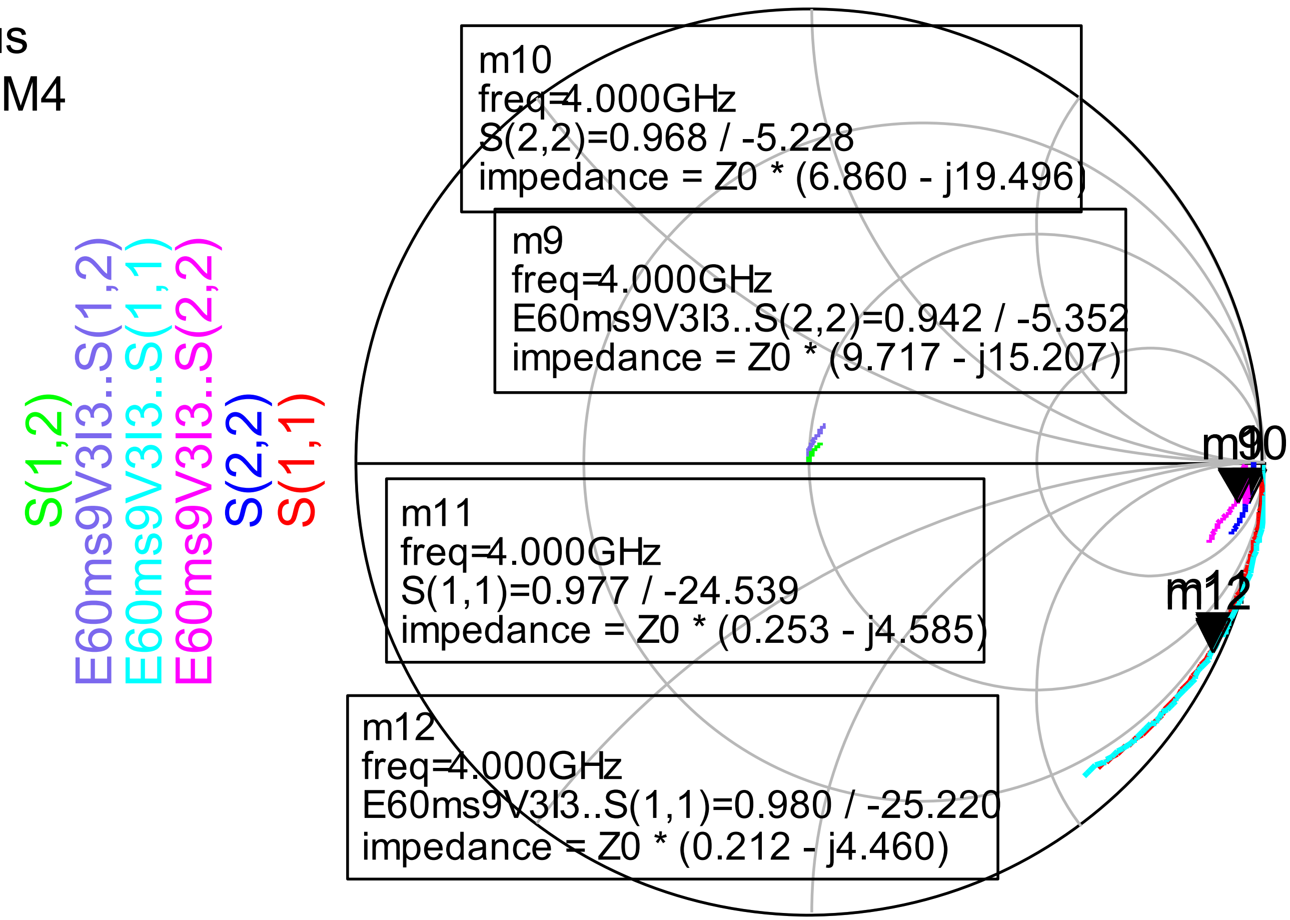


ADS

PHEMT Measurements—Emode 4x15 um (ADS)

3V3mA Bias
Versus
ADS TOM4

Input Reflection Coefficient

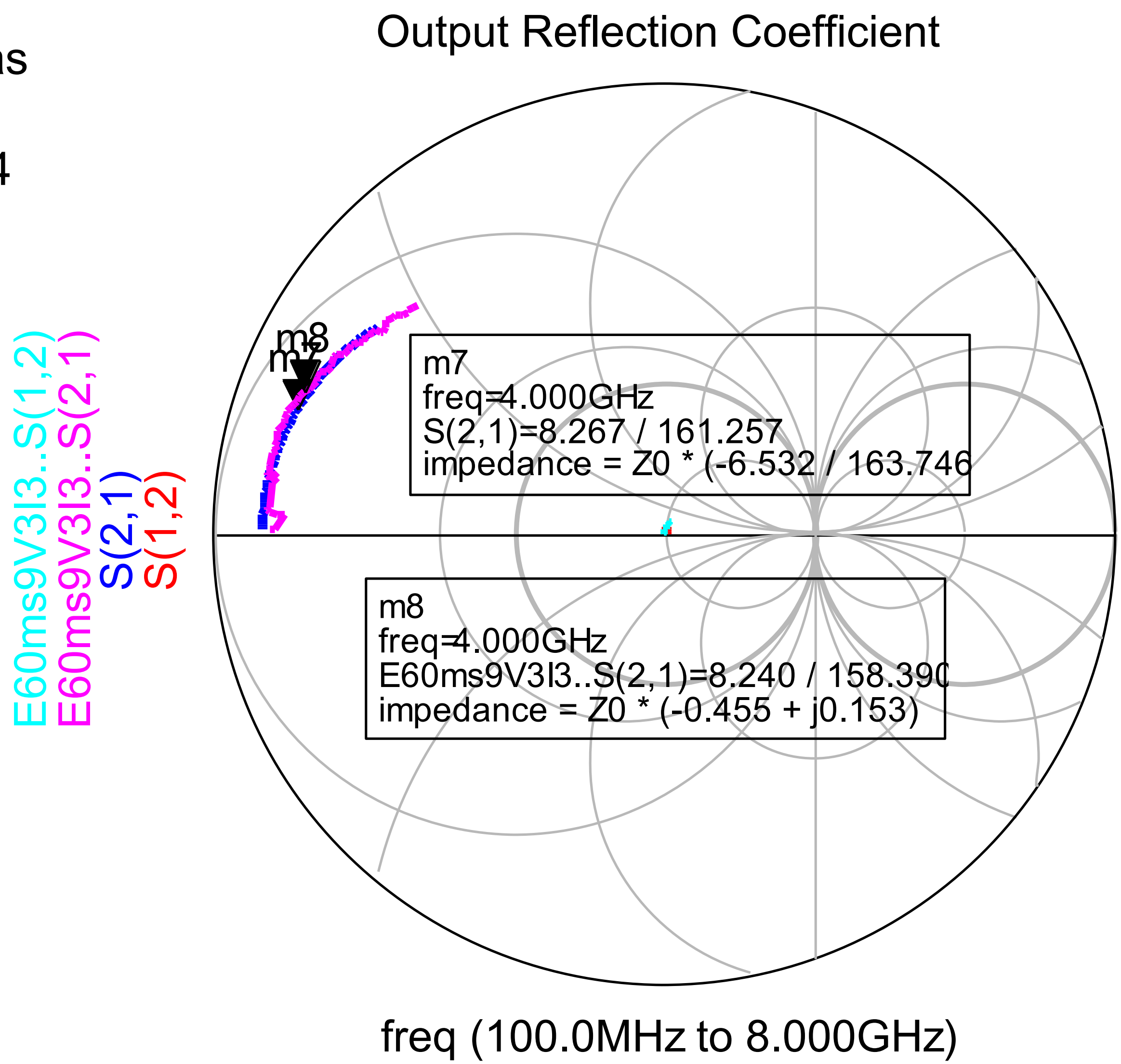


freq (100.0MHz to 8.000GHz)

ADS

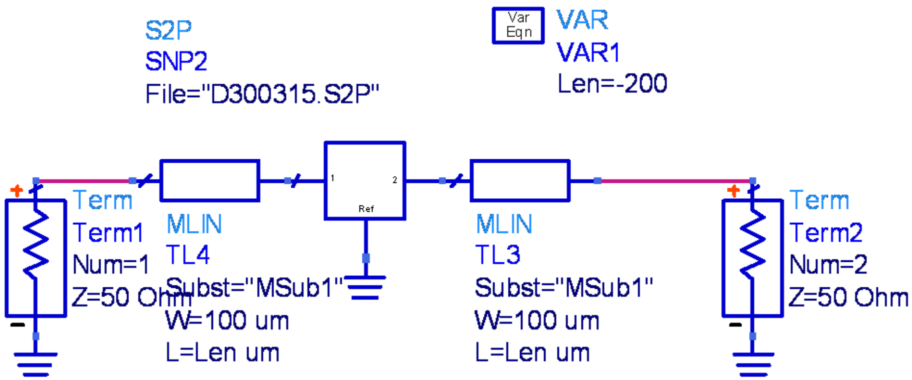
PHEMT Measurements—Emode 4x15 um (ADS)

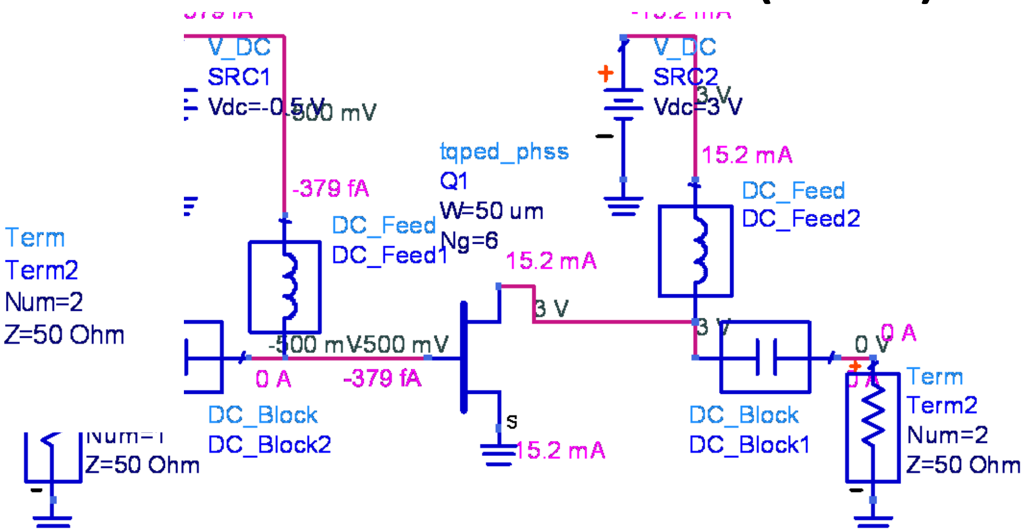
3V3mA Bias
Versus
ADS TOM4



ADS

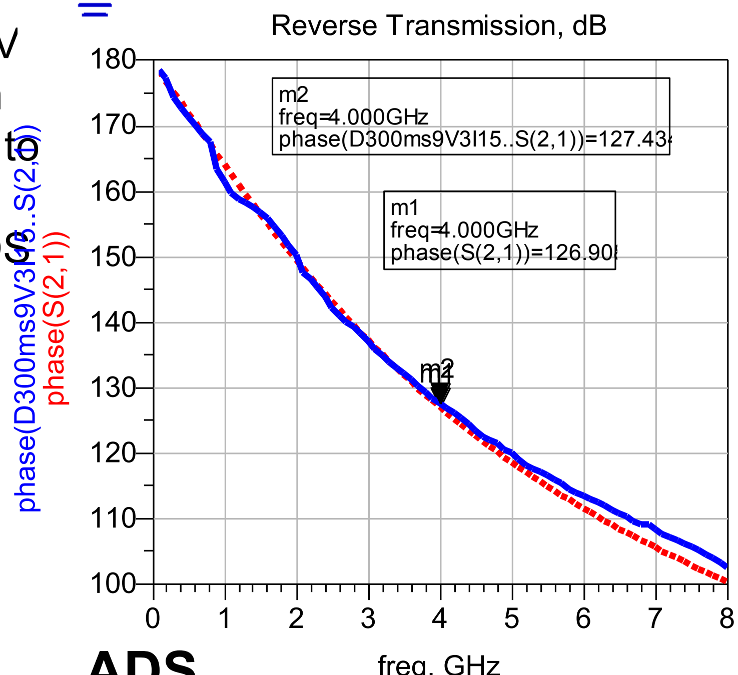
PHEMT Measurements—Emode 6x50 um (ADS)





Emode 6x50 um PHEMT

E300310 3V 10mA 300 um vg = +0.52V
Used a negative length of transmission line to de-embed GSG probe structure to reference plane of PHEMT (model).
Compare to non-linear model using ADS and MWO.

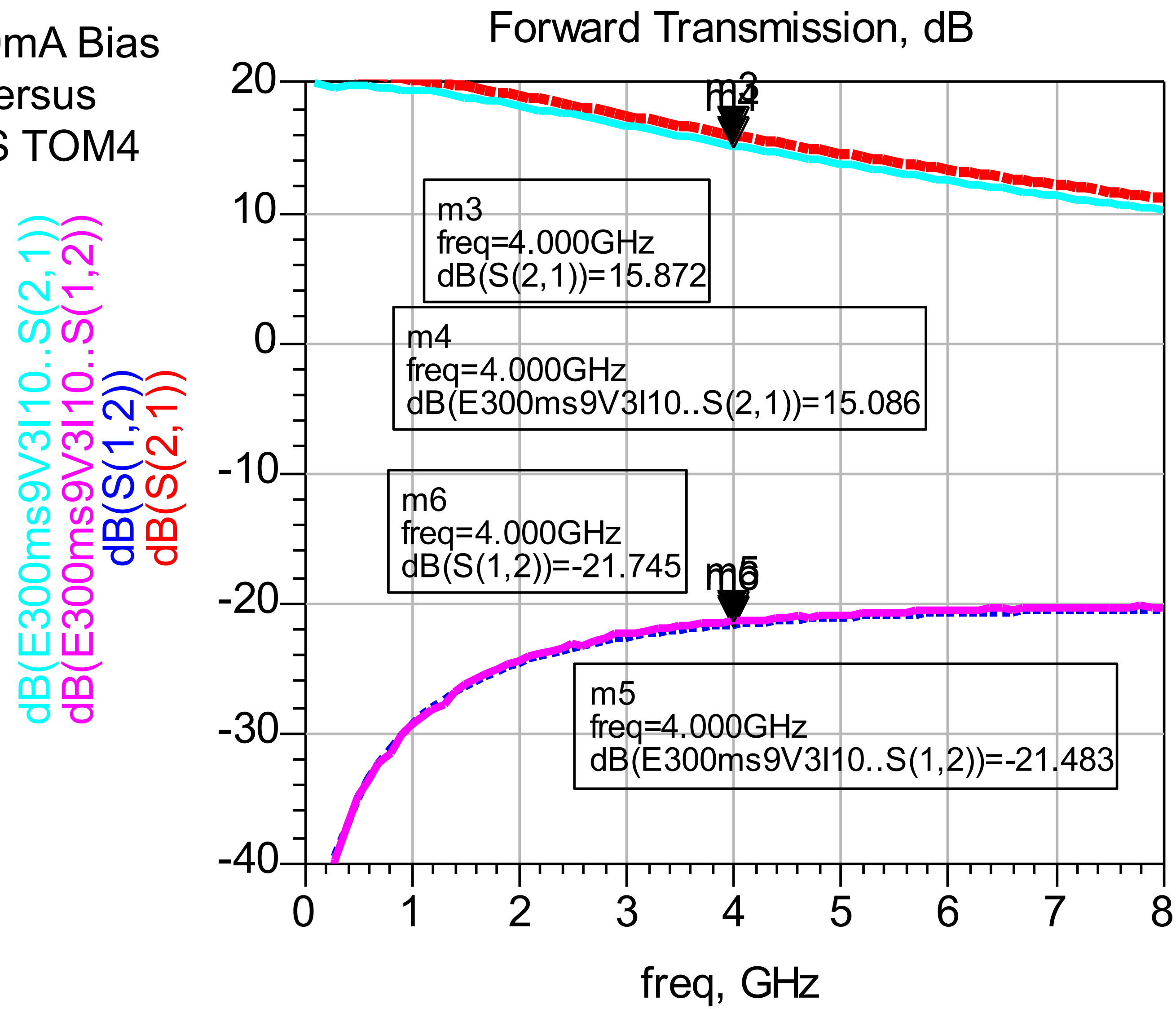


ADS

3V10mA Bias
Versus
ADS TOM3

PHEMT Measurements—Emode 6x50 um (ADS)

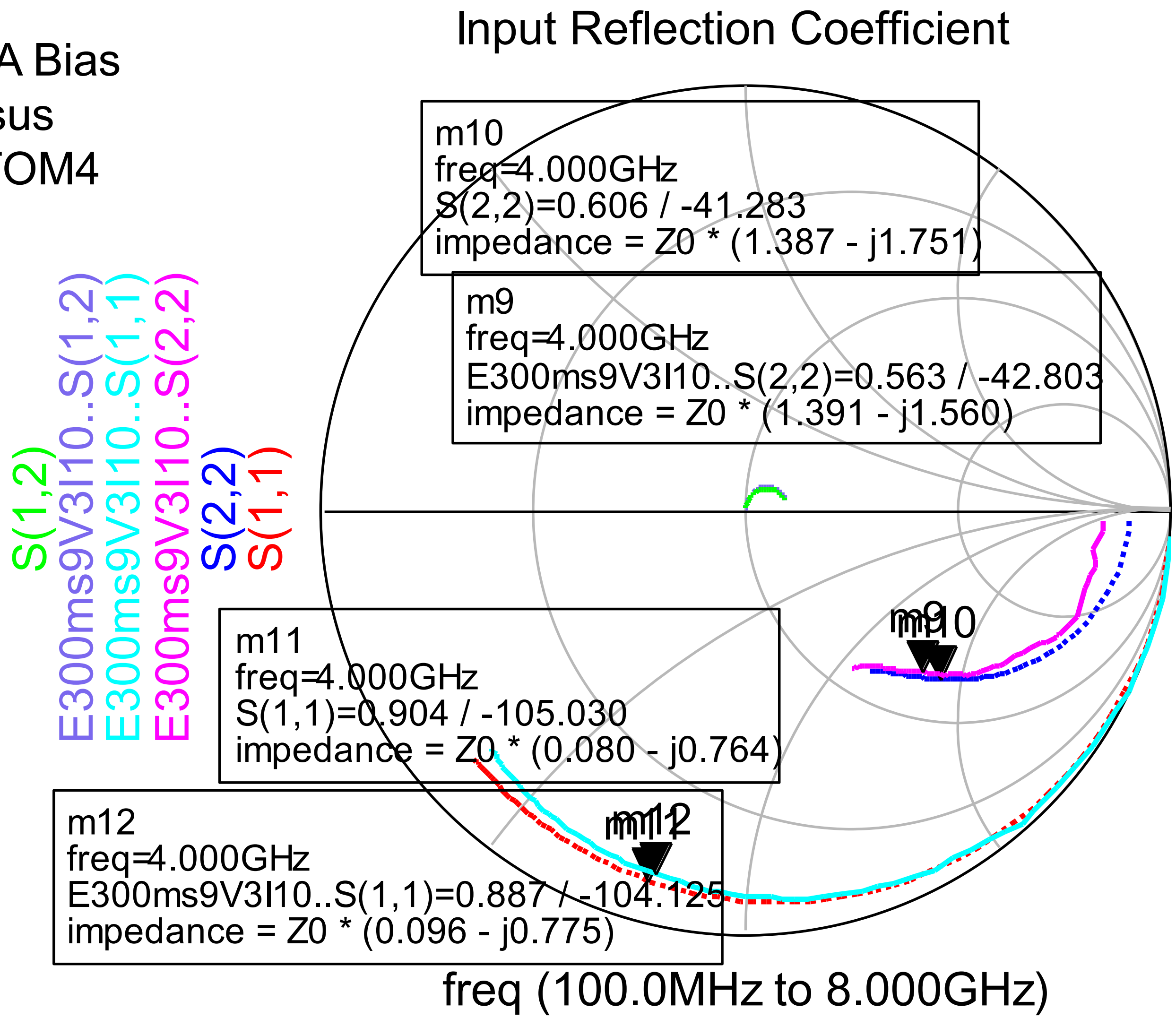
3V10mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Emode 6x50 um (ADS)

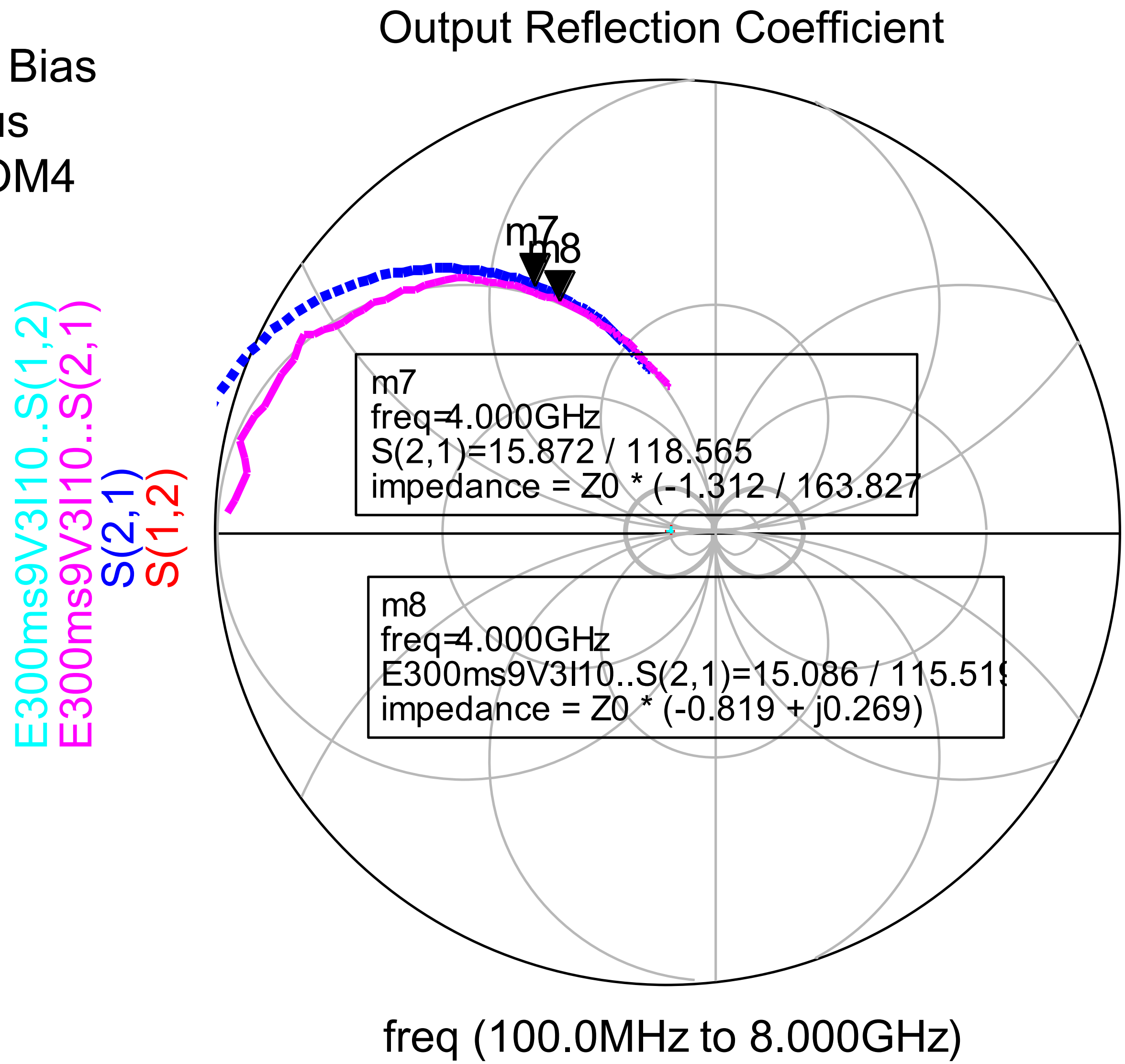
3V10mA Bias
Versus
ADS TOM4



ADS

PHEMT Measurements—Emode 6x50 um (ADS)

3V10mA Bias
Versus
ADS TOM4



ADS